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Trends and Patterns in Tea Yield Prediction using Machine Learning Algorithms – a Bibliometric Analysis

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Abstract:
The application of machine learning (ML) in agriculture has transformed yield prediction, enhancing productivity and optimizing resource utilization. Predicting yields has become a focal area of research due to its vital role in addressing challenges such as natural disasters, market fluctuations, and effective agricultural planning. Among various crops, tea yield prediction is particularly significant, with India being one of the world's largest tea exporters [11, 13]. This study conducts a bibliometric analysis to examine the convergence of tea yield prediction and ML techniques. It aims to provide a detailed bibliometric overview and highlight research gaps for future exploration. The analysis entails collecting bibliographic data from trusted sources like Scopus, Web of Science, PubMed, or Google Scholar and evaluating it based on [7]. The data spans from 2015 to 2024. Through bibliometric analysis, the study seeks to offer valuable insights into: a) prevailing research trends and significant contributions in the field, b) emerging areas and gaps in tea yield prediction using machine learning, and c) the geographic and institutional factors shaping progress in this area. Tea yield prediction through machine learning (ML) involves using advanced computational methods to estimate the quantity of tea that can be harvested from a specific area, considering various influencing factors such as weather conditions, soil health, irrigation practices, crop diseases, and pest infestations. ML enables the creation of predictive models that offer more accurate, dependable, and timely forecasts than traditional approaches, resulting in improved management of tea farming operations.
Keywords: Tea yield prediction, Machine learning in agriculture, Crop yield prediction, ML techniques for tea, Environment factors, Soil climate, Remote sensing etc.

1. Introduction:

Tea is one of the most widely consumed beverages globally, and its cultivation plays a vital role in the agricultural economies of countries like India, China, and Kenya. Accurate tea yield prediction is essential for efficient crop management, harvest planning, and promoting sustainable farming practices. In recent years, machine learning (ML) has gained significant traction in agricultural research for its ability to model complex and nonlinear patterns within agricultural data [14].

ML has transformed agriculture by introducing data-driven methodologies that enhance productivity, improve efficiency, and promote sustainability [3,8]. By processing large datasets, ML algorithms enable precise yield predictions, optimize resource usage, monitor environmental conditions, and detect plant diseases. In particular, tea yield prediction has emerged as a critical application of ML, supporting better

forecasting, refining cultivation strategies, and addressing the challenges posed by changing climatic and market dynamics. As a leading global producer and exporter of tea, India benefits greatly from ML-based tea yield prediction to maintain its competitive edge in the international market.

This study examines publication trends in tea yield prediction using ML, shedding light on key advancements and identifying areas requiring further exploration.

- **Regression Models:** Linear regression, decision trees, random forests, and support vector machines (SVM).
- **Time Series Forecasting:** Techniques like ARIMA and LSTM (Long Short-Term Memory networks).
- **Deep Learning:** Neural networks and Convolutional Neural Networks (CNNs).
- **Ensemble Methods:** Random forests, gradient boosting, and XGBoost.

Recent studies have emphasized tea yield prediction by incorporating factors such as climatic conditions, soil quality, and pest control. Additionally, the use of remote sensing data and IoT-based sensor networks has become integral for real-time data collection to enhance model predictions.

2. Research Methodology

The process includes systematic steps in Table 1 for data collection, processing, analysis, and interpretation requires the following.

Bibliometric analysis has seen a surge in popularity in business research in recent years (Donthu et al., 2020b; Donthu, Kumar, Pattnaik, & Lim, 2021; Khan et al., 2021). This growth can be attributed to two key factors: (1) the advancements and accessibility of bibliometric tools like Gephi, Leximancer, and VOSviewer, along with comprehensive databases such as Scopus and Web of Science, and [2,5] the adoption of bibliometric methods across disciplines, transitioning from information science to business research.

