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Farmers' Challenges in Mentha Cultivation: A Regional Perspective

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ABSTRACT

Mentha, or mint is a valuable aromatic and therapeutic crop that has important agricultural and economic implications. However, growing it presents a number of region-specific challenges for farmers, endangering both sustainability and profitability. In addition to economic problems like price volatility and high input costs, this review highlights important agronomic challenges like soil salinity, water scarcity, and pest outbreaks. These challenges are made worse by technological obstacles, such as a lack of mechanization and a sluggish adoption of sophisticated farming methods. Mentha production is further impacted by environmental factors like climate variability and diminishing water supplies, and farmer resilience is hampered by a lack of policy support and poor agricultural extension services. We suggest implementing technological advancements like integrated pest management, effective irrigation systems, and drought-resistant cultivars to address these issues. Farmers can be empowered through government initiatives like increased subsidies and equitable pricing structures, as well as strengthened extension services and training initiatives. Resilience also depends on sustainable practices like organic farming and water conservation. The necessity of all-encompassing approaches to guarantee sustainable mentha cultivation is highlighted by this review.

INTRODUCTION

Mentha, or mint, is a genus of aromatic perennial herbs that are important both medicinally and economically. *Mentha*, a member of the Lamiaceae family, includes several species such as *Menthaarvensis* and *Menthapiperita*, which are extensively grown for their essential oils, chiefly menthol. It is a high-value commercial crop due to the wide use of these oils in the culinary, flavoring, cosmetics, and medicinal industries (Anwar et al., 2019). *Mentha*'s role in both conventional and modern therapeutic uses is reinforced by the strong antibacterial, antifungal, and antioxidant properties of its essential oils. It is primarily cultivated in temperate and subtropical climates, with the United States, China, and India being the top producers. India alone accounts for more than 80% of the world's mentha oil supply and has emerged as a major exporter (Kushwaha et al., 2024). However, mentha cultivation demands careful management due to its sensitivity to agronomic, environmental, and economic variables. Its productivity and profitability are negatively impacted by pest infestations, soil degradation, water scarcity, and market fluctuations (Salehi et al., 2018). Given its wide commercial applications and role in supporting rural livelihoods, a review of the difficulties faced by mentha farmers is essential. This review aims to highlight the various constraints and explore practical solutions (Carpenter & Carpenter, 2015). In regions where smallholder farmers depend on high-revenue crops for income, *Mentha* plays a key role in agricultural diversification. By producing menthol-rich essential oils that are in constant global demand across the food, cosmetic, and pharmaceutical sectors, mentha cultivation significantly contributes to the agricultural value chain (Paliwal, 2023). Despite its potential, mentha cultivation faces threats from several agronomic and environmental constraints. In addition to reducing crop yields, challenges such as pest attacks, water shortages, and soil fertility loss place extra financial pressure on farmers. The crop's vulnerability to climate change, reflected in erratic rainfall, temperature rise, and extreme weather, exacerbates these issues. When combined with market instability, high input costs, and limited access to advanced technologies, these factors hinder the adoption of sustainable practices and threaten long-term viability (Wei et al., 2023). Tackling these challenges promotes sustainable agriculture by enhancing resource efficiency, reducing environmental harm, and improving climate resilience. Farmers can overcome these constraints with well-targeted policy, technology, and market interventions, ensuring economic gains and environmental sustainability (Zafar et al., 2024). A thorough analysis of these concerns is vital to safeguarding mentha's contribution to rural livelihoods and the global essential oil market (Singh et al., 2024). This review aims to systematically identify and critically assess region-specific challenges to mentha cultivation with a focus on agronomic, economic, technological, environmental, and institutional aspects (Singh et al., 2022). It also aims to explore and recommend evidence-based, long-term solutions adapted to these regional challenges. Special focus will be on integrating innovative technologies, improved agronomic methods, and supportive policy frameworks. The overarching goal is to establish a sustainable mentha production system rooted in social equity, economic viability, and environmental conservation, ensuring the crop's continued relevance in the global agriculture and essential oil sectors.

