frontiers | Frontiers in Agronomy

TYPE Systematic Review
PUBLISHED 12 August 2024
DOI 10.3389/fagro.2024.1423233

Check for updates

OPEN ACCESS

EDITED BY
Nasim Ahmad Yasin,
University of the Punjab, Pakistan

REVIEWED BY
Muhammad Rizwan Tariq,
University of the Punjab, Pakistan
Saber Hussain,
University of the Punjab, Pakistan
Zain Mushtaq,
University of the Punjab, Pakistan
Samia Faiz,
University of Sargodha, Pakistan

*CORRESPONDENCE
Bahati Hakimu Msomba
hakimubahati@gmail.com

RECEIVED 25 April 2024
ACCEPTED 23 July 2024
PUBLISHED 12 August 2024

CITATION
Msomba BH, Ndaki PM and Joseph CO (2024) Sugarcane sustainability in a changing climate: a systematic review on pests, diseases, and adaptive strategies. *Front. Agron.* 6:1423233. doi: 10.3389/fagro.2024.1423233

Sugarcane sustainability in a changing climate: a systematic review on pests, diseases, and adaptive strategies

Bahati Hakimu Msomba[1,2*], Patrick Madulu Ndaki[2] and Charles O. Joseph[3]

[1]Regulatory Services Directorate, Sugar Board of Tanzania, Dar es Salaam, Tanzania, [2]Institute of Resource Assessment, Centre for Climate Change Studies, University of Dar es Salaam, Dar es Salaam, Tanzania, [3]Department of Crop Science and Beekeeping Technology, College of Agriculture and Food Technology, University of Dar es Salaam, Dar es Salaam, Tanzania

The cultivation of sugarcane (*Saccharum officinarum* L.) in the face of climate change requires robust strategies for managing pests, diseases, and weeds. This systematic review exposes critical deficiencies in current practices and underscores the need for climate-adaptive strategies. Climate change differentially influences pest behaviour, disease progression, and weed growth across various regions, yet the lack of region-specific responses impairs effective management. The review emphasizes the necessity for localized approaches that consider specific climatic conditions and the development of predictive models to anticipate pest and disease outbreaks. These models include Decision Support Systems (DSS), Support Vector Machines (SVM), Susceptible-Exposed-Infectious-Recovered (SEIR) models, Geographic Information Systems (GIS), Species Distribution Models (SDMs), Agricultural Production Systems sIMulator (APSIM), and Integrated Pest Management (IPM). Crucial strategies encompass integrated pest and disease management, adaptive breeding, precision agriculture, and ongoing innovation. Precision agriculture technologies, such as remote sensing and drones, enable early detection and prompt interventions. By adopting these adaptive measures and addressing existing research gaps, the sugarcane industry can bolster its resilience and maintain productivity amidst evolving climatic conditions.

Systematic review registration: https://www.bmj.com/content/372/bmj.n71.

KEYWORDS

agroecology, biotic stressors, climate adaptation, crop resilience, environmental impact, integrated pest management

1 Introduction

Sugarcane (*Saccharum officinarum* L.) stands as a vital global crop, playing a pivotal role in sugar production, bio-energy through bagasse, and livestock feed from straw (Msomba et al., 2021). Its cultivation spans 124 countries, with Brazil, India, and China dominating production. However, the sugar industry faces threats from climate change-induced shifts in temperature and weather patterns, amplifying the impact of insect pests, noxious weeds, and diseases (Bordonal et al., 2018; Sorvali et al., 2021).

Climate change exacerbates the outbreak and spread of pests like yellow sugarcane aphids (YSA) and diseases like gummosis and smut, impacting global sugarcane productivity (Cock and Allard, 2013; Lu et al., 2021). The primary driver of the challenges faced by the sugarcane industry is climate change, affecting temperature, rainfall, and humidity (Tamiru and Fekadu, 2019). The consequent impact on insect pests and diseases poses a significant threat to sugarcane cultivation globally. Yellow sugarcane aphids (YSA) (*Sipha flava* (Forbes)), white scales (*Pseudaulacaspis pentagona* (Targioni)), and white grubs (*Phyllophaga* sp.) are recognized culprits affecting sugarcane productivity worldwide (Ramanujam et al., 2021). The increasing prevalence of pests such as YSA, attributed to climate-driven shifts, necessitates a thorough examination of their impact and strategies for sustainable management (Way et al., 2015). It is inevitable that climate parameters significantly impact insect pests and disease pathogens in agriculture (Raid et al., 2013).

Diseases, including gummosis, ratoon stunting disease, smut, leaf scald, sugarcane mosaic virus, and leaf rust, further compound the challenges faced by the sugarcane industry (Lu et al., 2021). High temperatures are predicted to escalate the incidence of smut disease (Matthieson, 2007), while dry weather exacerbates ratoon stunting disease symptoms (Ramanujam et al., 2021). Climate-induced extreme weather events are cited as major contributors to diseases like leaf brown rust and orange rust (Raid et al., 2013). The impact of these diseases on sugarcane requires meticulous study to develop effective adaptation and mitigation strategies.

The significant sugarcane producers face challenges like insect pests infestation and disease proliferation, but comprehensive studies on the prevalence and severity of these factors are lacking (January et al., 2020). Understanding the influence of climate variability and sugarcane varieties on pests and diseases in different regions is critical for tailoring interventions. Economic thresholds, considering factors like pest density, crop variety, and market value, are essential for informed decision-making in pest management (Knutson et al., 2016). The absence of such thresholds specific to notorious pests like YSA highlights the need for focused research in this area (Bowling et al., 2016).

Climate change affects population dynamics, distribution, and activity of pests, necessitating adaptive management strategies (Mercer, 2020). Yet, limited information exists on the effects of climate change on sugarcane pests and diseases, emphasizing the need for research and innovative management tactics (Mercer, 2020). There is also a need to evaluate the influence of agro-ecological zones and sugarcane varieties on pest and disease variability. This addresses the gap in understanding how these factors contribute to the source-sink dynamics, timing, and severity of infestations (Pekarcik and Jacobson, 2021). For instance, considering the rapid population growth potential of sugarcane aphids, economic thresholds are crucial for effective pest management and sustainable sugarcane productivity (Bowling et al., 2016; Brewer et al., 2017). Therefore, this systematic review intends to provide a comprehensive understanding of the factors influencing sugarcane production globally and their interplay with climate change. The study aims to contribute valuable insights into sustainable sugarcane cultivation strategies, considering the increasing challenges posed by climate-induced changes in pest and disease dynamics by analyzing existing literature and conducting new research. The findings can inform policymakers and practitioners, enabling evidence-based decision-making to ensure the long-term viability of the sugarcane and sugar industry worldwide.

