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# Climate Change and Indian Grapes: Analyzing the Economic Impact on Export-Dependent Agriculture (2022-2023)

Shivam Satyawan Madrewar[1*], Apurva Shrishty[2], Snehal Netaji Sathe[3], Prathamesh Balasaheb Tavhare[4], Om Vijay Suryawanshi[5], Bhakti Balavant Kulkarni[6]
[1,3]R.C.S.M. College of Agriculture, Kolhapur
[2]I.I.M Lucknow
[4,5] I.F.M.R Graduate School of Business, Chennai
[6]Dr. J. J. Magdum College of Engineering, Kolhapur
**Corresponding Author:** Shivam Satyawan Madrewar shivammadrewar@gmail.com

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A B S T R A C T

This study examines the impact of climate change on India's export-dependent grape industry, focusing on the 2022-23 season. The 2022-23 season was marked by climatic anomalies that adversely affected grape yields and quality, leading to substantial economic losses for both farmers and exporters.During the 2022-23 season, average temperatures in key grape-growing regions increased by 1.5°C above the long-term norm during critical growth periods. This temperature rise accelerated the ripening process, resulting in smaller berries with lower sugar content, which diminished fruit quality. Additionally, unseasonal rains in October 2022 and February 2023 exacerbated the situation by causing fungal diseases, waterlogging, and grape splitting, further compromising the crop. The study reveals a 12% decline in grape production in Maharashtra, with total production dropping from 2.8 million metric tons in 2021-22 to 2.5 million metric tons in 2022-23. This reduction was mirrored by a 15% decrease in grape export volumes, from 280,000 metric tons to 238,000 metric tons, and an 18% decline in export value, from USD 335 million to USD 275 million

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## INTRODUCTION

India's agricultural sector plays a crucial role in the country's economy, with horticulture being a key component. Among horticultural crops, grapes hold a prominent position due to their high commercial value and significant contribution to the country's agricultural exports. India is one of the leading producers of grapes globally, with the majority of production concentrated in the states of Maharashtra, Karnataka, and Tamil Nadu. The country's grape industry is not only vital for domestic consumption but also serves as an important source of foreign exchange, with significant exports to regions like the European Union, the Middle East, and Southeast Asia.

The Indian grape industry, however, is facing mounting challenges due to climate change. Grapes are a climate-sensitive crop, requiring specific environmental conditions to thrive. Any deviations from these optimal conditions can have a direct impact on grape yield, quality, and, consequently, the economic returns for farmers and exporters. Climate change has manifested in various forms across India's grape-growing regions, including rising temperatures, unpredictable rainfall patterns, and an increase in the frequency and severity of extreme weather events. These changes have disrupted traditional agricultural practices and have introduced new risks for grape production.

The 2022-23 grape-growing season in India was particularly illustrative of the impact of climate change on this sector. The season was characterized by a series of climatic anomalies that significantly affected grape production and export performance. Unseasonal temperature increases, coupled with irregular rainfall, created challenging conditions for grapevines, leading to reduced yields and compromised fruit quality. This, in turn, had a cascading effect on the export market, where stringent quality standards are essential for maintaining India's competitive edge.

Given the importance of the grape industry to India's agricultural economy, it is critical to understand how climate change is influencing this sector, particularly in terms of production and export dynamics. This research aims to provide a comprehensive analysis of the impact of climate change on the Indian grape industry during the 2022-23 season. It will examine how specific climatic factors—such as temperature fluctuations and rainfall variability—affected grape yields and quality, and how these changes translated into economic outcomes for farmers and exporters.

The study is structured to address several key objectives. First, it seeks to identify and quantify the specific climatic anomalies that occurred during the 2022-23 season and to assess their direct impact on grape production. Second, the research will analyze the export data for the same period, identifying trends and patterns that highlight the economic consequences of climate-induced production challenges. Third, the study will explore the broader implications for stakeholders within the grape industry, including the challenges faced by farmers and exporters in adapting to these new conditions.

In addition to providing an in-depth analysis of the 2022-23 season, this research also aims to contribute to the broader discourse on climate change

adaptation within agriculture. The findings of this study will offer insights into the resilience of the grape industry and the effectiveness of current practices in mitigating climate risks. Furthermore, the study will propose adaptive strategies that could be implemented to enhance the sustainability of grape production and to safeguard the livelihoods of those dependent on this vital agricultural export.

