



Sustainable Strategies for Large Cardamom Cultivation in the Sikkim Himalayas: Addressing Climate, Socioeconomic, and Biodiversity Challenges

Md Abdullah ^{1*}, Sefali Sultana Parvin ²

Abstract

Background: Large cardamom (*Amomum subulatum*) is a significant cash crop in the Sikkim Himalayas, contributing to the region's agricultural economy and farmer livelihoods. However, changing climatic and socio-economic conditions have adversely impacted its production, highlighting the need for a comprehensive approach to address challenges in its cultivation and market access. This study focuses on identifying technical gaps and interventions needed to enhance the large cardamom value chain and its potential to meet global demand. **Methods:** The study involved a detailed review of existing literature, government reports, and agricultural practices in the Sikkim region. A combination of qualitative and quantitative data collection methods was employed, including interviews with local farmers, field surveys, and consultations with experts in climate change, agroforestry, and market systems. A thorough analysis of the current status of large cardamom production, as well as the socio-economic and environmental challenges faced by farmers, was conducted. **Results:** The findings

revealed critical gaps in large cardamom production, including a lack of disease-resistant varieties, inadequate extension services, and poor post-harvest handling techniques. Climate change and socio-economic pressures were identified as major factors limiting the crop's potential. However, the study also identified opportunities for growth, including promoting sustainable farming practices, strengthening market access, and enhancing biodiversity conservation. Recommendations for improving the value chain include the development of location-specific varieties, better disease management, improved drying techniques, and establishing direct market linkages. **Conclusion:** A long-term, multi-disciplinary strategy is essential to address the technical, economic, and environmental challenges in the large cardamom sector. Implementing the proposed interventions will not only enhance farmer incomes but also contribute to increased foreign exchange earnings for India. The study emphasizes the need for coordinated efforts among research institutions, government agencies, and farmers to build a resilient and sustainable large cardamom sector, capable of meeting both domestic and global demand while ensuring biodiversity conservation.

Keywords: Large Cardamom, Sustainable Agriculture, Climate Change, Biodiversity Conservation, Sikkim Himalayas

Significance | This study demonstrated strategies for sustainable large cardamom farming, improving livelihoods, and conserving biodiversity amid climate change challenges.

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Introduction

Large cardamom (*Amomum subulatum*) is a significant cash crop

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in the eastern Himalayan region, including Sikkim and the Darjeeling hills in India, the eastern part of Nepal, and southern Bhutan (Sharma et al., 2000). Sikkim is the largest producer of large cardamom in India and ranks second globally after Nepal. The crop contributes between USD 500 and 1,700 annually to household cash income in Sikkim, depending on landholding size and farm management practices (Sharma, 2013; Sharma et al., 2000). For many rural households, large cardamom represents the sole source of cash income, underpinning food security and livelihoods in these mountainous regions.

Over the past few decades, the cultivation of large cardamom has expanded into other northeastern Indian states, including Nagaland (550 hectares), Arunachal Pradesh (400 hectares), Mizoram (400 hectares), Meghalaya (250 hectares), Manipur (250 hectares), and even the central Himalayan state of Uttarakhand (41 hectares) (Srinivasa, 2006; Indian Spices Board, n.d.). The plant thrives in subtropical conditions characterized by moist, sloped terrains, making it uniquely suited to these regions' ecological and climatic conditions.

Large cardamom is celebrated for its aroma and high medicinal value, possessing diverse physiological and pharmacological properties. Besides its culinary uses, such as being a key component of garam masala, it holds significant importance in Ayurvedic medicine and other traditional practices. Its essential oil has demonstrated antimicrobial properties (Agnihotri, 2010). Additionally, recent trends in high-value processed products, such as pan masala, have created new market opportunities for the crop. Increased urbanization and lifestyle changes, including the preference for ready-to-use spice mixes, have driven up demand, resulting in higher prices for large cardamom. Consequently, this crop has become a high-value, low-volume, and perishable cash crop integral to rural economies.

The cultivation of large cardamom also contributes to ecological sustainability through agroforestry practices that conserve tree biodiversity in the region. Its adaptability to mountain niches, combined with its economic viability, has helped many smallholder farmers alleviate poverty. However, the sector faces significant challenges, including declining productivity due to pests, diseases, aging plantations, lack of quality planting material, and inadequate irrigation and financial support. These issues are exacerbated by climate change, with erratic rainfall, extended dry spells, and changing seasonal patterns increasing the vulnerability of both the crop and its pollinators, such as bumblebees and honeybees (Sinu & Shivanna, 2007, 2011; Deka et al., 2011; Kishore et al., 2011).