The rationale of this review emphasizes the impact of climate change on sugarcane pests and diseases, plus explicitly addressing potential adaptation and mitigation strategies, especially climate-driven adaptation strategies. Importantly, Mercer's (2020) suggestions modified integrated pest management tactics and monitoring climate and pest populations, but the study could benefit from a more detailed exploration of innovative approaches and practices that could enhance the industry's resilience to climate-induced challenges. Much of the existing research focuses on the global impact of climate change on sugarcane production but somewhere lacks a detailed examination of region-specific challenges and solutions. Sugarcane cultivation is highly influenced by local agro-ecological conditions, and there may be unique factors affecting pest and disease dynamics in different regions (Lu et al., 2021). There is also a gap in the exploration of existing or potential pest and disease forecasting models in literature (Mulianga et al., 2013; Donatelli et al., 2017; Bhatt et al., 2022; Koralewski et al., 2022; Daphal and Koli, 2023; Ngcobo et al., 2023). Developing accurate and reliable models for predicting the occurrence and severity of pests and diseases can be crucial for proactive and timely management (Ngcobo et al., 2023; Sharma et al., 2023; Subedi et al., 2023). The research could delve into incorporating a more in-depth analysis of the available forecasting models and propose improvements or new models tailored to the sugarcane industry, considering the specific challenges posed by climate change. Addressing these research gaps would contribute to a more holistic and actionable understanding of the complex interplay between climate change, sugarcane pests and diseases, and sustainable cultivation practices.

Developing climate-resilient sugarcane varieties through genetic research and adaptive breeding is essential. Further studies on integrated pest and disease management (IPDM) that combine biological, chemical, and cultural practices are necessary for effective management under changing climates. Advancing precision agriculture technologies like drones, remote sensing, and can enhance early detection, monitoring, and targeted treatment of pest and disease outbreaks. Researching soil health and biodiversity, particularly the role of soil microbiomes, is vital for improving resilience. Additionally, sustainable cultivation practices such as reduced tillage, organic amendments, and crop rotation should be investigated. Finally, examining the effects of extreme weather events on pest and disease dynamics and developing mitigation strategies is crucial. These research directions can enhance the resilience and sustainability of sugarcane cultivation. It would also provide practical insights for stakeholders in the sugarcane industry, enabling them to make informed decisions and implement effective strategies to ensure long-term productivity and resilience (Ncoyini et al., 2022; Kadam et al., 2023; Shawky et al., 2023). Addressing the research gaps in understanding the interplay between climate change, sugarcane pests, diseases, and sustainable cultivation practices is crucial. Key initiatives include developing climate-resilient sugarcane varieties through genome sequencing, editing, and field trials. IPDM by creating biocontrol agents and testing related protocols can improve pest and disease management. Enhancing precision agriculture technologies with AI, machine learning, and drone integration aids in early detection and outbreak management.

Early detection of pests and diseases in sugarcane can be significantly enhanced through a variety of advanced technologies and methods (Li, 2024). One crucial tool is remote sensing, which involves the use of satellites and drones equipped with multispectral or hyperspectral sensors (Waters et al., 2024). These sensors can detect subtle changes in plant health and vigour, allowing for early identification of stress indicators associated with pest infestations or disease outbreaks. Remote sensing data is processed using sophisticated algorithms and software to generate maps that pinpoint areas of concern in sugarcane fields, enabling targeted intervention (Fresneda-Quintana et al., 2024).

Diagnostic tools play a pivotal role in early detection as well. These include handheld devices and laboratory assays that analyze plant samples for specific pathogens or pest infestations (Vinayaka and Prasad, 2024). Polymerase chain reaction (PCR) techniques, for instance, can rapidly detect the presence of pathogens with high accuracy (Archana et al., 2024). Immunological assays and DNA-based diagnostics also contribute to precise identification and monitoring of pest and disease threat (Tu et al., 2024).Emerging technologies such as Internet of Things (IoT) devices and sensor networks are increasingly integrated into precision agriculture systems. These devices monitor environmental parameters like temperature, humidity, and soil moisture in real-time (Narayana et al., 2024). They can provide continuous data streams that are analyzed to detect anomalies indicative of pest activity or disease development.

Artificial intelligence (AI) and machine learning algorithms are transforming early detection capabilities by analyzing large datasets from remote sensing, IoT sensors, and diagnostic tools (Vinayaka and Prasad, 2024). These algorithms can identify patterns and predict potential outbreaks before visible symptoms manifest, allowing farmers to implement proactive management strategies promptly (Chaiyana et al., 2024). Collaboration between researchers, agricultural extension services, and technology developers is crucial for advancing these technologies. Funding opportunities from governmental agricultural departments, research grants, and partnerships with private sector entities may further drive innovation in early pest and disease detection technologies. By leveraging these advanced tools and methods, sugarcane growers can achieve more effective pest and disease management, leading to improved crop health and productivity. Soil microbiomes, can boost plant resistance (Xiao et al., 2024). Researching sustainable practices like reduced tillage, organic amendments, and crop rotation promotes sustainability. Examining the effects of extreme weather events on pest and disease dynamics and developing climate adaptation strategies can mitigate risks. Funding and collaboration opportunities include national agricultural departments, international organizations, private sector investments, academic institutions, NGOs, and innovation grants. These efforts can significantly enhance sugarcane resilience and sustainability.

2 Methodology for literature search

This baseline desk review of literature and synthesis of the findings spanned from January to April 2024 (See details in Table 1; Figure 1). The literature search followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework outlined by Tlatlaa et al. (2023). PRISMA serves to enhance transparent reporting by elucidating the motivations behind the study (answering "why")?, detailing the actions undertaken by the authors (answering "what")?, and presenting the review findings (answering "what")?. The PRISMA furnishes a checklist for a systematic literature review report, covering various sections such as title, abstract, introduction, methods, results, discussion, and other pertinent information, following the PRISMA 2020 checklist guidelines updated by Page et al. (2021). The PRISMA emphasizes that the title should unmistakably denote the report as a literature review, while the abstract needs to provide a structured summary. It also stresses that the introduction should discuss the rationale and objectives of the review. Methods entail specifying eligibility criteria, information sources, search strategy, selection process, and risk of bias assessment. Results involve detailing the study selection process, characteristics, risk of bias, and individual study outcomes. The discussion segment is dedicated to interpreting results, addressing limitations, and exploring implications. Additional information includes registration details, funding sources, conflicts of interest, and the availability of data and materials.

3 Findings of the review and synthesis

The review presents findings organized into six main sections: (1) Limited emphasis on climate-driven adaptation strategies for pest and disease control, (2) Inadequate examination of region-specific climate effects on pest and disease dynamics, (3) Sparse assessment of pest and disease forecasting models under climate change, (4) Impact of climate change on insect pests affecting sugarcane, (5) Impact of climate change on sugarcane diseases, and (6) Climate change influence on prominent sugarcane weeds.

TABLE 1 Methods utilized for literature search.