1. ChallengesinMentha Cultivation

S.No.	Category	Specific Challenges	Region-Specific Insights	Impact
1.	Agronomi c Challenges	Soil fertility issues,salinity, and acidity	Highsalinityin Western Uttar Pradesh;acidic soils in Assam	Reducedcrop productivity
		Waterscarcity and irrigation inefficiencies	Erraticrainfallin MadhyaPradesh; dependence on tubewells	Increasedcosts, lower yield
		Pestanddisease outbreaks	Majorissuein Punjab with specific pest/disease	Yield loss, increased pesticideuse
2.	Economic Challenge s	Price fluctuations	Market instabilityin Tarai belt, Uttarakhan d	Reducedprofit margins
		Highinputcosts	In Barabanki, Uttar Pradesh reportssoaring fertilizercosts	Discourages menthafarming
		Narrowprofit margins	Pressures from competingcrops in Haryana	Shift to alternativecrops
3.	Technological Barriers	Limited mechanization	Traditional farmingmethods dominant in Eastern Uttar Pradesh	Labor-intensive processes
		Lowadoptionof advanced	Lack of awarenessin Bihar	Inefficient resourceuse
4.	Environmental Challenges	Climate variabilit y	Extreme temperaturesin Odisha	Stress oncrops
		Decliningwater resources	Groundwate r depletion in Rajasthan	Irrigation challenges
5.	Policy and Institutional	Weak agricultural extensio n	Lackoftraining programs in Bundelkhand, UttarPradesh	Pooragronomic practices
		services		

Table1: Key Challenges in Mentha Cultivation with Regional Insights

1.1 AgronomicChallenges

The productivity of *Mentha* is greatly influenced by soil fertility, as the crop requires nutrient-rich soils for optimal growth and essential oil biosynthesis. However, its cultivation faces challenges due to the depletion of organic matter, overuse of chemical fertilizers, and intensive cultivation practices, all of which degrade soil fertility (as demonstrated in Table 1). Nutrient imbalances—particularly deficiencies in nitrogen, phosphorus, and potassium—hinder root development, reduce biomass, and lower oil content, leading to suboptimal yields (Kumar et al., 2022). Salinity poses another significant constraint, especially in regions where poor irrigation practices cause salt accumulation in the root zone. While *Mentha* can tolerate moderate salinity, elevated levels impair nutrient uptake, cause osmotic stress, and diminish oil quality (Mahajan& Pal, 2023). Soil acidity, often a result of excessive rainfall, poor drainage, or acid-forming fertilizers, also limits productivity by reducing nutrient availability and increasing the toxicity of elements like manganese and aluminum (Mirzamohammadi et al., 2021). Addressing these issues requires integrated soil management involving balanced fertilization, organic amendments, and amelioration techniques. Site-specific nutrient strategies and precision agriculture tools are also essential for maintaining soil health and ensuring sustainable yields.Water scarcity and inefficient irrigation practices are additional agronomic constraints limiting mentha production. Being a water-intensive crop, *Mentha* requires consistent soil moisture to support its rapid growth and essential oil accumulation (Marino et al., 2019). Declining water availability due to overextraction, erratic rainfall, and competition from other sectors exacerbates water stress (Sahu et al., 2022). Traditional methods like flood irrigation contribute to inefficiencies by causing nutrient leaching, degrading soil structure, and increasing salinity risks. The limited adoption of modern irrigation systems such as drip and sprinkler further restricts water-use efficiency (Brar et al., 2021). Implementing precision irrigation alongside soil moisture sensors can optimize water use and reduce waste. Additionally, the development of drought-tolerant varieties and farmer training in sustainable water management practices is crucial for enhancing resilience under water-limited conditions (Molaei et al., 2021).Pest and disease outbreaks also pose serious threats to *Mentha* cultivation, affecting both yield and essential oil quality. Common pests include aphids (*Aphis* spp.), flea beetles (Chrysomelidae), and armyworms (*Spodopteralitura*), which reduce photosynthetic efficiency and biomass accumulation, particularly during key growth stages (Pandey&Hembram, 2025). Fungal diseases such as rust (*Pucciniamenthae*), powdery mildew (*Erysiphe* spp.), and wilt (*Fusarium* spp.), along with bacterial leaf spot (*Pseudomonas syringae*) and viral infections, further reduce leaf quality and oil biosynthesis (Carrubba et al., 2015). Under favorable environmental conditions, these pathogens can lead to rapid outbreaks, jeopardizing crop sustainability. An integrated pest and disease management (IPDM) approach is essential, involving resistant cultivars, eco-friendly biopesticides, and biological control agents (Riudavets et al., 2020). Precision tools such as real-time pest monitoring and predictive disease models can enhance early detection and targeted interventions, supporting long-term management strategies (Gupta et al., 2023).