By examining the intersection of climate change and agricultural economics through the lens of the Indian grape industry, this research intends to shed light on the complex challenges faced by export-dependent agricultural sectors in an era of increasing environmental uncertainty. The outcomes of this study are expected to inform policy-making and industry practices, helping to ensure that India's grape industry remains resilient and competitive in the global market despite the growing threats posed by climate change.

## LITERATURE REVIEW

### Climate Change and Agriculture

Climate change has been widely recognized as a critical factor influencing agricultural productivity globally. The Intergovernmental Panel on Climate Change (IPCC) has highlighted that rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events can significantly impact crop yields and quality (IPCC, 2021). For grape cultivation, which is highly sensitive to climatic conditions, these changes can disrupt the delicate balance required for optimal growth and fruit development (Klein et al., 2018).

### Impact of Temperature Changes on Grapes

Temperature is a key determinant of grape quality and yield. Research has shown that higher temperatures can accelerate grape ripening, resulting in smaller berries with reduced sugar content and altered flavor profiles (Jones et al., 2005). A study by Van Leeuwen and Desvignes (2017) demonstrated that rising temperatures lead to earlier harvests and increased risk of heat stress, which can negatively affect the physiological development of grapevines. The 2022-23 season in India saw an average temperature increase of 1.5°C, which aligns with these findings, highlighting the potential for adverse effects on grape quality and yield.

### Rainfall Variability and Its Effects

Unpredictable rainfall patterns and extreme precipitation events are also critical factors affecting grape production. Excessive rainfall can lead to waterlogging, fungal diseases, and reduced fruit quality (Dry et al., 2009). A study by Kearney and Porter (2017) emphasized that increased rainfall during critical growth stages, such as flowering and fruit set, can result in significant yield losses and quality degradation. During the 2022-23 season, unseasonal rains in key grape-growing regions of India led to increased incidence of diseases such as downy mildew and powdery mildew, corroborating the literature on the adverse effects of excess moisture.

### Economic Implications of Climate Change for Agriculture

The economic impact of climate change on agriculture is well-documented. A comprehensive review by Lobell et al. (2014) illustrated how climate-induced reductions in crop yields can lead to increased food prices and financial instability for farmers. For the grape industry, the economic repercussions

include not only reduced revenues from lower yields and quality but also increased costs associated with pest control and quality management (Schultz, 2018). The 2022-23 season's reduced production and export performance reflect these economic challenges, as evidenced by the significant declines in both volume and value.

**Adaptation Strategies for Grapes**

Adapting to climate change is crucial for maintaining the viability of grape production. Strategies such as the development of climate-resilient grape varieties, improved irrigation practices, and advanced pest management techniques have been suggested to mitigate the impacts of climate variability (Rienth et al., 2016). Research by Medrano et al. (2015) highlights the importance of adopting precision agriculture and enhanced weather forecasting to better manage the effects of climate change on grape cultivation. The 2022-23 season underscores the need for such adaptive measures to address the observed challenges.

**Policy and Support Mechanisms**

Effective policy interventions are necessary to support farmers in adapting to climate change. Policies that promote research and development of resilient agricultural practices, provide financial support for climate adaptation, and facilitate market access for affected producers are essential (Howden et al., 2007). The Indian government and industry bodies need to collaborate on policies that address the specific challenges faced by grape growers, as highlighted by the economic impacts observed during the 2022-23 season.

**Previous Studies on Indian Grape Production**

Previous research on the Indian grape industry has documented various challenges and opportunities related to climate change. Studies by Suryanarayana et al. (2021) and Sharma et al. (2022) provide insights into the impacts of climate variability on grape production and export performance in India. These studies emphasize the need for targeted adaptation strategies and policy support to ensure the sustainability of the grape industry amidst changing climatic conditions.

## METHODOLOGY

**Study Design**

This research utilizes a mixed-methods approach, integrating quantitative analysis of climatic, production, and export data with qualitative insights from stakeholder interviews to evaluate the impact of climate change on the Indian grape industry during the 2022-23 season.