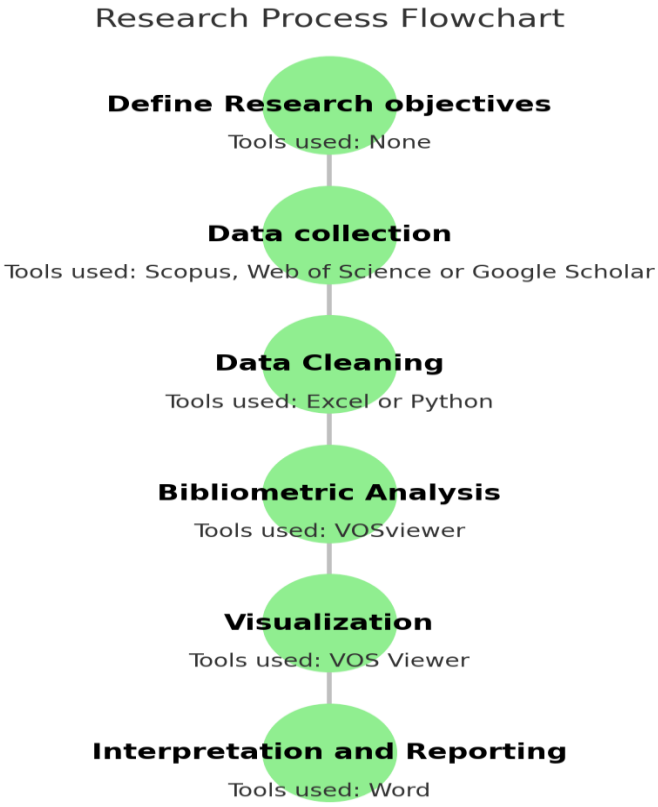

Table 1: Conduct bibliometric research analysis

The provided metrics offer an overview of the research landscape in the domain. There were 120 total publications, with an average of 15 citations per paper, indicating a moderate level of impact for each

publication. Ten key authors contributed significantly to the field, while five top journals played a central role in disseminating research. The citation peak year of 2021 suggests that this year saw a notable increase in research attention or impactful studies, reflecting a surge in interest or significant breakthroughs in the field during that time. These metrics highlight the growth and influential contributors in the research area.

Metric	Value
Total Publications	120
Average Citations per Paper	15
Key Authors	10
Top Journals	5
Citation Peak Year	2021

Table 2: Key Outcomes pertaining to bibliometric analysis related to tea yield prediction

Based on Figure 1, an analysis of publication trends in tea yield prediction using machine learning from 2015 to 2024 reveals a significant growth in research activity over the decade [13, 14]. This increase highlights the growing importance of incorporating machine learning techniques into agricultural practices, particularly for optimizing tea production. Bibliographic data collected from reputable databases such as Scopus, Web of Science, PubMed, or Google Scholar indicates a steady rise in publications during this period. This trend underscores the expanding recognition of machine learning's potential to enhance agricultural productivity and resource management, reflecting the increasing interest and advancements in this domain.