1.1 EconomicChallenges

Major economic barriers to mentha cultivation include price volatility and erratic market access, which significantly affect farmers' financial security and profitability. The price of mentha oil, the main commercial product, fluctuates due to factors like export regulations, global demand-supply dynamics, and commodity market speculation (Rathore). This volatility creates uncertainty, impairing farmers' capacity to make informed investment decisions. Market access problems, especially for smallholder farmers in remote areas, further worsen economic challenges (Yankson et al., 2016). Poor infrastructure, limited storage facilities, and unorganized supply chains hinder fair pricing. Reliance on middlemen often reduces profit margins (Abdulsamad et al., 2015). To address these issues, strong market infrastructure such as cooperatives, direct platforms, and regulated marketplaces is needed. Policy measures like minimum support prices (MSP) and input subsidies can provide added protection (Anjum et al., 2024). Additionally, incorporating value-adding procedures like essential oil branding and high-value derivative production can enhance revenue streams (Singh et al., 2023).One significant financial challenge is the high cost of inputs—seeds, fertilizer, and pesticides. Mentha cultivation requires quality planting material to ensure vigorous growth and high oil yields. However, a lack of affordable certified seeds often compels farmers to use inferior alternatives, risking productivity (Saha&Basak, 2020). The crop's high nutrient demand requires regular fertilizer application, raising input costs, especially amid global supply disruptions. Moreover, heavy use of pesticides—due to pest and disease prevalence—further increases costs and raises environmental concerns (Fallah et al., 2024). Promoting affordable, quality inputs is essential. Strategies such as improved cultivars, biofertilizers, and integrated pest management (IPM) can significantly reduce reliance on costly chemicals (Parrey et al., 2023). Government-supported input networks and subsidies also play a key role in affordability and accessibility (Gupta et al., 2023).High production costs, volatile prices, and limited value addition opportunities result in narrow profit margins. Rising labor and irrigation costs, combined with erratic mentha oil prices, compel farmers to sell at uncompetitive rates (Sharma et al., 2023; Riaz et al., 2021). A market preference for raw mentha oil over processed derivatives restricts income potential, compounded by lack of access to advanced distillation technologies (Meng, 2023). Smallholders are disproportionately affected due to limited economies of scale. To address this, a comprehensive strategy focused on cost-efficiency and income diversification is necessary. Sustainable practices, support for cooperatives, better market infrastructure, and access to credit and insurance can enhance resilience (Oliveira, 2021). Branding and value addition, particularly for premium mentha derivatives, further improve profitability.

1.1 TechnologicalBarriers

Mechanization and contemporary irrigation techniques are still not widely used in mentha farming, which reduces output and efficiency. Most mentha farming remains labor-intensive, involving repetitive tasks like planting, harvesting, and post-harvest processing. Limited access to mechanized equipment, such as automated planters, harvesters, and distillation units, raises labor costs and reduces operational efficiency. This lack also hinders large-scale cultivation and slows responses to market and climate challenges (Anas&Abusad, 2022). Additionally, many farmers rely on traditional irrigation methods like flood irrigation, which wastes water, increases evaporation, and causes uneven distribution—ultimately affecting crop health and yield. The lack of advanced irrigation systems like drip or sprinkler systems worsens water stress in areas with erratic rainfall or scarcity (Babu et al., 2023). Modern irrigation technologies can significantly improve water use efficiency, salinity control, and crop productivity. Targeted interventions are needed to promote mechanization and efficient irrigation in mentha cultivation. Adoption can be encouraged through government subsidies, training programs, and affordable credit. Moreover, research tailored to mentha's agronomic needs can accelerate integration of modern tools, enhancing productivity and sustainability (Gupta et al., 2023). A major barrier to sustainable intensification is the sluggish adoption of advanced farming technologies. Despite the potential of biotechnology, digital tools, and precision agriculture, many mentha farmers are unable or unwilling to adopt them due to financial constraints, limited infrastructure, and knowledge gaps (Sanghera et al., 2020). Precision tools like soil moisture sensors, remote sensing, and data-driven crop management can optimize input use and yields, but adoption remains low due to high upfront costs and limited awareness. The lack of training programs and weak extension services further hinder technology dissemination (Sishodia et al., 2020). Promising biotechnological tools, such as genome editing and GM varieties, are still underutilized due to regulatory barriers, market concerns, and

lack of awareness (Gupta et al., 2023). To accelerate technology adoption, policies should reduce entry barriers through public-private partnerships, targeted extension services, and accessible financing. Including farmers in innovation networks and designing region-specific, affordable technologies will be crucial for advancing sustainable mentha cultivation.