**Data Collection**

1. Climatic Data
   - Source: Indian Meteorological Department (IMD) and local meteorological stations.
   - Data Collected:
     - Temperature: Monthly average temperatures for Maharashtra, Karnataka, and Tamil Nadu.
       - Maharashtra: Average temperature increased from 29.5°C in 2021-22 to 31.0°C in 2022-23.

- ❖ Karnataka: Average temperature increased from 27.8°C in 2021-22 to 29.3°C in 2022-23.
- ❖ Tamil Nadu: Average temperature increased from 30.2°C in 2021-22 to 31.7°C in 2022-23.

- Rainfall: Total monthly and seasonal rainfall data.
  - ❖ Maharashtra: Total rainfall increased from 1,200 mm in 2021-22 to 1,500 mm in 2022-23, with significant unseasonal rains of 100 mm in October 2022 and 150 mm in February 2023.
  - ❖ Karnataka: Total rainfall increased from 900 mm in 2021-22 to 1,100 mm in 2022-23, with 80 mm of unseasonal rains in October 2022 and 120 mm in February 2023.
  - ❖ Tamil Nadu: Total rainfall increased from 950 mm in 2021-22 to 1,200 mm in 2022-23, with 90 mm of unseasonal rains in October 2022 and 130 mm in February 2023.

2. Production Data
   - ➢ Source: Ministry of Agriculture & Farmers Welfare, Agricultural and Processed Food Products Export Development Authority (APEDA).
   - ➢ Data Collected:
     - Production Volumes:
       - ❖ Maharashtra: Production decreased from 2.4 million metric tons in 2021-22 to 2.1 million metric tons in 2022-23 (12.5% reduction).
       - ❖ Karnataka: Production decreased from 0.3 million metric tons in 2021-22 to 0.25 million metric tons in 2022-23 (16.7% reduction).
       - ❖ Tamil Nadu: Production decreased from 0.4 million metric tons in 2021-22 to 0.35 million metric tons in 2022-23 (12.5% reduction).
     - Yield Data:
       - ❖ Maharashtra: Average yield per hectare decreased from 14.0 metric tons in 2021-22 to 12.0 metric tons in 2022-23.
       - ❖ Karnataka: Average yield per hectare decreased from 13.5 metric tons in 2021-22 to 11.2 metric tons in 2022-23.
       - ❖ Tamil Nadu: Average yield per hectare decreased from 12.8 metric tons in 2021-22 to 11.0 metric tons in 2022-23.
3. Export Data
   - ➢ Source: APEDA, Directorate General of Foreign Trade (DGFT).
   - ➢ Data Collected:
     - Export Volumes:
       - ❖ 2021-22: 280,000 metric tons.
       - ❖ 2022-23: 238,000 metric tons (15% decrease).
     - Export Value:
       - ❖ 2021-22: USD 335 million.
       - ❖ 2022-23: USD 275 million (18% decrease).
       - ❖ Average Price per Metric Ton:
       - ❖ 2021-22: USD 1,196.
       - ❖ 2022-23: USD 1,154 (3.5% decrease).

4. Stakeholder Interviews
   - Participants: Grape farmers, exporters, agricultural experts, and industry representatives in Maharashtra, Karnataka, and Tamil Nadu.
   - Data Collected: Qualitative data on impacts, adaptation strategies, and economic challenges.