Literature search	Steps
Identification of key databases	**Utilizes:** PubMed, Scopus, Web of Science, and Agricola
	Exploring specialized databases on: agriculture, climate science, and pest management
Search string formulation	**A search string with keywords:** "sugarcane," "climate change," "pests," "diseases," "adaptive strategies"
	Use of Boolean operators (AND, OR) for refining search queries
Inclusion and exclusion criteria	**Definition criteria:** articles published in the last decade, peer-reviewed, and in English
	Excluded: Studies lacking relevance to interconnections in sugarcane sustainability
Snowballing and citation tracking	Review reference lists for additional sources
	Implement citation tracking to identify subsequent studies
Grey literature search	Exploring conference proceedings, reports, theses, and grey literature
	Included: relevant institutional repositories and government publications
Data extraction	Developing a systematic extraction form for key study information
	Ensure consistency across all extracted data
Quality assessment	Use of established tools (e.g., Joanna Briggs Institute Critical Appraisal) for quality assessment
	Document the quality assessment process clearly
Synthesis of findings	Employing thematic analysis for synthesis
	Considering interconnections between climate change, pests, diseases, and adaptive strategies
Risk of bias assessment	Evaluate bias in study design, data collection, and reporting
	Enhance transparency and reliability of the review

3.1 Limited emphasis on climate-driven adaptation strategies for pest and disease control

While existing literature comprehensively acknowledges the influence of climate change on sugarcane pests and diseases, it somewhat overlooks the need for detailed exploration of climate-driven adaptation strategies. Some literature highlights the impact of climate change on the proliferation of insect pests and diseases, emphasizing the role of temperature, atmospheric carbon dioxide levels, and precipitation patterns (Delcour et al., 2015; Skendžić et al., 2021; Shivanna, 2022; Nguru and Mwongera, 2023). However, the specific measures and practices that can be implemented to adapt sugarcane cultivation to these changing conditions are not extensively discussed. Understanding how climate change alters the dynamics of pest and disease populations is crucial, but equally important is the identification of adaptive measures that farmers and stakeholders can employ (Sakdapolrak et al., 2024; Sarkar et al., 2024). For instance, the study could be required delving into the development and implementation of climate-resilient agronomic practices, pest-resistant sugarcane varieties, and precision farming technologies. Integrating these adaptation strategies into the research framework would provide a more comprehensive guide for practitioners seeking sustainable solutions in the face of climate-induced challenges (Araújo et al., 2023; Durán-Díaz, 2023).

Limited emphasis on climate-driven adaptation strategies for pest and disease control of sugarcane reflects a critical gap in addressing the evolving challenges posed by climate change in agricultural systems (Shahzad et al., 2021; Grigorieva et al., 2023). Grigorieva et al. (2023) conducted a comprehensive review of adaptation strategies and interventions proposed globally to mitigate the impact of climate change on agricultural development and production and underscored the importance of context-specific adaptation strategies, cautioning against limiting discussions to singular "top-down" or "bottom-up" approaches. Grigorieva et al. (2023) pointed out that some adaptation measures may be insufficient or even exacerbate vulnerability to climate change. In many agricultural contexts, including sugarcane cultivation, historical approaches to pest and disease control have primarily relied on conventional methods such as chemical pesticides and resistant crop varieties (Budeguer et al., 2021). While these methods have been effective to some extent, they often overlook the complex interplay between climate change and pest/disease dynamics. Pests and diseases may adapt and spread in ways that traditional management practices can no longer adequately address as climate conditions continue to change (Singh et al., 2019; Shahzad et al., 2021).

There is a pressing need for comprehensive studies to understand how climate variability influences the behaviour, life cycles, and prevalence of sugarcane pests and diseases. Without knowledge on these aspects, it becomes challenging to devise targeted adaptation strategies that can effectively mitigate risks and enhance resilience in sugarcane production systems (Grigorieva et al., 2023). Resource constraints further exacerbate the issue, as agricultural research and development budgets may prioritize other pressing concerns over climate-driven adaptation strategies for sugarcane (Khan and Akhtar, 2015). Limited funding and resources hinder the innovation and implementation of novel approaches that could bolster the resilience of sugarcane crops against pest and disease pressures exacerbated by climate change (Dixon et al., 2014).

Moreover, policy frameworks and agricultural extension programs may not adequately emphasize the importance of climate-resilient pest and disease management practices in sugarcane cultivation (Peng et al., 2020; van Zonneveld et al., 2020). There is a need for policymakers to integrate climate adaptation considerations into agricultural policies and provide

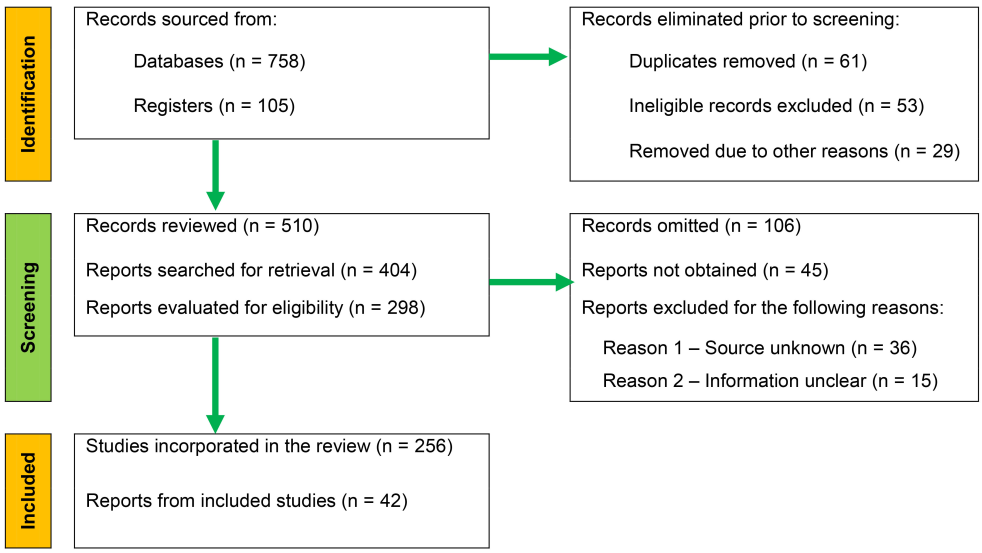

FIGURE 1
Quantity of studies identified and incorporated into the analysis. Adapted from Tlatlaa et al. (2023).

incentives for adopting sustainable practices. Additionally, raising awareness among farmers and stakeholders about the implications of climate change on sugarcane production and the necessity for proactive adaptation measures is essential for fostering widespread adoption of climate-smart practices (Vermeulen et al., 2018; Adesipo et al., 2019; Kalimba and Culas, 2020; Das and Ansari, 2021; Majhi et al., 2023). Increased vulnerability to pest infestations and disease outbreaks can result in reduced yields, lower-quality produce, and economic losses for farmers and the sugar industry (Tripathi et al., 2022; Ward et al., 2022). Moreover, reliance on chemical pesticides and fungicides may contribute to environmental degradation, posing risks to soil health, water quality, and biodiversity (Boudh and Singh, 2019; Mandal et al., 2019; Alengebawy et al., 2021). Addressing this requires a concerted effort from multiple stakeholders, including researchers, policymakers, industry representatives, and farmers (Bartels et al., 2013). Investments in research and development, capacity building, policy support, and public awareness are crucial for developing and implementing effective climate-resilient pest and disease management strategies in sugarcane cultivation (Khatri-Chhetri et al., 2019; Shrestha and Thapa, 2019). By prioritizing climate adaptation in agricultural decision-making processes, stakeholders can enhance the sustainability and resilience of sugarcane production systems in the face of climate change (Andrieu et al., 2019).