1.2 EnvironmentalChallenges:

For mentha cultivation, climate variability and extreme weather events pose serious environmental challenges that significantly impact crop productivity and sustainability. Mentha is highly sensitive to climate changes, especially fluctuations in temperature, erratic rainfall, and extreme events like droughts, floods, and storms. These conditions can reduce yields, alter essential oil composition, and cause crop failure (Yadav et al., 2024). Rising temperatures due to climate change can stress mentha plants, affecting transpiration, photosynthesis, and water uptake. Heat stress, especially during extreme heat events, can cause wilting, stunted growth, and reduced oil content. Irregular rainfall and dry spells worsen water scarcity, restricting mentha's ability to thrive. Conversely, heavy rainfall and flooding can lead to waterlogging, damaging roots and encouraging soil-borne pests and diseases (Aishwath et al., 2016). Extreme weather also threatens infrastructure like transport routes, storage, and irrigation, disrupting supply chains.To address these issues, climate-resilient practices must be adopted. These include heat- and drought-tolerant mentha cultivars, soil conservation techniques, and water-efficient irrigation systems (Moshrefi et al., 2023). Integrating climate-smart approaches like crop diversification and agroforestry can also strengthen resilience.Another major concern is the declining availability of water for irrigation, especially where consistent water is critical for mentha yield. Climate change, over-extraction of groundwater, and poor water management reduce water accessibility, putting stress on agricultural systems (Chrysargyris et al., 2021). As a water-intensive crop, mentha requires steady water access during the growing season. Any supply interruption can significantly reduce yield and quality. Groundwater depletion, worsened by inefficient irrigation like flood methods, heightens water scarcity (Brar et al., 2021). Droughts and erratic rainfall further limit irrigation potential. Moreover, inadequate irrigation causes soil salinization and fertility loss, impacting long-term soil health. High salinity disrupts nutrient uptake and plant vigor, posing a serious challenge to mentha growth (Mohanavelu et al., 2021).Adopting efficient irrigation systems like drip and sprinkler methods ensures targeted water delivery, reduces waste, and promotes conservation. Rainwater harvesting and precision irrigation technologies can alleviate water scarcity (Campisano et al., 2017). In water-stressed areas, climate-smart practices such as mulching and soil moisture retention enhance water-use efficiency and support sustainable mentha cultivation.

1.3 PolicyandInstitutionalChallenges:

Insufficient government assistance, especially in the form of insurance plans and subsidies, is a major institutional and policy obstacle to the long-term growth of mentha farming. Even though mentha is a valuable aromatic and medicinal crop, farmers frequently lack access to financial support and risk-reduction resources needed to sustain livelihoods amid agricultural uncertainties (Singh et al., 2024). In many areas, subsidies for essential inputs like seeds, fertilizer, pesticides, and irrigation equipment remain inadequate or poorly targeted, placing a burden on smallholders.

The absence of comprehensive subsidies limits access to quality inputs crucial for boosting productivity and reducing cultivation costs (Rhioui et al., 2024). Consequently, many farmers cannot invest in climate-resilient crops or modern technologies, leaving them vulnerable to pests, market volatility, and environmental stressors. Without strong crop insurance programs, financial risks from extreme weather, pests, and diseases increase. Farmers lacking sufficient insurance coverage struggle to recover from losses, making reinvestment difficult (Macaluso et al., 2024). Reforming agricultural policies to provide specialized, accessible, and long-term support systems for mentha farmers is essential (Stevanovic&Pljevljakusic, 2015). Key steps include enhancing input subsidies, promoting crop insurance tailored to mentha, and improving access to credit. Strengthening extension services to provide timely information on farming practices, market dynamics, and risk management will further boost farmers' resilience (Singh et al., 2024).One major issue impeding sustainable mentha cultivation is the ineffectiveness of agricultural extension services and the scarcity of specialized training. Effective extension is vital for disseminating knowledge on sustainable practices, pest control, and innovative technologies. However, these services are often underfunded, understaffed, or poorly equipped, particularly in rural areas. As a result, farmers lack access to essential guidance for improving productivity and sustainable farm management (Kadoglidoum&Chatzopoulou, 2023). The problem is compounded by the absence of training programs tailored to mentha. General agricultural training often overlooks mentha-specific needs such as post-harvest processing, irrigation, and pest control (Durotoye, 2014).The slow dissemination of research findings and weak collaboration between farmers, academia, and research institutions further widen the knowledge gap, limiting farmers' capacity to adapt to emerging challenges (Zhou et al., 2024). Strengthening extension services through investment in infrastructure, regional capacity building, and development of customized extension materials is critical. Additionally, implementing practical training programs focused on pest management, modern irrigation, and market strategies can enhance sustainability and resilience (Che'Ya et al., 2022). Fostering stronger ties between academic institutions and farming communities will help translate research into real-world applications.