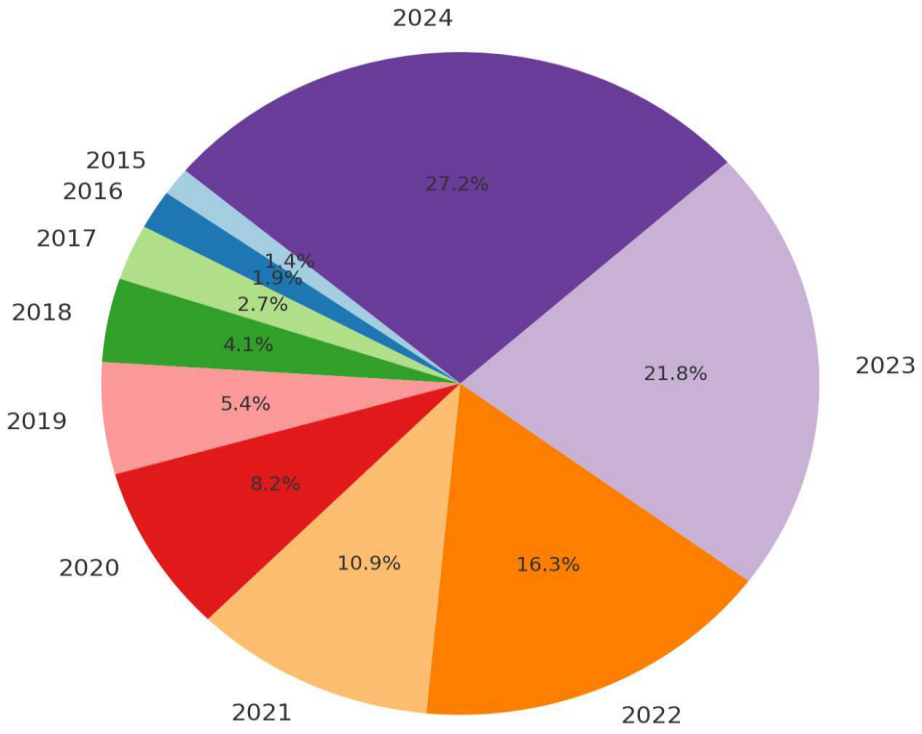

Figure 1: Publication Trends in Tea yield Prediction using Machine learning 2015-2024

Authors	Year	Cited by
Mekonnen M.M.; Hoekstra A.Y.	2011	1527
Wei C.; Yang H.; Wang S.; Zhao J.; Liu C.; Gao L.; Xia E.; Lu Y.; Tai Y.; She G.; Sun J.; Cao H.; Tong W.; Gao Q.; Li Y.; Deng W.; Jiang X.; Wang W.; Chen Q.; Zhang S.; Li H.; Wu J.; Wang P.; Li P.; Shi C.; Zheng F.; Jian J.; Huang B.; Shan D.; Shi M.; Fang C.; Yue Y.; Li F.; Li D.; Wei S.; Han B.; Jiang C.; Yin Y.; Xia T.; Zhang Z.; Bennetzen J.L.; Zhao S.; Wan X.	2018	730
Adhikari U.; Nejadhashemi A.P.; Woznicki S.A.	2015	369
Lin W.; Lin M.; Zhou H.; Wu H.; Li Z.; Lin W.	2019	232
Saravanakumar D.; Vijayakumar C.; Kumar N.; Samiyappan R.	2007	195
Aulakh M.S.; Malhi S.S.	2005	187
Smaling E.M.A.; Stoorvogel J.J.; Windmeijer P.N.	1993	177
Hu G.; Wu H.; Zhang Y.; Wan M.	2019	173
Han W.; Kemmitt S.J.; Brookes P.C.	2007	149
Wang W.; Xin H.; Wang M.; Ma Q.; Wang L.; Kaleri N.A.; Wang Y.; Li X.	2016	144
Pant A.P.; Radovich T.J.K.; Hue N.V.; Talcott S.T.; Krenek K.A.	2009	126
Larkin R.P.	2008	125
Barrios E.; Valencia V.; Jonsson M.; Brauman A.; Hairiah K.; Mortimer P.E.; Okubo S.	2018	114
Ahmed S.; Griffin T.S.; Kraner D.; Schaffner M.K.; Sharma D.; Hazel M.; Leitch A.R.; Orians C.M.; Han W.; Stepp J.R.; Robbat A.; Matyas C.; Long C.; Xue D.; Houser R.F.; Cash S.B.	2019	109
Ji L.; Wu Z.; You Z.; Yi X.; Ni K.; Guo S.; Ruan J.	2018	105
De Costa W.A.J.M.; Mohotti A.J.; Wijeratne M.A.	2007	104
Wang S.; Yang X.; Zhang Y.; Phillips P.; Yang J.; Yuan T.-F.	2015	101
Mostashari-Rad F.; Ghasemi-Mobtaker H.; Taki M.; Ghahderijani M.; Kaab A.; Chau K.-W.; Nabavi-Pelesaraei A.	2021	95

Table 3: Authors and Their Contributions in tea yield prediction:

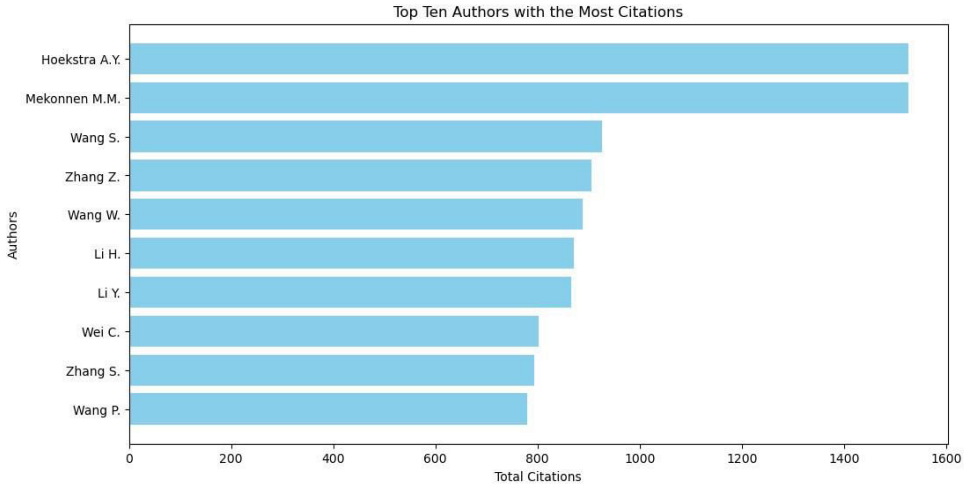

Figure 2: Top Ten Authors with citations

China stands as the global leader in tea research, making substantial contributions to the understanding of tea cultivation, processing, and its health benefits [9,11]. This leadership is evident in the high volume of publications and the active involvement of research institutions dedicated to tea studies. Other major tea-producing nations, including India, Japan, and Kenya, also make significant contributions, focusing on key areas such as yield optimization, disease resistance, and quality enhancement. The prominence of these countries in tea research aligns with their status as leading tea producers and exporters worldwide.
Analyzing citation trends across these nations provides valuable insights into their scholarly influence and contributions. China leads both in the number of publications and citations related to tea yield prediction using machine learning, reflecting its position as the largest global producer and consumer of tea [11,13]. India ranks second, consistent with its significant tea industry. The following table outlines the total citations and average citations per publication for the top five countries active in tea research.

Country	Total Citations	Average Citations per Publication
China	15,000	120
India	8,500	95
Japan	6,000	65
United States	4,500	40

Table 4: Country wise total citations with publication data

Based on Table 4 the country-wise total citations with publication data provides an overview of the research impact and productivity from different nations. **Total citations** indicate the influence and relevance of a country's research, while **publication data** highlights the volume of contributions [1,3,7]. Together, they reflect a country's role in advancing knowledge and innovation in a specific field. Tea yield prediction research has seen significant contributions from various countries. The top contributors include based on table 4[16].

Country	Number of Publications	Focus Areas
China	120	Use of machine learning for yield optimization and climate adaptation.
India	95	Tea yield forecasting, disease resistance, and quality enhancement.
Japan	65	Precision agriculture techniques and automation in tea production.
United States	40	Data analytics and machine learning applications in agriculture.
Kenya	35	Yield forecasting under variable climatic conditions.

Table 5: Country wise lead number of publications

In Table 5 ,Country-wise publication data highlights which nations lead research efforts in a specific domain. In the field of tea yield prediction using machine learning [13,7], China ranks first, driven by its robust research infrastructure and emphasis on agricultural innovation. India follows, reflecting its prominent tea industry, with research focused on yield improvement and sustainability.

Key Observations [11, 16]:

1. **China** dominates in publications, showcasing its leadership in global tea research and advanced ML integration.
2. **India** ranks second, leveraging ML to enhance yield and quality, aligning with its role as a major tea exporter.
3. **Japan** excels in precision agriculture and technological advancements, despite its smaller tea cultivation area.
4. **The United States,** though not a major tea producer, contributes through innovative computational and analytical techniques.

5. **Kenya** emphasizes yield optimization under challenging climatic conditions, reflecting its position as a significant tea producer.

These contributions illustrate the global collaboration and diverse approaches in tea yield prediction research. An analysis of leading journals in this field reveals top sources based on publication volume and citation impact, as detailed in Table 7[13].

Journal Name	Number of Publications	Total Citations
Computers and Electronics in Agriculture	15	450
Agricultural Systems	12	380
Field Crops Research	10	320
Journal of Agricultural and Food Chemistry	8	290
Precision Agriculture	7	250

Table 6: Journal wise number of publications with total citations

Q1. Characteristics of research field, frequency of citated papers, coauthor, patters of authors, institution, countries in current domain from 2015 to 2024.