3.2 Inadequate examination of region-specific climate effects on pest and disease dynamics

There is a notable research gap concerning the exploration of region-specific climate impacts on sugarcane pests and diseases. Climate change manifests differently in various geographic locations, influencing the prevalence and behaviour of pests and diseases in distinct ways (Giliba et al., 2020; Hauser et al., 2021; Skendžić et al., 2021; Singh et al., 2023). To address this gap, the research could incorporate a more nuanced examination of how local climate patterns and environmental conditions contribute to the challenges faced by sugarcane growers (Finch et al., 2021; Montalvo-Navarrete and Lasso-Palacios, 2024). This regional focus would facilitate the development of tailored recommendations and strategies, accounting for the specific interactions between climate variables and pest/disease dynamics in sugarcane fields. For instance, Nguru and Mwongera (2023) assessed the impact of climate change on the suitability of natural habitats for crop pests and diseases, and project an increased geographical spread of suitable habitats for crop pests in warmer environments by the 2030s. According to Nguru and Mwongera (2023), the importance of future-facing, long-term climate adaptation and mitigation measures create less suitable microclimates for crop pests and diseases.

Finch et al. (2021) conducted a study focusing on the global increase in mean surface temperatures, drawing attention to the rise of approximately 0.7°C per century since 1900 and a more accelerated pace of 0.16°C per decade since 1970. Studies emphasize that the primary driver of this warming trend is the heightened concentration of greenhouse gases resulting from human activities (Jorgenson et al., 2019). Literature also addresses changes in precipitation patterns, acknowledging their variability compared to temperature changes (Alexander, 2016). Despite this variability, it is argued that future climatic changes, even under conservative emission scenarios, are likely to include further temperature increases and a significant increase in drought conditions in some regions, as highlighted by the Intergovernmental Panel on Climate Change (IPCC) in 2007 (Finch et al., 2021).

The alterations in temperature and precipitation patterns will affect invasive species in various ways. Notably, climate change is anticipated to challenge conventional perceptions of nonnative invasive species, as the impacts on some species may shift while others remain unaffected (Hume et al., 2021). Moreover, certain nonnative species could become more invasive, posing additional challenges for ecosystems. Additionally, Finch et al. (2021) anticipate shifts in the geographic ranges of native species into novel habitats due to climate change. These changes in distribution patterns among both invasive and native species are expected to have profound ecological implications (Gaertner et al., 2017). The importance of considering these dynamics is also acknowledged when addressing the challenges posed by invasive species in the context of a changing climate (Finch et al., 2021; Hume et al., 2021). The analysis by Finch et al. (2021) provides valuable insights into the interconnected impacts of climate change and invasive species, based on a robust examination of global temperature trends and their implications for ecological systems.

3.3 Sparse assessment of pest and disease forecasting models under climate change

Sparse assessment of pest and disease forecasting models under climate change encompasses the limited evaluation of predictive models designed to anticipate the emergence, spread, and impact of pests and diseases on agricultural and ecological systems amidst shifting climatic conditions (Hamdi et al., 2022; Fassnacht et al., 2024). This field of study is of paramount importance due to the significant threats posed by pests and diseases to global food security, ecosystem health, and economic stability, particularly in the face of climate change-induced alterations in temperature, precipitation patterns, and extreme weather events (Abbass et al., 2022; Mwangi et al., 2023).

Model development involves constructing predictive models based on historical data and assumptions about environmental conditions, incorporating factors such as temperature, humidity, precipitation, host plant physiology, pathogen biology, and insect behaviour to simulate the spread and impact of pests and diseases (Donatelli et al., 2017; Lee and Yun, 2023). Climate change considerations are crucial as climate change alters environmental conditions, including temperature regimes, rainfall patterns, and the frequency of extreme weather events (Lee et al., 2022). Incorporating climate change variables and scenarios into predictive models presents significant challenges due to uncertainties in future climate projections and complex interactions between climate and biological systems (Kamga et al., 2022). Data limitations contribute to sparse assessment, arising from challenges in the availability, quality, and spatial/temporal resolution of data required to calibrate, validate, and refine forecasting models (Petropoulos et al., 2022; Yang et al., 2022). Insufficient data on pest and disease occurrences, environmental variables, and management interventions can hinder the accuracy and reliability of predictive models, particularly in regions with limited monitoring infrastructure and research capacity (Akhter and Sofi, 2022; Dhanaraju et al., 2022; Taylor et al., 2023).

This systematic review emphasizes the critical role of predictive models in developing adaptive strategies for sugarcane sustainability. Decision Support Systems (DSS), such as the DSSAT framework, integrate crop growth models, weather data, and management practices to simulate crop growth and predict pest and disease outbreaks (Equation 1). Tailoring DSSAT for localized climate patterns allows for the anticipation of pest and disease threats, enabling timely interventions.

$$Y = f(T, P, N, W) \tag{1}$$

Where Y is yield, T is temperature, P is precipitation, N is nutrient availability, and W is water availability.

Machine learning models, including Random Forest and Support Vector Machines (SVM), analyze large datasets, including climate variables and historical disease incidence, to forecast future disease outbreaks (Equation 2). These models, trained on localized climate data, are effective in predicting specific disease threats.

$$\hat{y} = \frac{1}{n}\sum_{i=1}^{n}\hat{y}_i \tag{2}$$

Where $\hat{y}$ is the predicted outcome, and $\hat{y}_i$ are the predictions from individual trees in the forest.

Epidemiological models like Susceptible-Exposed-Infectious-Recovered (SEIR) can be adapted to predict the spread of sugarcane diseases by incorporating local climate variables, pest population dynamics, and crop growth stages, thus helping devise targeted control measures (Equation 3).

$$\frac{dS}{dt} = -\beta SI, \quad \frac{dE}{dt} = \beta SI - \sigma E, \quad \frac{dI}{dt} = \sigma E - \gamma I, \quad \frac{dR}{dt} = \gamma I \tag{3}$$

Where S is susceptible, E is exposed, I is infectious, R is recovered, β is the transmission rate, σ is the incubation rate, and γ is the recovery rate.

Geographic Information Systems (GIS) combined with Species Distribution Models (SDMs) predict pest infestations by analyzing spatial and climatic data (Equation 4), identifying high-risk areas for pest outbreaks and enabling proactive pest management strategies.

$$P(x) = \frac{1}{1 + e^{-(\beta_0 + \sum_{i=1}^{n}\beta_i x_i)}} \tag{4}$$

Where $P(x)$ is the probability of species presence, β_0 is the intercept, β_i are coefficients, and x_i are the predictor variables.