Bumblebees are recognized as the most efficient pollinators for large cardamom, yet the presence of *Apis cerana* (the indigenous honeybee) has sparked debate. While some studies indicate that *Apis cerana* enhances yield (Verma, 1987), others highlight its limitations, describing it as a "pollen robber" that inadequately

pollinates only 10–20% of flowers (Sinu & Shivanna, 2007; Kishore et al., 2011). Despite this, beekeeping with *Apis cerana* is a longstanding practice in Sikkim, where both species coexist. Understanding how different pollinators influence cardamom yield under field conditions is crucial for improving production outcomes.

The decline in large cardamom farming is further compounded by socio-economic factors, including limited government support for infrastructure development, market facilitation, and farmer training. As a result, many farmers are turning to off-farm employment, jeopardizing the economic resilience of this traditional livelihood. Addressing these challenges requires a comprehensive, integrated approach that combines ecological sustainability, high-value crop management, and minimal labor intensiveness.

In addition to its economic and ecological importance, large cardamom cultivation has socio-cultural implications. By generating employment and reducing migration from hill regions to lowland areas, it stabilizes local communities and preserves cultural heritage (Ranjit & Deward, 1975). Previous studies have highlighted the economic benefits of cardamom farming, such as increased household income and foreign exchange earnings (Sangraula, 1989; Suresh, 1984). However, the rapidly changing cultivation and trading environments necessitate updated research and strategies to address current challenges.

The objectives of this study are to assess the role of large cardamom in rural livelihoods in Sikkim, propose measures to improve cultivation practices, ensure poverty alleviation and food security, and evaluate its socio-economic contributions. By synthesizing insights from extensive literature and field research, this paper aims to provide a comprehensive understanding of the challenges and opportunities in large cardamom farming.

This study also identifies gaps in the marketing and economic aspects of spice cultivation, an area often overlooked despite its historical and economic significance (Jose, 1978; Thomas, 1984). With the sector poised for growth, addressing these challenges will ensure that large cardamom continues to be a sustainable livelihood option for mountain communities.

Methodology

This review utilized a range of tools and materials, including a research schedule, structured questionnaires, and checklists, to systematically gather information. A camera was employed for documenting observations and collecting visual data. The study relied on both primary and secondary data sources. Primary data were collected through field surveys in selected regions of Sikkim, whereas secondary data were obtained from government offices, official state reports, research publications, and online resources.

Study Area

The study was conducted in the state of Sikkim, India, situated in the Eastern Himalayas. Sikkim is a mountainous state with an area of 7,096 km² and altitudes ranging from 300 to 8,583 meters above sea level. The state borders Tibet in the north, Bhutan in the east, Nepal in the west, and West Bengal in the south. The state is divided into four districts: East, West, North, and South Sikkim. This study focused on West and North Sikkim, as these districts are the major cardamom cultivation zones. The study areas were characterized by varied agro-climatic conditions, slopes of 10° to 30°, and elevations ranging from 1,000 to 2,200 meters above sea level. The primary cash crop in these regions is large cardamom, cultivated using traditional farming methods.

Sampling Design

The study employed a multi-stage random sampling technique to select participating households (Figure 1). A total of 100 households were surveyed across six sites distributed in three districts of Sikkim. In the East District, 22 households were from Sumik-Khamdong, 14 from Sang-Martam, and 14 from Dhanbari-Tumin. In the South District, 14 households were selected from Lingee-Sokpay. Finally, in the West District, 12 households each were surveyed in Hee-Pechreak and Hee-Martam. These sites were strategically chosen based on their active engagement in large cardamom cultivation.

Data Collection

Primary Data

Primary data were collected through direct observation, structured questionnaires, and face-to-face interviews. The questionnaires were designed and pre-tested in the study area to ensure their relevance and accuracy. The surveys focused on three key areas: the socio-economic status of farmers, the contribution of cardamom cultivation to household income, and the agricultural practices and environmental impacts associated with cardamom farming.