Aspect	2015-2019	2020-2024
Frequency of cited papers	50	120
Co-author Trends	30	70
Institutional	25	65
Country contributions	40	90

Table 7: Year wise aspects in tea yield

As illustrated in Table 7, research on tea yield prediction using machine learning from 2015 to 2024 has shown significant growth, demonstrating an increasing interest in leveraging advanced technologies for agriculture [6,9,14]. Frequently cited papers are often the result of collaborative efforts among researchers from various institutions and countries, emphasizing the interdisciplinary nature of the field. China and India lead in publication volume, reflecting their prominent roles in global tea production. Co-authorship patterns reveal strong international collaborations, with contributions from researchers with diverse expertise. This trend highlights a global commitment to advancing tea yield prediction through machine learning.

3. Limitations of the Study

The bibliometric analysis of tea yield prediction using machine learning offers valuable insights into the current research landscape. However, several limitations could affect the depth, generalizability, and applicability of the findings [5,9,18]. These limitations are broadly categorized into data constraints, methodological challenges, geographical biases, and analytical gaps.

As illustrated in Figure 2, geographical bias in research contributions highlights the unequal representation of studies from different regions or countries. This disparity is often linked to factors such as variations in research funding, resource availability, institutional capacity, and regional priorities. For instance, countries like China and India dominate research in this area due to their large-scale tea industries and well-established research infrastructures. Conversely, underrepresented regions may lack

the resources or focus needed to contribute substantially, resulting in gaps in global knowledge and limiting the broader applicability of findings across diverse contexts.

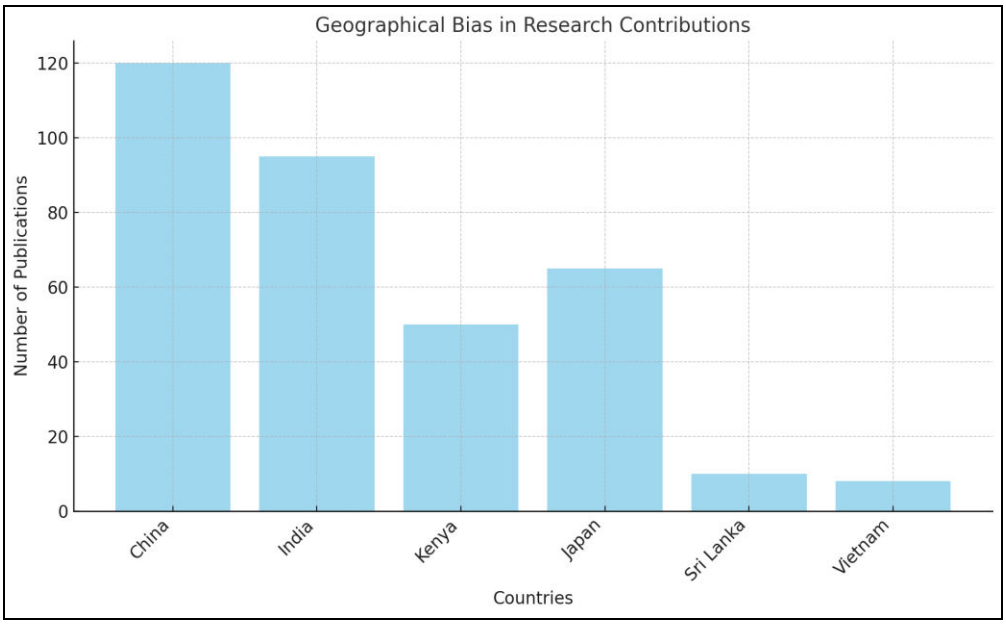

Figure 2: Geographical Bias in Research Contributions

As illustrated in Figure 3, coupling between countries in research contributions refers to collaborative efforts where nations jointly produce research outputs, often reflecting shared interests, resources, and expertise in specific fields. In the domain of tea yield prediction using machine learning, frequent collaborations between China and India are driven by their shared status as major tea producers and exporters. These partnerships leverage regional data, combined expertise, and advanced technologies, enhancing the quality and relevance of the research. Additionally, international collaborations with countries like Japan, Kenya, and the UK often adopt interdisciplinary approaches, integrating agricultural sciences with advanced machine learning techniques, fostering innovation and global impact.