Climate-driven crop simulation models, such as Agricultural Production Systems sIMulator (APSIM), simulate the growth and yield of sugarcane under different climate scenarios (Equation 5). The APSIM predicts the impact of climate variables on sugarcane growth and the likelihood of pest and disease problems, facilitating the development of adaptive strategies to enhance crop resilience by incorporating localized climate data.

$$G = G_{max} \times \left(\frac{T_{opt} - |T - T_{opt}|}{T_{opt} - T_{min}}\right) \times \left(\frac{P}{P_{opt}}\right) \tag{5}$$

Where G is growth, G_{max} is maximum growth, T is temperature, T_{opt} is optimal temperature, T_{min} is minimum temperature, and P is precipitation.

Bioeconomic models, which combine climate data with pest and disease management costs, optimize Integrated Pest Management (IPM) strategies by predicting the most cost-effective and sustainable approaches to pest and disease control, tailored to localized climate patterns (Equation 6). These predictive models present the necessity of adapting to localized climate patterns to effectively manage pest and disease threats, ensuring the resilience and productivity of sugarcane cultivation amidst evolving climate conditions.

$$NPV = \sum_{t=0}^{T}\left(\frac{B_t - C_t}{(1+r)^t}\right) \tag{6}$$

Where NPV is the net present value, B_t are benefits in year t, C_t are costs in year t, r is the discount rate, and T is the time horizon.

While literature explains upon the importance of monitoring climate and pest populations, there is a notable gap in the exploration of existing or potential pest and disease forecasting models. Climate change not only affects the prevalence of pests and diseases of sugarcane but also alters their spatial and temporal distribution (Srinivasan et al., 2024). Robust forecasting models can play a pivotal role in predicting the occurrence and severity of outbreaks, enabling proactive and targeted management strategies (Subedi et al., 2023).

There exists complex relationship between the explosive growth of the global population, technological advancements, and the challenges posed by climate change to agricultural e production (Subedi et al., 2023). Subedi et al. (2023) indicated that the confluence of these factors has given rise to a complex scenario where the progress that has fuelled increased food demand is under threat due to the adverse impacts of climate change. The significantly acknowledged issues arising from climate change include rising carbon dioxide levels, frequent droughts, and temperature fluctuations (Waheed et al., 2023; Yanagi, 2024). These environmental shifts pose substantial challenges to crop production and, consequently, jeopardize global producing systems. The focus of much literature in this discipline lies in understanding how these climatic variables affect the biology and ecology of insect pests, which play a pivotal role in the delicate balance of agricultural ecosystems (Skendžić et al., 2021; Abbass et al., 2022). Given the dependence of insect pests on climate factors, any alterations in these variables have far-reaching implications for crop productivity (Subedi et al., 2023). The interconnectedness of insect pests, climate change, and crop yields underscores the urgency of comprehending the impact of climate change on insect pest dynamics (Table 2). A key contribution of literature lies in its exploration of modern pest monitoring technologies and prediction tools. Literature advocates for the integration of these advanced tools to enhance ability to monitor and predict pest behaviour in the face of changing climatic conditions. Despite the valuable insights provided by literature, there remain certain research gaps that merit further investigation. One crucial aspect is the need for more extensive field studies to validate the efficacy of the proposed pest monitoring technologies and prediction tools in diverse agricultural settings (Chawade et al., 2019; Preti et al., 2021). Additionally, understanding the socio-economic impacts of implementing these technologies, especially in resource-limited regions, is crucial for ensuring the practicality and accessibility of these strategies (Maduka et al., 2023). Furthermore, studies emphasize the importance of climate variables in influencing insect pest biology, but there is room for additional research into the potential feedback loops between insect pests and climate change (Barton et al., 2019; Yang et al., 2021). How, for instance, changes in pest populations may further exacerbate climate issues

TABLE 2 Interconnections between sugarcane cultivation and sustainability.

Interconnections	Key elements
Sugarcane cultivation:	
Climate change catalyst	Altered temperature, rainfall patterns
	Atmospheric conditions
	Dynamic environment
Pest proliferation	Rising temperatures
	Yellow sugarcane aphid (YSA)
	Direct threat to yield and quality
Disease dynamics	Shifts in temperature and extreme weather events
	Impact on diseases like smut and ratoon stunting disease
Local variability	Region-specific climate patterns
	Interaction with agro-ecological conditions
	Influences specific challenges in different regions
Adaptive management strategies	Modified integrated pest management tactics
	Climate-resilient agronomic practices
	Development of pest-resistant sugarcane varieties
Economic thresholds	Define thresholds for intervention
	Consider pest density, crop variety, market value
	Guide timely interventions for sustainable
Sustainability in diverse climates:	
Forecasting models	Incorporate climate variables
	Predict occurrence and severity of pests and diseases
	Enable proactive management decisions
Global and local perspectives	Balance global insights with local variability
	Ensure comprehensive strategies for sugarcane

or create new challenges for agricultural sustainability is an intriguing avenue for future exploration.

These gaps may be addressed by the research that could include a more thorough evaluation of existing forecasting models, examining their applicability to changing climate conditions (Balogun et al., 2020). Moreover, it could explore the development of new models that incorporate climate change variables, providing accurate predictions for sugarcane growers. This emphasis on forecasting would empower stakeholders with timely information, helping them anticipate and mitigate the impact of emerging pest and disease threats in the context of a changing climate (Rocklöv et al., 2023). By incorporating these considerations, the research could bridge critical gaps and offer a more holistic understanding of the relationship between climate change, sugarcane pests and diseases, and the adaptive measures necessary for sustaining the industry (Grandis et al., 2024).

3.4 Impact of climate change on plant growth-reducing factors of sugarcane

Sugarcane growth is significantly hindered by insect pests, diseases, and weeds, with climate change exacerbating these challenges. Elevated temperatures and altered precipitation patterns enhance pest populations and disease prevalence, disrupting plant health. Weeds thrive under these warmer conditions, competing aggressively with sugarcane and reducing yields. Climate change also disrupts the phenology and life cycles of pests, diseases, and weeds, making traditional management practices less effective. These shifts necessitate integrated management strategies, including cultural, biological, and chemical controls, alongside precision agriculture and adaptive breeding programs to develop resilient sugarcane varieties and ensure sustainable cultivation amidst evolving climatic conditions. The details of these factors are described in subsequent sections.

3.4.1 Influence of climate change on insect pests of sugarcane

Climate change profoundly influences insect pest dynamics in sugarcane cultivation, complicating efforts to maintain sustainable production. The relationship between shifting climatic conditions and pest behaviour necessitates a comprehensive understanding to develop long-term strategies for sustainability (Weier et al., 2024). A primary effect of climate change is the alteration of temperature patterns (Balasundram et al., 2023; Bibi and Rahman, 2023; Johnson, 2023; Singh et al., 2023). Pests such as white scales (*Aulacaspis tegalensis*) (Sarjan et al., 2021), white grubs (*Cochliotis melolonthoides*) (Kumar and Prasad, 2020), and yellow sugarcane aphids (*Sipha flava*) (Dumont et al., 2023) impact sugarcane productivity globally.