Focus Group Discussions (FGDs)

Six focus group discussions (FGDs), each involving at least ten participants, were conducted to gain in-depth insights into the impacts of climate change, traditional management practices, and adaptation strategies employed by farmers.

Interviews with Key Informants

Interviews were carried out with 20 key informants, including progressive cardamom farmers, local government representatives, agricultural extension officers, and researchers. These interviews provided valuable information on the trends in plantation areas, production levels, the impact of climate variability, and the challenges and opportunities within the cardamom value chain.

Secondary Data

Secondary data were sourced from government reports, such as agricultural censuses and annual reports, as well as from academic journals, articles, and previous research on the cardamom value chain in Sikkim, Bhutan, and Nepal. Additionally, relevant online

resources, including government websites and agricultural marketing data, were used to supplement the findings.

Research Design

The research was designed to analyze the socio-economic and environmental aspects of cardamom cultivation. Data were examined through participatory rural appraisal and rapid rural appraisal techniques, which included participatory mapping and community-based methods. A combination of qualitative data (e.g., interviews, FGDs) and quantitative data (e.g., statistical analysis) was used to ensure a comprehensive understanding of the subject.

Climate and Environmental Observations

Annual rainfall in the study areas averages 3,500 mm, ranging from 1,000 to 4,000 mm based on elevation. The sites experience occasional snowfall, hailstorms, and frost in winter, contributing to a diverse agro-climatic setting. The impacts of plant diseases like Chirkey and Furkey were also documented during the surveys, with farmers reporting severe losses in affected areas.

Statistical Analysis

The collected data were analyzed using both qualitative and quantitative approaches. Microsoft Excel and SPSS (version 10.5) were employed to perform statistical analyses, including analysis of variance, regression analysis, and descriptive statistics. Statistical techniques such as Z-scores, correlation coefficients, and t-tests were applied to examine relationships among variables.

To showcase spatial variations in cardamom cultivation, Choropleth maps were generated using ArcGIS. The findings were then presented using various charts, tables, and graphics to ensure clarity and comprehensibility.

Results

Large-Cardamom Area and Yields

Large cardamom is a significant cash crop in Sikkim, but its production trends have shown considerable fluctuations due to various environmental, socio-economic, and management factors. In 1997, the total plantation area under large cardamom in Sikkim was reported to be 26,734 hectares (ha) according to the Spices Board of India and the Horticulture and Cash Crops Development Department of Sikkim. However, this figure represents the total plantation area, not the actual production area that contributes to agronomic yields. In 1999, the production area was 19,912 ha, which expanded marginally over the following years to 22,714 ha by 2003 (Figure 2).

Decline Due to Environmental Factors

Between 2004 and 2007, Sikkim experienced prolonged dry spells and widespread disease infestations, leading to a substantial decline in both the production area and yields. This period marked a sharp decrease in production area, with a 37% drop from 20,000 ha in 2006 to 12,500 ha in 2007. Consequently, yields also suffered,

severely impacting the livelihoods of farmers who depended on cardamom cultivation (Figure 3).

Revival Strategies and Production Recovery

In response to this decline, several revival strategies were introduced by farmers and government bodies. These included improved farm management practices, such as applying organic manures before flowering and after harvesting, irrigation during dry winters, and manual pest and disease control supplemented with bio-pesticides. Farmers also began planting cardamom in new fields while leaving old plantations fallow. The Sikkim Government Horticulture and Cash Crops Development Department, along with the Spices Board, supported these efforts by providing incentives and extension services.

These measures resulted in a gradual recovery of production areas and yields over the next six years. By 2013, the production area had increased by 14% compared to 2007, reaching 16,010 ha, with an average annual production of 3,312 metric tonnes (t).

Trends in Yield

Large-cardamom yields have varied over the decades. During the early 1990s, yields were low, averaging 148 kg/ha. This improved slightly in the late 1990s to 228 kg/ha. However, yields declined again during 2006–2007 due to adverse conditions, averaging between 220 and 225 kg/ha. By 2013, yields showcased improvement, reaching an average of 238 kg/ha. Statistical analyses using linear regression modeling revealed a positive correlation between the yielding area and the year from 2007 to 2013 ($y = 661.64x - 1E+06$, $R^2 = 0.95$, $P < 0.001$).