**Data Analysis**

1. Climatic Data Analysis
   - Temperature Analysis: Compare average temperatures of 2022-23 with long-term averages. Analyzed temperature increase of 1.5°C in key grape-growing regions.
   - Rainfall Analysis: Correlate increased rainfall and unseasonal rains with production issues. Analyzed impact of 100-150 mm of unseasonal rains on disease incidence and waterlogging.
2. Production Data Analysis
   - Production Trends: Calculate percentage changes in production volumes. Maharashtra: 12.5% reduction.
     - ❖ Karnataka: 16.7% reduction.
     - ❖ Tamil Nadu: 12.5% reduction.
   - Yield Analysis: Compare yield per hectare.
     - ❖ Maharashtra: 14.0 metric tons (2021-22) to 12.0 metric tons (2022-23).
     - ❖ Karnataka: 13.5 metric tons (2021-22) to 11.2 metric tons (2022-23).
     - ❖ Tamil Nadu: 12.8 metric tons (2021-22) to 11.0 metric tons (2022-23).
3. Export Data Analysis
   - Volume Analysis: Compare export volumes for 2022-23 with 2021-22.
     - ❖ 15% decrease in total export volume.
   - Value Analysis: Assess changes in export revenue and price per metric ton. 18% decrease in export value.
     - ❖ 3.5% decrease in average price per metric ton.
4. Economic Impact Analysis
   - Farmer Income: Analyze decline in income per acre.
     - ❖ 20% decrease in income per acre.
   - Exporter Costs: Evaluate increased costs for quality control and logistics.
5. Qualitative Data Analysis
   - Stakeholder Perspectives: Summarize feedback on impacts and adaptations. Categorize into themes related to climate effects, financial pressures, and adaptation practices.
6. Statistical and Analytical Tools
   - Statistical Software: SPSS or R for quantitative data analysis, including correlation and trend analysis.
   - Qualitative Analysis Software: NVivo for coding and thematic analysis of interview data.
7. Validation and Reliability
   - Data Triangulation: Cross-verify data from multiple sources for accuracy.
   - Stakeholder Validation: Confirm findings with stakeholders to ensure accuracy of reported impacts and adaptation strategies.

**RESULT**

1. Climatic Data Analysis
   - Temperature Changes
     - ❖ Maharashtra: The average temperature during the 2022-23 season increased from 29.5°C in 2021-22 to 31.0°C in 2022-23, an increase of 1.5°C.
     - ❖ Karnataka: The average temperature rose from 27.8°C in 2021-22 to 29.3°C in 2022-23, reflecting a 1.5°C increase.
     - ❖ Tamil Nadu: The average temperature increased from 30.2°C in 2021-22 to 31.7°C in 2022-23, a 1.5°C rise.

   These temperature increases are above the long-term average and have been associated with accelerated grape ripening, leading to smaller berries and altered flavor profiles.
   - Rainfall Variability
     - ❖ Maharashtra: Total seasonal rainfall increased from 1,200 mm in 2021-22 to 1,500 mm in 2022-23. Unseasonal rains of 100 mm in October 2022 and 150 mm in February 2023 contributed to waterlogging and fungal diseases.
     - ❖ Karnataka: Seasonal rainfall rose from 900 mm in 2021-22 to 1,100 mm in 2022-23, with 80 mm of unseasonal rains in October 2022 and 120 mm in February 2023. Increased moisture led to higher disease incidence.
     - ❖ Tamil Nadu: Total rainfall increased from 950 mm in 2021-22 to 1,200 mm in 2022-23. Unseasonal rains were 90 mm in October 2022 and 130 mm in February 2023, causing water stress and disease outbreaks.
2. Production Data Analysis
   - Production Volumes
     - ❖ Maharashtra: Grape production decreased from 2.4 million metric tons in 2021-22 to 2.1 million metric tons in 2022-23, a reduction of 12.5%.
     - ❖ Karnataka: Production fell from 0.3 million metric tons in 2021-22 to 0.25 million metric tons in 2022-23, representing a 16.7% decrease.
     - ❖ Tamil Nadu: Production declined from 0.4 million metric tons in 2021-22 to 0.35 million metric tons in 2022-23, showing a 12.5% reduction.
   - Yield per Hectare
     - ❖ Maharashtra: Average yield per hectare decreased from 14.0 metric tons in 2021-22 to 12.0 metric tons in 2022-23, a decline of 14.3%.
     - ❖ Karnataka: Average yield fell from 13.5 metric tons in 2021-22 to 11.2 metric tons in 2022-23, a 16.7% reduction.
     - ❖ Tamil Nadu: Average yield decreased from 12.8 metric tons in 2021-22 to 11.0 metric tons in 2022-23, a decline of 14.0%.
3. Export Data Analysis
   - Export Volumes
     - ❖ 2021-22: Total grape export volume was 280,000 metric tons.
     - ❖ 2022-23: Export volume dropped to 238,000 metric tons, a decrease of 15%.
   - Export Value
     - ❖ 2021-22: Export value was USD 335 million.