The yellow sugarcane aphid (YSA) is particularly sensitive to temperature variations (Skendžić et al., 2021; Bhattacharyya et al., 2023; Bouri et al., 2023; Prajapati et al., 2023). Climate change-induced temperature increases expand YSA's suitable habitat range, leading to greater prevalence in sugarcane fields (Chen et al., 2023; Li P. et al., 2024; Nikpay et al., 2023). Higher temperatures also accelerate YSA's reproductive capacity, exacerbating challenges for growers (Bhagarathi and Maharaj, 2023; Walia and Kaur, 2024). Changing rainfall patterns further contribute to insect pest proliferation in sugarcane fields (Valencia Arbeláez et al., 2021). Altered precipitation affects water availability, influencing pest abundance and distribution (Subedi et al., 2023). In regions with changing rainfall, pests like white scales, white grubs, and YSA may find new ecological niches, shifting population dynamics (See Table 3). This necessitates adaptive pest management strategies that consider evolving climatic conditions (Janousek et al., 2023; Waheed et al., 2023).

Climate change also alters the phenology and behaviour of insect pests (Subedi et al., 2023; Shafiq et al., 2024). Shifts in life stage timing, such as reproduction and larval development, are linked to climatic signals. Disruptions in these signals can increase pest pressure on sugarcane crops, impacting yield and quality (Tait et al., 2021; Zheng et al., 2024). For instance, the reproductive patterns of *Heteronychus paolii* Arrow (Dynastinae) and *Schizonycha vastatrix* Chiaramonte (Melolonthinae) are influenced by temperature and rainfall variability, causing population fluctuations (Cock and Allard, 2013). Extreme weather events associated with climate change, such as hurricanes and cyclones, complicate insect pest dynamics in sugarcane cultivation (Cilas and Bastide, 2020; Volk et al., 2023). These events disrupt habitats and pest behaviour, leading to altered infestation patterns (Volk et al., 2023). Post-hurricane conditions may favour rapid pest proliferation, threatening sugarcane production sustainability (Palanivel and Shah, 2021).

3.4.2 Influence of climate change on diseases of sugarcane

Climate change presents numerous challenges to sugarcane production, particularly through its influence on disease pathogens (Savary and Willocquet, 2020). Understanding the relationship between changing climatic conditions and sugarcane diseases is crucial for developing effective long-term sustainability strategies (See Table 4). One significant impact of climate change on sugarcane diseases is the alteration in temperature patterns (Linnenluecke et al., 2020). Rising global temperatures create favourable conditions for the proliferation of certain disease pathogens. For instance, smut disease, caused by the fungus *Sporisorium scitamineum*, thrives in warmer conditions (Bhuiyan et al., 2021; Rajput et al., 2021). Increased temperatures associated with climate change contribute to the incidence and severity of smut, posing a substantial threat to sugarcane yields. Similarly, leaf scald, caused by the bacterium *Xanthomonas alibilineans*, is influenced by temperature shifts, with high temperatures exacerbating its symptoms (Bini et al., 2023; Li H. et al., 2024).

Changing rainfall patterns also play a pivotal role in the spread and severity of sugarcane diseases (Kim et al., 2024). Climate change leads to shifts in rainfall timing, distribution, and intensity, affecting the water-dependent life cycles of disease-causing organisms. Gummosis, caused by the bacterium *Xanthomonas axonopodis* pv. vasculorum, is highly influenced by moisture conditions

TABLE 3 Common insect pests affecting sugarcane and the target parts.

Insect pest	Commonly affected parts	References
Sugarcane Borer (*Diatraea saccharalis* (Fabricius))	Stalks, particularly internodes	Joyce et al. (2014); Simões et al. (2015); Fogliata et al. (2016); Pavinato et al. (2017); Valencia Arbeláez et al. (2021); Simões et al. (2022)
Aphids (*Melanaphis sacchari*)	Leaves, young shoots, and stems	Calvin et al. (2021); Esquivel et al. (2021); Pekarcik and Jacobson (2021); Faris et al. (2022)
Whiteflies (*Aleurolobus barodensis*)	Undersides of leaves, sap-sucking	Askarianzadeh and Minaeimoghadam (2018); Behnam-Oskuyee et al. (2020)
Termites (*Odontotermes assmuthi*)	Roots and base of sugarcane plants	Saha et al. (2016); Zaman et al. (2022)
Armyworms (*Spodoptera frugiperda*)	Leaves, can cause defoliation	Li et al. (2021); Makgoba et al. (2021); Soumia et al. (2023)
Wireworms (*Melanotus communis* Gyllenhal)	Roots and underground plant parts	Karounos et al. (2020); Williams et al. (2022)
Leafhoppers (*Pyrilla perpusilla*)	Leaves and young shoots	Mahesh et al. (2019); Sharma and Shera (2021)
Mealybugs (*Saccharicoccus sacchari*)	Leaves, stems, and nodes	Qin et al. (2020)
Root Borers (*Polyocha depressella*)	Roots and base of sugarcane plants	Dessoky et al. (2021); Viswanathan et al. (2022); Muhammad et al. (2023)
Grasshoppers (*Hieroglyphus banyan*)	Leaves and stems, can cause defoliation	Bam et al. (2020)
White grubs (*Holotrichia serrata*)	Roots and base of sugarcane plants	Cock and Allard (2013)

(Hussain et al., 2024; Li H. et al., 2024; Parthasarathy et al., 2024). Altered rainfall patterns can facilitate the spread of this bacterium or create conducive conditions for its development, increasing gummosis incidences in sugarcane fields. Leaf rust, caused by *Puccinia melanocephala*, is also sensitive to moisture levels, with deviations from normal rainfall patterns affecting its prevalence (Wójtowicz et al., 2020).

The geographical distribution and behaviour of disease vectors, such as insects and fungi, are influenced by climate change. These vectors are crucial in transmitting pathogens, and their altered patterns contribute to disease spread in sugarcane fields. Climate-induced shifts in the distribution and behaviour of pests like white scales, white grubs, and yellow sugarcane aphids can lead to variations in disease transmission patterns, further complicating disease dynamics in sugarcane cultivation (Dumont et al., 2023).

Extreme weather events associated with climate change, such as hurricanes and cyclones, also impact sugarcane disease dynamics (Badillo-Márquez et al., 2021; Christina et al., 2021). These events can cause physical damage to sugarcane plants, creating entry points for pathogens and facilitating disease spread. Hurricanes and cyclones can increase sugarcane crops' vulnerability to diseases like leaf rust and smut (Ahmad, 2023). Additionally, the aftermath of extreme weather events can create conditions favourable for rapid pathogen proliferation, threatening sugarcane production sustainability (Singh et al., 2018; Noureen et al., 2022).

3.4.3 Influence of climate change on notorious weeds of sugarcane

Climate change has a multifaceted impact on the dynamics of notorious weeds affecting sugarcane cultivation, presenting challenges to the sustainability of this vital crop (Chaki et al., 2023; Vasileiou et al., 2024; Nath et al., 2024). The interplay between shifting climatic conditions and the behaviour of noxious weeds requires a comprehensive understanding to develop effective strategies for long-term sustainability.