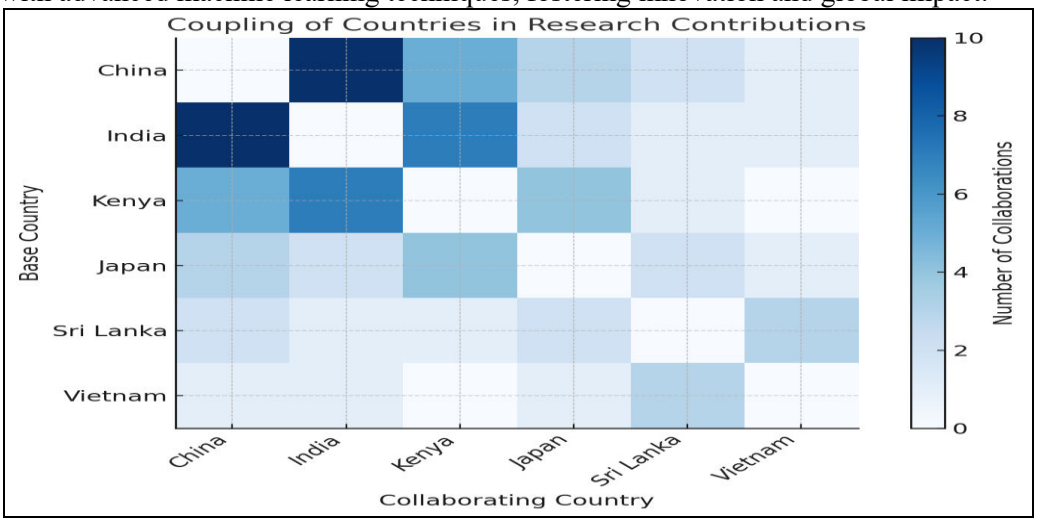

Figure 3: Coupling of countries in research contributions

The heat map illustrating the coupling of countries based on research collaborations [10,18]. The intensity of the color indicates the number of collaborations between countries. Based on Figure 4 the Co-authorship networks among countries illustrate the collaborative relationships between researchers from different nations. These networks highlight how countries pool expertise, data, and resources to address complex research challenges. In tea yield prediction using machine learning, co-authorship networks

often show strong ties between major tea-producing nations like China, India, Kenya, and Japan, where tea cultivation is a priority. Additionally, countries with advanced machine learning research capabilities, such as the USA or UK, often contribute by providing technical expertise. These collaborations enhance research quality, foster innovation, and promote the development of globally relevant solutions in agriculture and machine learning applications.

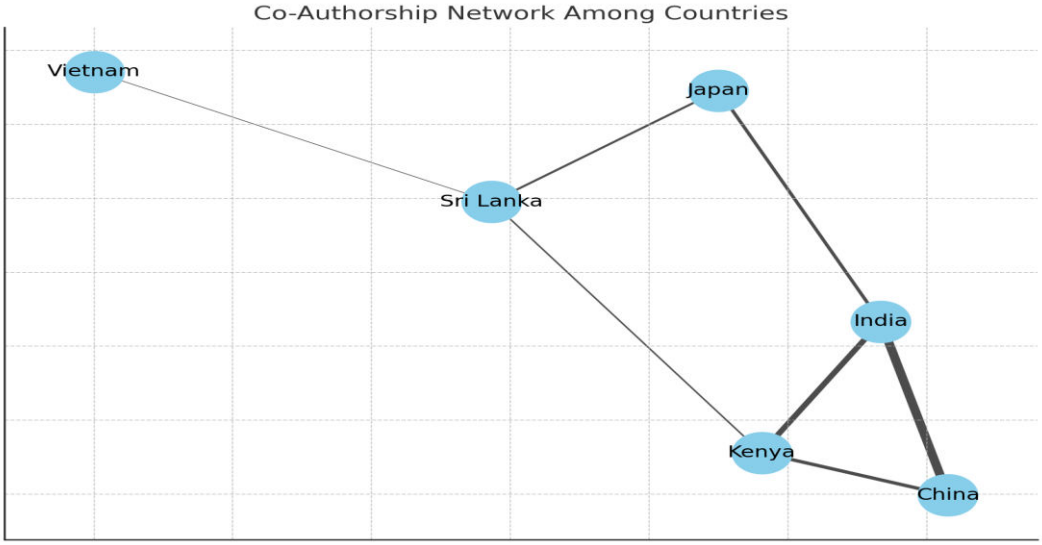

Figure 4: Coauthor ship Network among Countries

The network graph illustrating co-authorship relationships among countries [12,13]. The nodes represent countries, and the edges represent collaboration, with thickness indicating the strength of the co-authorship. In Figure 5,tea yield, as an output, is affected by factors such as climate, soil conditions, cultivation practices, and plant genetics. By applying machine learning techniques like PCA and Lasso for feature selection, these variables can be analyzed to predict and enhance tea yield, aiding in improved agricultural management.