Challenges in the Cardamom Value Chain

Export and Pricing Constraints

The marketing and export of large cardamom are dominated by middlemen who operate on a commission basis, leaving farmers with limited control over pricing. This system, coupled with issues such as illiteracy, poverty, inadequate transportation infrastructure, and lack of policy support, prevents farmers from reaping fair profits. Farmers also face challenges in accessing credit facilities and building local storage or processing facilities, further hindering the expansion and sustainability of cardamom production.

Environmental Sustainability Concerns

From a biodiversity conservation perspective, the sustainability of cardamom cultivation is questionable. The practice of cultivating cardamom in forest areas has led to significant ecological issues, including forest degradation and loss of biodiversity. Farmers often rely on both private and community forests for cardamom cultivation, which hampers forest regeneration by suppressing the growth of tree seedlings. Additionally, the high demand for fuelwood for drying cardamom exacerbates deforestation.

Organizations such as the Federation of Community Forest Users Nepal (FECOFUN) have raised concerns about these practices. While advocating for biodiversity conservation, they have

discouraged cardamom cultivation in community forests. However, these efforts have been met with limited success due to the absence of alternative income-generating activities or agricultural products to replace cardamom cultivation.

Socio-Economic Implications

Inequities in Land Use

In rural areas, influential individuals often privatize large portions of forest land for cardamom cultivation, leaving smaller, less productive plots for other community members. This inequitable distribution of resources restricts access to forest-based products such as grasses, fodder, and grazing areas, which are vital for alternative livelihoods like livestock raising.

Limited Opportunities for Livelihood Diversification

The dependence of rural communities on forest-based products, including non-timber forest products (NTFPs) like cardamom, restricts the diversification of income sources. With limited access to alternative enterprises and forest products, many farmers remain economically vulnerable. Moreover, the control of marketing, trading, and processing activities by a few individuals further marginalizes small-scale farmers, who are unable to secure fair prices for their produce.

Addressing the challenges in the cardamom value chain requires a multi-pronged approach. Policymakers must prioritize the development of equitable land-use policies and provide support for alternative income-generating activities to reduce the pressure on forests. Initiatives to improve access to credit, transportation, and market linkages can empower farmers and enhance their economic returns. Furthermore, promoting sustainable agricultural practices and fostering community-based biodiversity conservation programs can help mitigate the environmental impacts of cardamom cultivation.

By balancing economic growth with environmental conservation, Sikkim's large-cardamom sector can continue to contribute to the livelihoods of rural communities while preserving the region's rich biodiversity.

Discussion

This study highlights the contemporary status of large cardamom cultivation and its multifaceted impacts on rural livelihoods, biodiversity conservation, and economic growth. By focusing on West Sikkim and North Sikkim, the research offers critical insights but also acknowledges limitations in generalizability, given the confined scope and short study duration. While this research provides valuable input for policymakers, researchers, and local communities, it underscores the necessity for more extensive investigations to develop sustainable cultivation practices and equitable economic systems.