One of the primary effects of climate change on weeds is the alteration in temperature and precipitation patterns (Sreekanth et al., 2023; Kachare et al., 2024). Rising global temperatures influence the germination, growth, and reproductive processes of weeds, with some species thriving in warmer conditions. Weeds such as *Imperata cylindrica* (cogon grass) and *Sorghum halepense* (Johnson grass), recognized as notorious competitors with sugarcane, may experience increased vigour and expansion of their ecological range in response to elevated temperatures (Shumail et al., 2022; Othman et al., 2023; Tan et al., 2024). Changes in precipitation patterns, including altered onset and distribution of rainfall, further contribute to the weed proliferation challenge. Weeds like *Cyperus rotundus* (purple nutsedge) and *Echinochloa colona* (jungle rice) are adapted to varying moisture conditions, and climate-induced shifts in precipitation can create favourable habitats for these aggressive competitors (Eslami and Arpanahi, 2023; Keerthi Sree et al., 2023; Mahgoub, 2023).

Climate change also influences the phenology and life cycles of notorious weeds in sugarcane fields (Pires da Silva et al., 2014; Giraldeli et al., 2021). The timing of seed germination, emergence, and flowering is intricately linked to environmental cues, including temperature and photoperiod. As these cues undergo alterations due to climate change, the phenological patterns of weeds may be disrupted, impacting their synchronization with sugarcane crops (Anwar et al., 2021; Deeksha et al., 2022; Santosh and Pavithran, 2024). This mismatch in timing can result in increased weed pressure on susceptible crops, affecting overall yields and hindering sustainable sugarcane production. The impact is particularly pronounced with weeds like *I. cylindrica*, known for its aggressive growth and ability to outcompete sugarcane in various agro-climatic conditions (Sivakumar et al., 2018).

Changing climatic conditions also influence the distribution and spread of notorious weeds, creating challenges for weed management practices (Anwar et al., 2021; Rao et al., 2023). Most notorious weeds often disperse their seeds through wind, water, or human activities (Balah, 2021; Khattak et al., 2024). Climate-

TABLE 4 Correlation between climate change and sugarcane diseases.

Disease	Transmitting agent	Targeted plant parts	Climate change influence	References
Sugarcane mosaic	Viruses	Leaves, stems	Climate shifts alter vector behaviour and virus transmission patterns	Rice et al. (2019); Lu et al. (2021)
Red rot	Fungi (*Colletotrichum falcatum* Went)	Stalks, roots	Increased rainfall and humidity enhance fungal growth and spread	Hossain et al. (2020)
Smut	Fungi (*Sporisorium scitamineum*)	Inflorescence, stalks	Higher temperatures increase incidence and severity	Bhuiyan et al. (2021)
Pokkah boeng	Bacteria (*Fusarium moniliforme*)	Leaves, stalks, roots	Higher humidity and temperature fluctuations increase occurrence	Singh et al. (2006)
Leaf rust	Fungi (*Puccinia* sp.)	Leaves, stems	Moisture changes affect prevalence	Virtudazo et al. (2001); Hoy and Hollier (2009)
Leaf scald	Bacteria (*Xanthomonas albilineans* (Ashby) Dowson)	Leaves, stems	High temperatures worsen symptoms	Govindaraju et al. (2019); Cervantes-Romero et al. (2021); Zhao et al. (2022)
Gummosis	Bacterium: *Xanthomonas axonopodis pv. vasculorum*	Leaves, stems	Altered rainfall boosts spread and development	Cock and Allard (2013); Lu et al. (2021)
Ratoon stunting	Phytoplasma (Candidatus *Phytoplasma sacchari*)	Stalks, roots	Water stress and variable temperatures contribute to disease spread	Viswanathan (2022)

induced alterations in wind patterns and increased frequency of extreme weather events can facilitate the long-distance dispersal of weed seeds, leading to the colonization of new areas (Table 5). This expansion of weed distribution zones poses a significant threat to the sustainability of sugarcane cultivation, as it increases the likelihood of weed infestations in previously unaffected regions (Allsopp et al., 2021; Baltazar and De Datta, 2023).

Extreme weather events associated with climate change, such as hurricanes, cyclones, and floods, further exacerbate the challenges posed by notorious weeds in sugarcane fields. These events can disrupt weed management practices and create conditions conducive to rapid weed proliferation. For example, flooding can displace weed seeds and rhizomes, redistributing them across fields and complicating efforts to control their spread (Smith et al., 2021; Haring, 2022). The aftermath of extreme weather events may necessitate intensive weed control measures to prevent the establishment of weed populations that could jeopardize the health and productivity of sugarcane crops.

TABLE 5 Notorious weeds of sugarcane.

Weed	References
Nutgrass (*Cyperus rotundus*)	Pires da Silva et al. (2014); Giraldeli et al. (2021)
Bermuda grass (*Cynodon dactylon*)	Girolamo-Neto et al. (2019); Spaunhorst (2021)
Johnson grass (*Sorghum halepense*)	Johnson et al. (2023)
Goosegrass (*Eleusine indica*)	Odero et al. (2013); Li et al. (2022)
Dallisgrass (*Paspalum dilatatum*)	Evers and Burson (2004)
Crabgrass (*Digitaria sanguinalis*)	Wang et al. (2018); Ghirardello et al. (2022)
Pigweed (*Amaranthus retroflexus*)	Lovelli et al. (2010)
Milkweed (*Asclepias syriaca*)	Karounos et al. (2019)
Pokeweed (*Phytolacca americana*)	Kim et al. (2005); Awasthi et al. (2015)
Thistle (*Cirsium arvense*)	Aysu (2016); Jogi et al. (2019)

3.5 Managing insect pests, diseases, and weeds in sugarcane fields amid climate change

Integrated management practices are vital for addressing the complex challenges posed by insect pests, diseases, and notorious weeds in sugarcane fields, especially in the context of climate change. These integrated approaches combine cultural, biological, and chemical control measures to mitigate impacts while minimizing environmental risks. Integrated Pest Management (IPM) strategies include crop rotation, the use of natural predators, and targeted pesticide applications (Koshariya et al., 2023; Lantero et al., 2023). These measures collectively help in reducing pest populations and protecting the environment (Baste and Watson, 2022; Morya and Kumar, 2023). Adaptive breeding programs are essential, focusing on developing pest-resistant sugarcane varieties that can adapt to evolving pest pressures, such as breeding for YSA resistance (Bakala et al., 2020; Naqvi et al., 2022; Shahid et al., 2024).

Integrated Disease Management (IDM) practices involve adjusting planting schedules, optimizing irrigation, and using biological controls such as natural predators or beneficial microorganisms (Bhuiyan et al., 2021; Ram et al., 2022). Chemical control, when carefully managed, remains a crucial tool against disease outbreaks (Grigorieva et al., 2023; Gyamfi et al., 2024). Breeding programs are also vital in developing disease-resistant varieties by incorporating traits that enhance resistance to specific pathogens influenced by climate change (Legros et al., 2021; Nunes et al., 2024; Parveen and Rashtrapal, 2024).