- ❖ 2022-23: Export value declined to USD 275 million, an 18% decrease.
- Average Price per Metric Ton
  - ❖ 2021-22: The average price per metric ton was USD 1,196.
  - ❖ 2022-23: The average price fell to USD 1,154, a decrease of 3.5%.

4. Economic Impact Analysis
   - Farmer Income
     - ❖ Income per Acre: Average income per acre for grape farmers decreased by 20% from 2021-22 to 2022-23, driven by reduced yields and lower grape quality.
   - Exporter Costs
     - ❖ Increased Costs: Exporters faced higher costs related to quality control and logistics due to adverse weather conditions and increased disease management.

4. Qualitative Data Analysis
   - Stakeholder Perspectives
     - ❖ Farmers: Many farmers reported reduced yields and increased costs for pest control and disease management. Unpredictable weather patterns were cited as a major challenge.
     - ❖ Exporters: Exporters faced difficulties in maintaining quality standards due to adverse climatic conditions, leading to reduced market competitiveness and financial pressures.
     - ❖ Agricultural Experts: Experts emphasized the need for adopting climate-resilient grape varieties and improving irrigation practices to cope with changing climatic conditions.
   - Adaptation Strategies
     - ❖ Farmers: Implemented adaptive practices such as adjusting planting dates and enhancing disease management.
     - ❖ Exporters: Increased focus on quality control measures and explored new markets to offset losses.

## DISCUSSION

The 2022-23 season has underscored the profound impact of climate change on the Indian grape industry, revealing significant challenges and highlighting critical areas for intervention. The detailed analysis of climatic data, production statistics, export performance, and stakeholder perspectives provides a comprehensive understanding of the adverse effects and necessary adaptations.

### Impact of Climatic Changes

The average temperature increase of 1.5°C across key grape-growing regions (Maharashtra, Karnataka, Tamil Nadu) has accelerated the ripening process of grapes, resulting in smaller berries and altered flavor profiles. This temperature rise has disrupted the physiological balance required for optimal grapevine growth, leading to reduced yield and quality.

The increase in total seasonal rainfall, along with unseasonal rains, has exacerbated production challenges. Excessive moisture has contributed to waterlogging, higher disease incidence, and reduced fruit quality. Specifically, the unseasonal rains of 100-150 mm in late 2022 and early 2023 have intensified fungal infections and water-related stresses, further diminishing grape production.

**Production and Yield Decline**

The reduction in grape production by 12.5% in Maharashtra, 16.7% in Karnataka, and 12.5% in Tamil Nadu during the 2022-23 season highlights the significant adverse effects of climate variability. Corresponding decreases in yield per hectare—14.3% in Maharashtra, 16.7% in Karnataka, and 14.0% in Tamil Nadu—illustrate the compounded impact on productivity. These declines are directly linked to the climatic stresses experienced during the season, including heat stress and excessive rainfall.

**Export Performance**

The drop in grape export volume by 15% and the reduction in export value by 18% reflect the broader economic impacts of climate change. The average price per metric ton decreased by 3.5%, indicating reduced market competitiveness and profitability. The decline in export performance underscores the challenges faced by the Indian grape industry in maintaining its market position amidst climatic adversities.

**Economic Implications**

The economic impact on grape farmers has been significant, with a 20% decrease in income per acre due to lower yields and reduced grape quality. Exporters have encountered increased costs related to quality control and logistics, further straining their financial viability. These economic pressures are exacerbated by reduced revenue and increased operational costs, affecting the overall sustainability of the grape industry.

**Adaptation and Recommendations**

The findings emphasize the urgent need for adaptation strategies to enhance the resilience of the grape industry. Key recommendations include:

- Development of Climate-Resilient Varieties: Investing in research to develop grape varieties that can withstand higher temperatures and variable rainfall.
- Improved Irrigation Practices: Implementing advanced irrigation systems to manage water resources more effectively and mitigate the impact of irregular rainfall.
- Enhanced Disease Management: Adopting integrated pest management strategies to control disease outbreaks resulting from increased moisture.
- Policy Support: Advocating for government policies that support climate adaptation initiatives, provide financial assistance for affected farmers, and promote sustainable agricultural practices.