Market Dynamics and Challenges

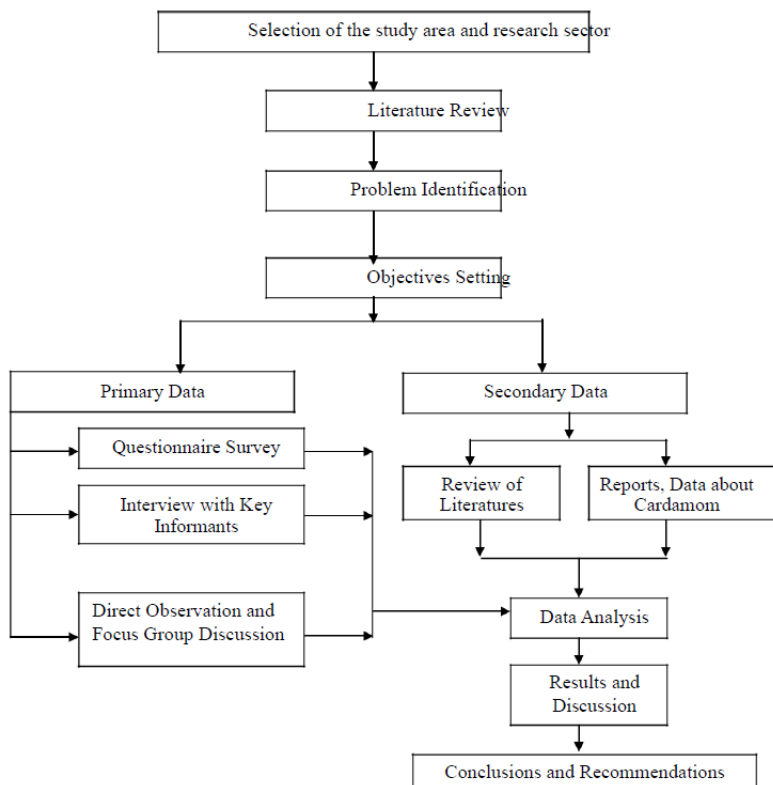


Figure 1. Logical Flow Chart of the Research

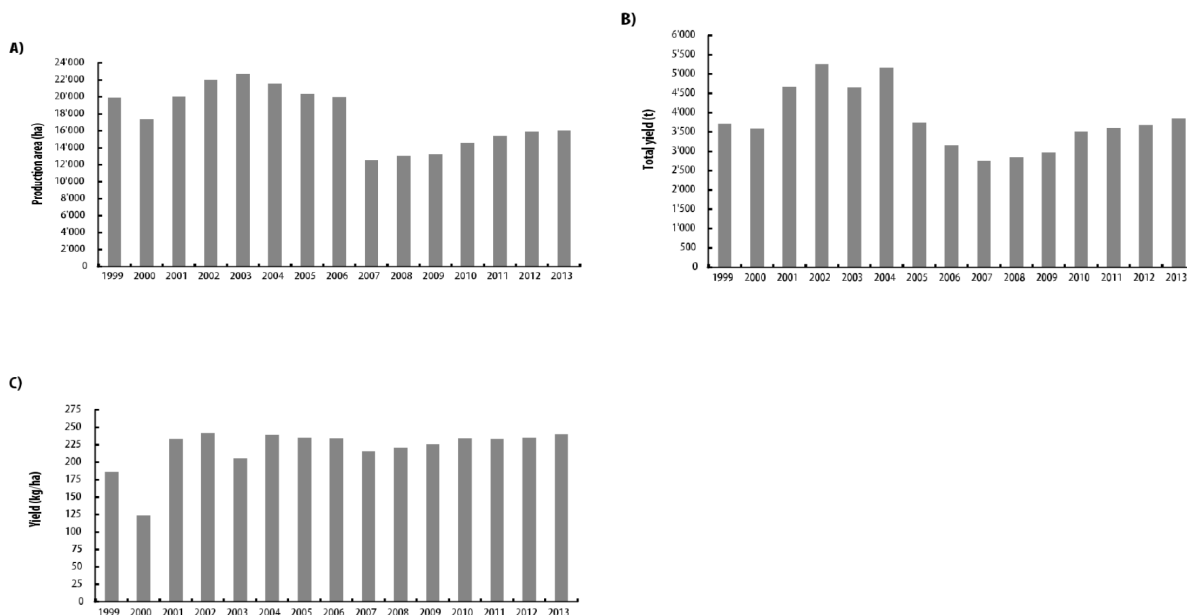


Figure 2. Large-cardamom productions in Sikkim. (Data sources: DESME 2002, 2005, 2006, 2010; HCCDD 2010; SOM 2014).

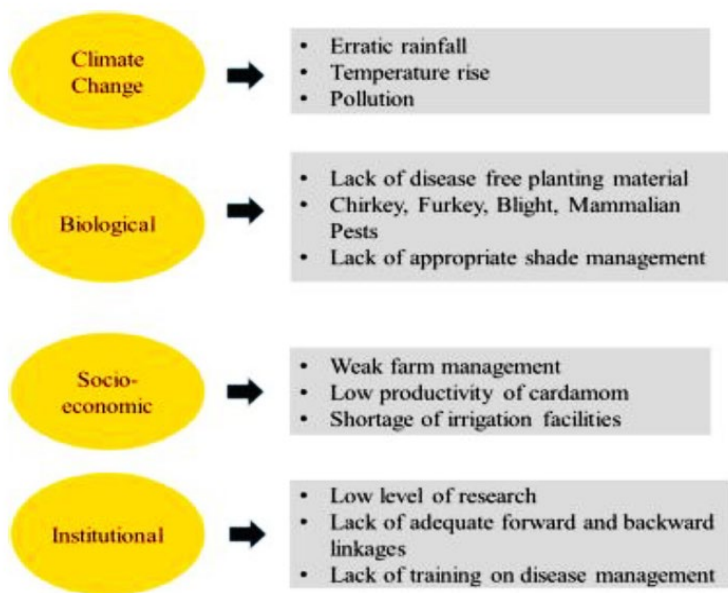


Figure 3. Factors Responsible for Decline in Large Cardamom Production (Source: (Uma et al. 2014), compiled by author)