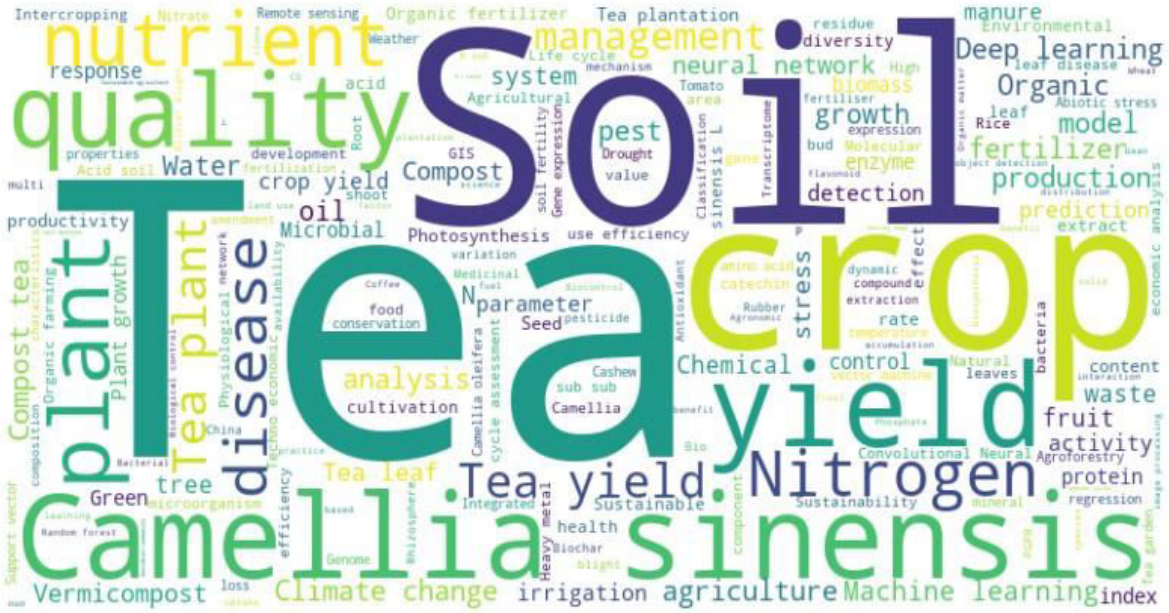

Figure 5: Keywords as output from present study

4. Conclusion:

Tea yield prediction is crucial for fostering sustainable production and optimizing resource utilization to meet the increasing global demand and address environmental challenges. Machine learning (ML) has emerged as a powerful tool, providing high accuracy and efficiency in analyzing complex datasets that include climatic conditions, soil properties, and agricultural practices. A bibliometric analysis shows significant growth in ML-based tea yield prediction research from 2015 to 2024, with a notable surge after 2018 due to advancements in computational techniques [2,5]. China leads in terms of publication volume and citation impact, followed by India and Japan, highlighting the focus of research in major tea-producing nations. A small yet influential group of authors and institutions has driven key studies, with limited but meaningful international collaborations [12,15]. Key research themes include "Machine Learning," “Deep learning”, "Tea Yield Prediction," "Precision Agriculture," and "Climate Change," while emerging areas like hybrid models that combine ML with crop simulation are gaining momentum. Groundbreaking studies often utilize IoT, real-time data, and remote sensing technologies to improve yield forecasting.

5. Future recommendation:

Future research should focus on improving data availability and standardization, fostering international collaborations, and integrating sustainability practices into machine learning models. Additionally, research efforts should be expanded to include underrepresented tea-producing regions, with a strong emphasis on validating models through field-level studies. These actions will enhance the broader applicability and practical effectiveness of tea yield prediction systems in real-world scenarios.

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