2. Strategiesand Solutions

Challenge	ProposedSolution	ExpectedBenefits	Implementation Region
Soil Fertility Issues	Use of soil conditioners (gypsum, lime, biochar).	Improved soil structure and fertility.	Western Uttar Pradesh
	Promotionoforganicmanure and biofertilizers.	Enhanced crop yieldandquality.	Assam
WaterScarcity	Adoptionofdripandsprinkler irrigationsystems.	Reduced water wastage.	Bundelkhand, UttarPradesh

	Training on water conservation techniques (e.g., mulching, rainwater harvesting).	Better crop resilience during dryspells.	
PestandDisease Outbreaks	ImplementationofIntegrated Pest Management (IPM).	Reduced dependency on chemical pesticides.	Tarai belt, Uttarakhand
	Use of disease-resistant menthavarieties.	Sustainable pest controlmeasures.	
Price Fluctuations	Establishment of Farmer Producer Organizations (FPOs).	Stable and predictableincome for farmers.	Barabanki, Uttar Pradesh
	Promotionofcontractfarming.	Strongerbargaining Power in markets.	
Limited Mechanization	Subsidiesformentha-specific equipment (e.g., distillation units,weeders).	Reduced costs. labor	Haryana
	Training programs on mechanized farming.	Improved efficiency in menthacultivation.	
Climate Variability	Developmentanddistribution of drought-resistant mentha varieties.	Resilience to extreme weather conditions.	Rajasthan
	Crop insurance to mitigate losses.	Reduced financial risks for farmers.	
Weak Extension Services	Establishment of dedicated mentha resource centers.	Enhanced farmer knowledge and skillsets.	Chhattisgarh
	Strengthening agricultural extensionservices.	Fasteradoptionof bestpractices.	

Table2:StrategiesandSolutionstoOvercomeChallengesin MenthaCultivation

2.1 TechnologicalInnovations:

To overcome the difficulties mentha farmers face—especially in light of climate change, water scarcity, and the demand for higher productivity—better cultivation methods must be implemented as shown in Table 2. The creation and application of drought-resistant mentha cultivars is one of the most promising solutions. These genetically modified or selected varieties significantly increase crop resilience in drought-prone areas (Anwar et al., 2019). Drought-resistant cultivars help maintain yield stability and reduce farmers' vulnerability to water stress. To maximize water use and ensure sustainability, efficient irrigation systems must be paired with these cultivars. Techniques like drip and sprinkler irrigation improve water-use efficiency by delivering water directly to plant roots, thereby conserving water and mitigating scarcity impacts (Brar et al., 2021). Precision irrigation systems further enhance water conservation by optimizing schedules based on soil moisture data. Integrating these systems with precision agriculture technologies—such as soil sensors and weather forecasting tools—can help farmers increase productivity, reduce input costs, and ensure long-term viability (Renu, 2022).Government subsidies, incentives, and extension services are essential to promote widespread adoption, particularly among smallholders (Salehi et al., 2018). Partnerships between private companies, farmer groups, and research institutions can further develop affordable, region-specific solutions. Promoting organic farming methods and Integrated Pest Management (IPM) is also key to improving sustainability and addressing concerns about pesticide use and environmental degradation. These methods improve agroecosystem health, enhance pest control, and ensure long-term viability (Salehi et al., 2018). IPM integrates various techniques to minimize pesticide reliance. It emphasizes prevention through cultural practices like crop rotation and intercropping, as well as biological control using natural predators (Rhioui et al., 2024). Targeted use of chemical pesticides, pheromone traps, and biopesticides ensures effective control with minimal ecological disruption.Organic farming practices meet growing consumer demand for pesticide-free products while enhancing soil fertility, biodiversity, and water retention (Costa et al., 2023; Chrysargyris et al., 2021). Natural inputs such as compost, organic fertilizers, and neem-based pesticides help reduce environmental harm and pesticide residues in mentha, increasing its marketability. Extension services, workshops, and demonstration plots are necessary to train farmers in IPM and organic methods. Supportive policies providing financial aid, certification programs, and incentives are also needed to facilitate adoption (Sekabira et al., 2022). Collaborations between farmer organizations, certification bodies, and research institutions will promote knowledge exchange and accelerate the transition to sustainable, profitable mentha farming. Incorporating IPM and organic approaches can enhance productivity, environmental sustainability, and market competitiveness (Rejesus et al., 2020).