Large cardamom is a significant export-oriented commodity for India, sharing prominence with tea and coffee. However, India is yet to position itself as a direct exporter to third countries, such as the Middle East, which remains a primary market for Indian cardamom after sorting and grading. Most cardamom from Sikkim and Darjeeling is exported through intermediaries, a practice that limits farmers' economic benefits.

Farmers often face challenges in marketing their produce due to the remoteness of cultivation areas, inadequate infrastructure, and dependency on local traders or merchants for financial advances. Many farmers sell their crops to these traders before harvest, often at prices significantly below the market average. While this system offers immediate financial relief, it perpetuates a cycle of economic dependency and limits farmers' bargaining power. Wholesalers and exporters based in Gangtok, Darjeeling, and Kerala dominate the trade, controlling pricing and access to broader markets.

Addressing these systemic issues requires the establishment of cooperatives or farmer-led organizations that can facilitate direct market access, eliminate exploitative intermediaries, and ensure fair pricing. Additionally, government initiatives to improve transportation infrastructure and provide financial support for farmers can alleviate some of these challenges.

Biodiversity Conservation and Environmental Implications

Large cardamom cultivation has significant implications for biodiversity conservation. As a shade-loving plant, it thrives under the partial canopy of forests, necessitating the clearance of undergrowth and replacement with cardamom plants. While this practice supports the growth of cardamom, it compromises the ecological integrity of forest ecosystems.

Research by Buckingham (2004) and others has demonstrated that cardamom plantations are less biodiverse than primary forests. The replacement of native understory vegetation with cardamom reduces habitat availability for various plant and animal species. Intensive management practices, including regular thinning of ground cover and diversion of water resources, further exacerbate these ecological impacts.

Studies, such as those by Reyes et al. (2006), warn that large cardamom cultivation in natural forests is unsustainable in the long term. Farmers often view partially cleared forests for cardamom as easier to convert into fields for annual crops, accelerating deforestation. While cardamom remains an economically lucrative crop, sustainable cultivation methods must be prioritized to mitigate land degradation and biodiversity loss.

Ecosystem Services and Sustainability

Despite its environmental challenges, large cardamom cultivation also offers potential ecosystem services when managed sustainably. Cardamom-based agroforestry systems contribute to soil and water conservation, improve soil fertility, and prevent erosion. By integrating cardamom cultivation with sustainable land-use

practices, farmers can enhance ecological resilience and maintain ecosystem functionality.

These agroforestry systems provide habitats for pollinators and biological control agents, supporting ecosystem services critical for agricultural productivity. Additionally, they serve as refuges for wildlife, promoting biodiversity conservation in managed landscapes. Large cardamom's shade-loving nature also aids in reducing deforestation, as its cultivation requires preserving tree canopies.

Sharma et al. (2008) describes large cardamom cultivation as a model for slope management and biodiversity conservation. By balancing economic productivity with ecological stewardship, this agroforestry system represents a potential avenue for integrating agricultural development with environmental sustainability.

Economic Impact on Rural Livelihoods

Large cardamom is a high-value crop, generating income three to four times greater than traditional crops. For many smallholder farmers in Sikkim, it has been a key factor in poverty alleviation, providing a stable source of income. As Sikkim produces approximately 80% of India's large cardamom, the region plays a vital role in meeting domestic and international demand. Major export markets include Pakistan, Singapore, and Middle Eastern countries, while domestic markets such as Delhi, Mumbai, and Kolkata also contribute to the crop's economic significance.

Beyond its direct financial benefits, large cardamom agroforestry systems offer supplementary products such as firewood, timber, fodder, and medicinal plants. These by-products further enhance rural livelihoods by diversifying income streams and reducing dependency on external resources.