**Future Outlook**

The Indian grape industry faces ongoing challenges due to climate change, with potential implications for both domestic and international markets. Continued monitoring of climatic trends and their impacts on production will be essential for developing effective adaptation strategies. Collaboration between researchers, policymakers, and industry stakeholders is crucial for addressing the vulnerabilities identified in this study and ensuring the long-term sustainability of the grape industry.

In conclusion, the 2022-23 season has highlighted the critical need for proactive measures to address the impacts of climate change on grape production and export. By implementing adaptive strategies and supporting innovation, the

Indian grape industry can work towards mitigating the adverse effects of climate variability and securing its future in a changing climate.

## CONCLUSION AND RECOMMENDATION

The findings of this study illustrate the substantial impact of climate change on the Indian grape industry during the 2022-23 season. The detailed analysis of climatic trends, production data, and export performance reveals how shifts in temperature and precipitation patterns have affected grape production and export outcomes. This discussion contextualizes these results within the broader framework of climate change impacts on agriculture and explores the implications for stakeholders and policy.

### Climatic Impacts on Grape Production

The increase in average temperatures across major grape-growing regions has had a marked effect on grape production. Grapevines are highly sensitive to temperature variations, and the observed 1.5°C rise in temperature has accelerated the ripening process. This has resulted in reduced berry size and altered sugar-acid ratios, affecting both the quality and marketability of the grapes. Research indicates that higher temperatures can lead to earlier harvests and reduced flavor profiles, which align with the findings of this study.

The increase in rainfall, particularly the unseasonal rains in late 2022 and earl 2023, has compounded these issues. Excessive moisture can lead to waterlogging, which impacts root health and overall plant vigor. Furthermore, increased humidity promotes the development of fungal diseases, which have been reported by farmers as a significant issue this season. Studies have shown that such conditions can reduce grape yields by promoting disease and affecting fruit set.

### Production and Yield Declines

The observed declines in production and yield are consistent with the adverse climatic conditions experienced. Maharashtra, Karnataka, and Tamil Nadu have all reported reductions in grape production ranging from 12.5% to 16.7%. This trend reflects the sensitivity of grapevines to climatic stressors. Research by the Indian Council of Agricultural Research (ICAR) and other institutions has demonstrated that climatic variability directly impacts crop yield, and the current findings support these conclusions.

The reduction in yield per hectare further underscores the negative impact of climate change. The average decrease of 14.3% to 16.7% in yield aligns with global observations of climate-induced yield reductions in horticultural crops. These reductions can be attributed to both direct effects, such as heat stress, and indirect effects, such as increased disease pressure from higher moisture levels.

### Export Performance and Economic Impact

The 15% decrease in export volume and the 18% decline in export value are indicative of broader economic repercussions. Lower production and quality issues translate into decreased competitiveness in international markets. The reduction in average price per metric ton by 3.5% reflects both the decreased quality and the oversupply issues faced by exporters. Research has shown that climatic disruptions lead to quality variability, which affects market prices and export revenues.

The economic impact on farmers, with a 20% decrease in income per acre, highlights the financial strain faced by producers. This aligns with findings from other regions affected by climate change, where decreased yields and quality result in reduced farmer incomes. The increased costs for disease management and quality control further exacerbate financial pressures on both farmers and exporters.

**Adaptation Strategies and Future Outlook**

The need for adaptation is crucial, as demonstrated by the findings. Developing climate-resilient grape varieties is essential for mitigating temperature and moisture stress. The promotion of advanced irrigation technologies and integrated pest management strategies can help manage water resources and control disease outbreaks more effectively. These strategies have been recommended in various studies as essential components of climate adaptation for agriculture.

Policy support is also vital. Government initiatives that provide financial assistance, research funding, and support for sustainable practices can significantly enhance the industry's resilience. The study's findings underscore the importance of collaborative efforts between researchers, policymakers, and industry stakeholders to address climate change impacts.

The future outlook for the Indian grape industry will depend on the implementation of these adaptation strategies and the continued monitoring of climatic trends. As climate change continues to evolve, ongoing research and adaptive management will be essential for ensuring the long-term sustainability of grape production and export.

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