2.2 ExtensionServices:

To solve the issues mentha farmers face and increase their ability to implement creative, sustainable farming methods, it is imperative that farmer training programs and knowledge-sharing platforms be strengthened. By providing farmers with the knowledge, tools, and resources they need to increase productivity and negotiate contemporary agricultural systems, effective extension services are essential in closing the gap between research institutions and farmers (Kadoglidou&Chatzopoulou, P. 2023). Farmer training programs should be thorough, region-specific, and practical. In addition to teaching the technical aspects of mentha cultivation, these programs ought to develop farmers' business acumen by teaching pricing strategies, post-harvest management, and market trends (Lothe et al., 2021). Training should be provided through workshops, field demonstrations, and on-site visits. The creation of digital platforms and mobile-based tools can extend training outreach by providing remote, on-demand access (Willingham et al., 2015). Sharing of knowledge platforms are crucial for fostering cooperation among farmers, researchers, and extension agents. Social media groups and farmer-led networks can promote best practices and regional solutions (Balyan et al., 2024). Creating FPOs or agricultural cooperatives can help advocate for better policies and decisions. Extension agents should be well-versed in traditional and modern methods (Masambuka et al., 2020). Locally sensitive services ensure region-specific solutions. Strengthening training and knowledge sharing helps farmers lower risks and improve decision-making (Tulinayo et al., 2022).Improving crop yields and modernizing mentha cultivation depend on expanding access to precision farming. Technologies such as soil sensors, automated irrigation, and GPS-based tools allow farmers to optimize inputs while preserving the environment (Carpenter & Carpenter, 2023). However, adoption is hindered by high costs and lack of awareness. Targeted subsidies and field demonstrations are crucial (Bloom et al., 2019). Demonstration programs allow farmers to observe the impact of technologies like soil moisture sensors and yield-monitoring systems. These promote experiential learning and adoption (Pal et al., 2015).Financial assistance is essential to overcome cost barriers. Government subsidies or low-interest loans can help farmers acquire drones, irrigation systems, and testing tools (Finger et al., 2019). Collaborations among research institutions, local governments, and equipment manufacturers can further lower costs (Mohamed et al., 2021). These efforts must be paired with training and support. Extension agents should be trained to help farmers integrate precision farming tools (Dang &Motohashi, 2015). These technologies increase profitability, reduce waste, and enhance sustainability in mentha farming.

2.2 GovernmentandInstitutionalSupport:

To reduce the financial risks involved in mentha cultivation and ensure farmers have the resources to adopt sustainable farming methods and technological advancements, it is imperative that subsidies, financial aid, and crop insurance programs be expanded (Salehi et al., 2018). These mechanisms offer crucial financial buffers for mentha farmers, especially smallholders who face capital constraints, market volatility, and environmental risks. Input subsidies for seeds, fertilizers, and pesticides can ease the burden of high input costs and enhance profitability. Targeted subsidies may also promote the adoption of sustainable practices such as integrated pest management and organic fertilizers (Kumar, 2015). Additionally, support for advanced technologies like soil sensors and precision irrigation can improve resource efficiency and productivity while reducing environmental impacts (Júnior et al., 2024). Financial aid and low-interest loans help farmers manage cash flow, particularly during off-seasons or in response to unexpected events like pest outbreaks or climate anomalies. Access to credit enables investments in equipment, infrastructure, and training programs (Soriano et al., 2022). Crop insurance plans are vital for protecting mentha farmers from climate-related hazards such as droughts and floods. Expanding such programs helps mitigate financial losses and encourages farmers to adopt innovative practices despite associated risks (Hussain, 2022).Alongside financial tools, policy reforms that enhance market access, ensure fair pricing, and reduce transaction costs are essential (Paliwal, 2023). Infrastructure development—such as storage, transportation, and processing facilities—supports a more favorable farming environment. These efforts collectively bolster productivity and profitability in mentha farming (Rhioui et al., 2024). Strengthening market infrastructure and fair pricing mechanisms enhances the economic sustainability of mentha cultivation. Efficient markets reduce transaction costs and promote price stability. Farmers benefit from improved access and fair pricing, encouraging the continued cultivation of mentha (Kumari et al., 2024). Modern infrastructure—like cold storage and packaging—minimizes post-harvest losses, while improved roads and logistics ensure timely delivery (Salehi et al., 2018). Developing value-added mentha products, such as essential oils and herbal teas, can diversify farmer income (Grigore et al., 2016). Transparent pricing systems and minimum support prices (MSPs) help counteract market volatility (Singh et al., 2024). Digital platforms for real-time pricing, cooperatives,

