



AGRI MAGAZINE

(International E-Magazine for Agricultural Articles)

Volume: 02, Issue: 06 (June, 2025)

Available online at <http://www.agrimagazine.in>

© Agri Magazine, ISSN: 3048-8656

Cultivation of Spice Crops in India Amidst Climate Change

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India, renowned as the "Land of Spices," is the world's largest producer and exporter of spices, contributing significantly to its agricultural economy and global trade. In, India produced 10.7 million tonnes of spices, with exports valued at approximately US\$4.18 billion. Among these, black pepper, small cardamom, ginger, and turmeric are pivotal, supporting the livelihoods of millions of smallholder farmers and playing a vital role in culinary, medicinal, and cultural practices. However, climate change, characterized by rising temperatures, erratic rainfall, and extreme weather events, poses a significant threat to the productivity and sustainability of these crops.

Current Cultivation Practices

Black Pepper: Black pepper (*Piper nigrum*), often called the "King of Spices," is primarily cultivated in the southern states of Kerala (94%), Karnataka (5%), and Tamil Nadu, covering approximately 1.36 lakh hectares with an annual production of 32,000 tonnes. It thrives in hot, humid climates with temperatures between 20°C and 30°C, tolerating a minimum of 10°C and a maximum of 40°C. The crop is grown as a climbing vine on support trees like silver oak or mango, requiring well-drained, fertile soils, preferably red or laterite, with optimal growth during the monsoon season. India accounts for 54% of the global area under black pepper but only 26.6% of production due to lower productivity compared to countries like Brazil and Indonesia.

Small Cardamom: Small cardamom (*Elettaria cardamomum*), known as the "Queen of Spices," is predominantly grown in the Indian Cardamom Hills (ICH) of Kerala and Tamil Nadu, with some cultivation in Karnataka. It requires a cool, humid climate with temperatures ranging from 10°C to 35°C and annual rainfall of 1500–4000 mm. The crop is cultivated under shade trees, which maintain the necessary microclimate, and is highly sensitive to changes in temperature and rainfall. Sikkim, a 100% organic state, also cultivates cardamom, with 75,000 hectares dedicated to organic farming.

Ginger: Ginger (*Zingiber officinale*), a perennial herb of the Zingiberaceae family, is cultivated across states like Kerala, Karnataka, Assam, Meghalaya, and other northeastern regions. It prefers warm, humid climates with temperatures between 20°C and 30°C and annual rainfall of 1500–3000 mm. Ginger is grown in well-drained, loamy soils and is highly susceptible to waterlogging, which can lead to rhizome rot. The crop is nutrient-intensive, requiring organic or chemical fertilizers to achieve high yields.

Turmeric: Turmeric (*Curcuma longa*), known as the "Golden Spice," is grown in diverse tropical conditions across Telangana, Maharashtra, Karnataka, Tamil Nadu, and Andhra Pradesh, covering 1.49 lakh hectares with an annual production of 527,960 tonnes. It thrives in temperatures between 20°C and 35°C with annual rainfall of 1500 mm or more, preferring well-drained, sandy or clay loam soils with a pH of 4.5–7.5. Turmeric is cultivated both conventionally and organically, with north-eastern states like Mizoram and Sikkim noted for high productivity.

Impact of Climate Change

Black Pepper: Climate change significantly affects black pepper cultivation, particularly in Kerala's Idukki and Wayanad districts. Higher temperatures during the third and fourth quarters negatively impact production, while rainfall in the second quarter (pre-monsoon) has a positive but insignificant effect. Over this period, maximum temperatures and rainfall showed negative growth trends, while minimum temperatures increased, indicating warmer nights. Nationally, black pepper production is projected to decline by 20% in 2025, from 55,000 tonnes to 46,000 tonnes, due to erratic weather conditions like unseasonal rainfall. This decline, coupled with global supply shortages, is driving up prices and intensifying competition for quality Indian pepper.

Small Cardamom: Small cardamom is highly sensitive to climate variability, particularly in the Indian Cardamom Hills. A multi-decadal study (1958–2017) revealed a significant decline in annual rainfall by 13.62 mm per year, with seasonal reductions of 0.87 mm (winter), 12.33 mm (pre-monsoon), 24.93 mm (southwest monsoon), and 18.10 mm (post-monsoon). The number of rainy days decreased by 19.75 days over 40 years. Maximum temperatures dropped by 2.1°C from 1978–1987 to 2008–2017, possibly due to increased irrigation, but minimum temperatures rose by 1.9°C, affecting the crop's growth cycle. A 120-day rainless period in 2024 caused a 60–70% yield reduction in some areas. There is a strong negative correlation between yield and rainfall/rainy days, while temperature has a weak positive correlation. In Idukki, the harvest gap has increased from 55–60 days to 85–90 days due to delayed monsoons.

Ginger: Specific studies on the impact of climate change on ginger cultivation in India are limited, but the crop's sensitivity to environmental changes suggests significant challenges. Ginger requires 1500 mm of annual rainfall and temperatures between 20°C and 30°C. Temperatures above 32°C cause heat stress, wilting, and reduced photosynthesis, while temperatures below 13°C induce dormancy. Altered rainfall patterns affect rhizome development and nutrient availability, and extreme weather events like floods and droughts increase pest and disease incidence, such as rhizome rot and bacterial wilt. In north-eastern states, high precipitation exacerbates pathogen issues, while southern states face yield declines due to rising temperatures and light intensity.

Turmeric: Turmeric cultivation is vulnerable to climate change, particularly in Kerala, where a geospatial study assessed current and future suitability. Currently, 28% of Kerala's area is highly suitable, 41% is moderately suitable, and 11% is not suitable for turmeric. By 2050, under the SSP 5-8.5 scenario, the highly suitable area is projected to decrease by 19% due to temperature fluctuations and increased rainfall. Erratic rainfall disrupts the crop's growth cycle, with excessive rainfall causing waterlogging and insufficient rainfall reducing yields. These changes threaten the sustainability of turmeric production, particularly for smallholder farmers.

Adaptation Strategies

To mitigate the impacts of climate change, several strategies are being implemented or proposed:

Crop	Adaptation Strategies
Black Pepper	Improved irrigation, crop diversification, climate-resilient varieties, maintaining $\geq 60\%$ shade cover to delay yield loss by 12 months
Small Cardamom	Enhanced irrigation, crop diversification, climate-resilient varieties, integrated pest management (IPM), maintaining shade cover.
Ginger	Organic farming, biological pest control, drip irrigation (267.4 mm water/ha with plastic mulch), IPM combining biological and cultural approaches.
Turmeric	Climate-smart practices like rainwater harvesting, drought-tolerant varieties, organic farming, IPM.

These strategies aim to enhance resilience by improving water management, reducing chemical inputs, and developing varieties that can withstand climatic stresses. Organic farming, as practiced in Sikkim, is gaining traction as a sustainable approach.

Conclusion and Future Outlook

Climate change poses a formidable challenge to the cultivation of black pepper, small cardamom, ginger, and turmeric in India. Black pepper production is declining due to erratic weather, with a projected 20% drop in 2025. Small cardamom faces significant yield losses due to reduced rainfall and warmer nights, while turmeric cultivation areas are expected to shrink by 2050. Ginger, though less studied, is likely affected by similar climatic stressors. Adaptation strategies, including climate-resilient varieties, improved irrigation, and sustainable farming practices, are critical to sustaining production. However, research gaps, particularly for ginger, highlight the need for further studies to document climate impacts and develop targeted solutions. Policy support and investment in climate-smart agriculture will be essential to ensure India's spice industry remains a global leader while supporting the livelihoods of millions of farmers.