However, the economic benefits are not evenly distributed. Influential individuals often control large portions of forest land for cardamom cultivation, marginalizing small-scale farmers and limiting their access to resources. This inequitable land use, coupled with a lack of alternative income-generating opportunities, exacerbates rural poverty and social disparities.

Bridging Economic and Environmental Goals

To reconcile the economic and environmental dimensions of large cardamom cultivation, adopting a holistic approach is crucial. Policymakers and development agencies must prioritize promoting sustainable practices by introducing farming techniques that minimize environmental degradation while maintaining productivity. This includes methods such as organic cultivation, water-efficient irrigation, and integrated pest management. Strengthening market access is another vital step, as establishing farmer cooperatives and improving market linkages can empower growers to negotiate fair prices and reduce their reliance on middlemen.

Enhancing biodiversity conservation is equally important. Encouraging mixed agroforestry systems that integrate native plant

species alongside cardamom can improve biodiversity and bolster ecological resilience. Additionally, providing livelihood alternatives can significantly benefit rural communities. Diversifying income sources through alternative crops, ecotourism, or value-added processing of cardamom can alleviate pressure on forest resources and enhance rural livelihoods. Finally, ensuring equitable land-use policies is critical to addressing socio-economic disparities. Equitable access to land and forest resources can foster inclusive development and contribute to the sustainable growth of the cardamom sector.

Conclusion and Perspective

Large cardamom is a high-impact crop that significantly contributes to the Indian economy by improving farmer incomes and boosting foreign exchange earnings. A review of the global demand and supply dynamics highlights a substantial unmet demand for large cardamom in international markets, offering India a unique opportunity to expand its footprint. However, changing climatic conditions and evolving socio-economic factors present critical challenges to the growth and sustainability of this sector.

This study conducted a comprehensive analysis of the technical gaps in the large cardamom value chain and outlined strategic interventions required at each stage. Addressing these gaps with a long-term, multi-disciplinary approach is essential for ensuring the sector's sustainable development. Such a strategy must encompass research advancements, effective policy implementation, and market integration to strengthen the entire value chain.

The development of location-specific, disease-resistant cardamom varieties, alongside the dissemination of quality inputs like suckers and manures, is crucial. Institutions like the National Seed Corporation (NSC), Agricultural Marketing Cooperatives (AMC), and regional research and development centers (RNR-RDCs) should be more deeply engaged. Enhancing extension services to educate farmers on modern agricultural practices, improving post-harvest techniques such as drying methods to boost crop marketability, and establishing direct market linkages are also critical interventions. Furthermore, creating niche market opportunities and integrating farmers into formal market institutions, including auction centres like NERAMAC, could vastly improve market access and profitability.

India's strong research infrastructure, with institutes like the Indian Cardamom Research Institute (ICRI), ICAR, TERI, and the Central Food Technological Research Institute, offers a robust foundation for advancing large cardamom cultivation. Innovations such as TERI's gasifier system, ICAR's mechanical-trolley system, and the improved Bhatti systems demonstrate the potential for technological advancements to enhance efficiency and sustainability in production.

To reconcile economic gains with environmental conservation, it is crucial for the government to devise mechanisms that support biodiversity maintenance within forest areas currently used for cardamom cultivation. Collaborative management of forest resources between cardamom user groups and local authorities can balance local livelihoods with biodiversity preservation. Such initiatives are vital for sustaining the ecological balance and ensuring long-term productivity.

Additionally, research on the impact of large cardamom cultivation on biodiversity conservation in regions like Sikkim is limited. Future studies should explore these impacts in greater depth to inform policies and practices that align agricultural productivity with environmental stewardship.

In conclusion, by addressing technical gaps, leveraging institutional strengths, and implementing sustainable practices, India can capitalize on the global demand for large cardamom. This will not only enhance foreign exchange earnings but also uplift the livelihoods of farmers. Simultaneously, attention to biodiversity conservation and further research into the ecological effects of cultivation will ensure the sustainable growth of this critical sector.

Author contributions

M.A. conceptualized the project and developed the methodology and conducted a formal analysis and drafted the original writing and contributed to the methodology. S.S.P. conducted investigations, provided resources, visualized the data and contributed to reviewing and editing the writing.

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None declared

Competing financial interests

The authors have no conflict of interest.

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