and Farmer Producer Organizations (FPOs) enhance negotiation power, reduce reliance on intermediaries, and facilitate market expansion. Government support for FPOs can provide mentorship and access to finance and marketing (Sumanth et al., 2020). These combined measures ensure stable farmer incomes and support the long-term sustainability of mentha farming (Arshad et al., 2023).

2.3 SustainablePractices:

To ensure the long-term viability of mentha cultivation, particularly in light of climate change and increasing water scarcity, it is imperative to promote water conservation and climate-resilient practices (Gendy et al., 2023). Since mentha requires substantial water, techniques that reduce water consumption while maintaining yield are essential. Incorporating climate-resilient practices helps farmers adapt to changing weather patterns, ensuring consistent yields and safeguarding livelihoods (Mumivand et al., 2023). Water conservation is a vital component of sustainable mentha farming. Efficient water management not only conserves resources but also mitigates environmental impacts. Techniques like drip irrigation minimize water waste by delivering water directly to plant roots. Rainwater harvesting systems provide supplemental water during dry spells (Gholamipourfard et al., 2021). Mulching and soil moisture retention methods further reduce evaporation losses, particularly useful in water-scarce areas.Climate-resilient strategies are crucial to buffer mentha crops against rising temperatures, erratic rainfall, and extreme weather (Gupta et al., 2023). Cultivating stress-tolerant mentha varieties and developing resilient cultivars are central to maintaining productivity (Gendy et al., 2023). Agroforestry practices—integrating trees into mentha fields—can provide shade, reduce soil erosion, and improve soil fertility, all while enhancing biodiversity and resilience to climatic extremes (Dissanayaka et al., 2024). Integrated Water Resource Management (IWRM) ensures sustainable water use across sectors by coordinating domestic, industrial, and agricultural needs. Crop rotation and the use of complementary low-water-demand crops help lower irrigation needs (Xiang et al., 2021). Early warning systems and climate forecasting tools further support irrigation planning and pest management, improving resilience (KC, 2016).To ensure both environmental and economic sustainability, promoting organic and eco-friendly farming is essential. Organic practices reduce environmental harm, including soil erosion, water contamination, and biodiversity loss, by relying on natural inputs and ecological processes (Marcelino et al., 2023). These methods also meet rising consumer demand for sustainable, chemical-free products, offering farmers premium market opportunities. Organic mentha farming favors alternatives to synthetic agrochemicals. Organic fertilizers such as compost and manure enhance soil fertility without ecological risks. These inputs improve nutrient cycling, boost soil biodiversity, and safeguard long-term soil health. They also reduce chemical runoff, protecting ecosystems and water bodies (Singh et al., 2020).Biological pest control, such as using beneficial insects and plant-based biopesticides, is central to organic systems. Integrated pest management (IPM) combines biological, mechanical, and cultural controls for holistic pest suppression (Baker et al., 2020). For instance, neem oil or predators like ladybugs control pests effectively without harming health or the environment (Muneret et al., 2018). Conservation tillage enhances organic matter and water infiltration, while reducing erosion and preserving soil structure (Ahmad et al., 2020). It also supports moisture retention in water-limited regions. Crop diversification and agroecological practices reduce dependency on chemicals and improve soil health. Intercropping with legumes like pulses fixes nitrogen and decreases fertilizer needs (Kakraliya et al., 2018). Cover crops and organic mulches further conserve moisture and improve soil quality.Fair Trade and eco-certifications incentivize sustainable practices by offering farmers access to niche markets and premium prices (Fallah et al., 2024). Promoting these methods not only boosts environmental sustainability but also improves farmer income and long-term productivity (Kumar et al., 2021). Furthermore, reduced chemical exposure benefits consumers and aligns mentha production with broader sustainable agriculture goals. By embracing organic and eco-friendly farming, mentha cultivation can thrive in harmony with the environment—benefiting ecosystems, farmers, and consumers alike.

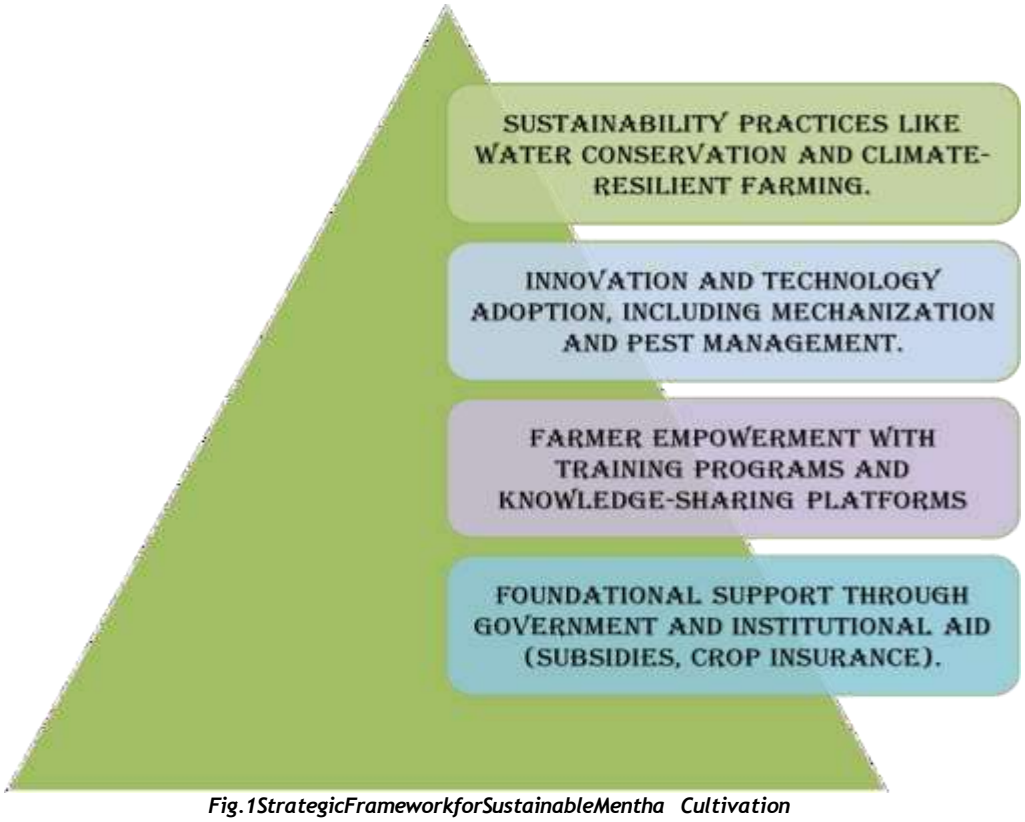

Fig.1StrategicFrameworkforSustainableMentha Cultivation

CONSLUSION

In conclusion, agronomic, economic, technological, environmental, and institutional barriers are just a few of the numerous obstacles that mentha cultivation must overcome to achieve sustainability and productivity. Significant challenges for farmers include problems with soil fertility, water scarcity, pest and disease outbreaks, and climate change. The economic strains are further compounded by volatile market prices, high input costs, and narrow profit margins. These problems are made worse by technological gaps, such as slow adoption of advanced farming techniques and limited mechanization. The adoption of sustainable practices is further hampered by the persistence of these issues, which are also exacerbated by insufficient government assistance and poor agricultural extension services. Improved extension services stand out among these complex issues as being essential to removing the obstacles mentha farmers face. Extension services are essential for closing the knowledge gap, promoting information sharing, and equipping farmers with the skills and methods they need to overcome financial and agronomic challenges. Governments and organizations can give farmers prompt access to scientific knowledge, best farming practices, and cutting-edge technologies that increase crop yield and sustainability by bolstering these services.Promoting training initiatives, demonstration farms, and the sharing of knowledge specific to a given area will enable mentha farmers to adjust to changing obstacles, especially those pertaining to market accessibility, soil health, water management, and pest control. Furthermore, expanding access to climate-resilient cultivars, modern farming equipment, and organic farming methods will help reduce environmental hazards and increase the mentha industry's long-term sustainability.In conclusion, a comprehensive strategy is needed to address the difficulties associated with mentha cultivation, with a particular focus on bolstering extension services. Mentha cultivation can be made into a more resilient, lucrative, and sustainable agricultural practice by providing farmers with the required tools, information, and assistance. This will benefit farmers as well as the larger agricultural industry.

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