Integrated Weed Management (IWM) combines cultural, mechanical, biological, and chemical control measures to manage weed populations effectively (Scavo and Mauromicale, 2020; Kousta et al., 2024). Strategies such as crop rotation, cover cropping, and targeted herbicide applications play integral roles in IWM, enhancing sugarcane resilience against weed encroachment (Cherubin et al., 2021; Schrader et al., 2024). Adaptive breeding programs also focus on developing sugarcane varieties that can better compete with and resist notorious weeds, ensuring sustainable production amidst evolving climatic conditions (Gobu et al., 2020; van Antwerpen et al., 2022; Geng and Yufeng, 2023; Spelman, 2024).

Precision agriculture utilizes cutting-edge technologies such as drones, sensors, and data analytics to offer transformative real-time monitoring and management of pests, diseases, and weeds (Ayoub-Shaikh et al., 2022; Karunathilake et al., 2023). This approach enhances resource efficiency and reduces environmental impacts through optimized interventions (Ahmad, 2023; Nikpay et al., 2023). Precision agriculture aligns with the broader goal of sustainable and efficient farming practices, ensuring the resilience of sugarcane cultivation amid changing climatic conditions (Grandis et al., 2024; Pachiappan et al., 2024; Shaktawat and Swaymprava, 2024).

Early detection of pest, disease, and weed infestations allows for targeted interventions, optimizing resource use and minimizing impacts on sugarcane (Mylonas et al., 2020; He et al., 2024). Research into innovative resistant varieties and novel control methods is essential for staying ahead of emerging challenges in sugarcane cultivation (Storkey et al., 2021; Gautam and Hens, 2022; Roy et al., 2023; Kamath et al., 2024). Continued research and innovation are crucial for sustainable sugarcane cultivation in a changing climate, as they inform adaptive management strategies and develop resistant varieties and novel control methods (Hill et al., 2011; Bordonal et al., 2018; Singh et al., 2019; Ali et al., 2023). Integrating IPM, IDM, and IWM strategies with precision agriculture and early detection ensures sustainable and productive sugarcane cultivation worldwide (Maxwell et al., 2019; Mercer, 2020; Walsh et al., 2020; Srinivasa Rao et al., 2022). These approaches help the sugarcane industry navigate the complexities of climate change and ensure long-term resilience (Chen et al., 2023; Harvey et al., 2023; Ranganathan et al., 2023).

3.6 Climate-resilient strategies for disease and pest management in sugarcane

Adaptive strategies play a pivotal role in mitigating the impact of climate change on sugarcane diseases and insect pests, offering prospects for the long-term sustainability of sugarcane cultivation (Shahzad et al., 2021; Bhatt et al., 2023; Kurmi et al., 2024). These strategies encompass a holistic approach that addresses the dynamic interactions between shifting climatic conditions and the complex ecosystems harbouring pathogens and pests. By integrating adaptive measures, the sugarcane industry can enhance resilience, minimize losses, and secure the sustainability of this crucial crop. One key adaptive strategy involves the development and implementation of climate-resilient sugarcane varieties (Taylor et al., 2023). Understanding the evolving dynamics of diseases and insect pests influenced by climate change allows breeders to incorporate traits that confer resistance or tolerance. For instance, breeding for resistance against yellow sugarcane aphids can lead to the creation of varieties capable of withstanding the changing pest pressures (Ademe et al., 2024). These climate-resilient varieties act as a frontline defence, reducing the susceptibility of sugarcane crops to diseases and pests, thereby contributing to sustainability in the face of climatic uncertainties.

Integrated disease management (IDM) practices represent a comprehensive adaptive strategy that combines cultural, biological, and chemical control measures to manage diseases effectively (Taylor et al., 2023). Cultural practices, such as adjusting planting schedules and optimizing irrigation, are tailored to mitigate disease risks influenced by climate change (Mishra and Mishra, 2023; Ademe et al., 2024). Biological control methods involve the introduction of natural predators or beneficial microorganisms to regulate disease vectors (Muhammad et al., 2024; Barathi et al., 2024). Chemical control, while being judiciously managed to minimize environmental impact, remains an essential tool in the arsenal against disease outbreaks (Collett et al., 2020; Dolatabadian et al., 2022). The IDM allows for a dynamic and adaptable approach, ensuring the sustainability of sugarcane production amidst the changing disease landscape. The use of drones, sensors, and data analytics in precision agriculture practices provide valuable insights into the status of crops, allowing early detection of outbreaks and targeted interventions (Shahi et al., 2023; Chaudhari et al., 2024). By staying ahead of disease and pest dynamics through real-time monitoring, precision agriculture contributes to the resilience of sugarcane cultivation in the face of evolving climatic conditions.

Climate-resilient agronomic practices play a crucial role in adapting sugarcane cultivation to the changing climate (del Pozo et al., 2019; Röling, 2019). Optimizing planting schedules, irrigation practices, and crop rotations based on climatic conditions helps mitigate the risks associated with diseases and insect pests (Richard et al., 2022; Kowalska et al., 2023). These adaptive practices ensure that sugarcane crops are strategically positioned to withstand varying environmental stresses. Farmers can proactively address challenges posed by diseases and pests, promoting the long-term health and sustainability of sugarcane crops by aligning agronomic activities with the evolving climatic conditions (Usman et al., 2020; Gonçalves et al., 2024).

On-going innovation ensures that the sugarcane industry remains dynamic and resilient in the face of climate-induced uncertainties (Aggarwal et al., 2022; Anekwe et al., 2023). Economic thresholds, another vital aspect of adaptive strategies, offer a systematic approach to making treatment decisions for diseases and insect pests. Determining the pest density at which management action should be taken to prevent economic losses guides intervention strategies (Hendrichs et al., 2021; Wolff, 2023). Economic thresholds are dynamic and can vary based on factors such as crop variety, growth stage, market value, and growing conditions. Ensuring effective control while minimizing unnecessary interventions by establishing and regularly updating economic thresholds, sugarcane growers can optimize pest management practices (Nikpay et al., 2023; Mangena et al., 2024; Reddy et al., 2024).

Adaptive strategies for sugarcane sustainability involve monitoring and predicting climate trends to anticipate future challenges (Linnenluecke et al., 2018; Grigorieva et al., 2023). Studying trends in rainfall and temperature over an extended period in sugarcane cultivation areas allows for the identification of potential shifts in disease and pest prevalence (Caron et al., 2018; Khatri et al., 2023). Growers can proactively plan interventions and implement adaptive measures by understanding how climate variables influence the dynamics of pathogens and pests (Heeb et al., 2019; Taylor et al., 2021). This forward-looking approach enables the development of climate adaptation and mitigation actions necessary to contain crop pests and diseases, fostering sustainability in the sugarcane industry (Altieri, 2002; Grigorieva et al., 2023; Mrabet, 2023). Adaptive strategies play a critical role in mitigating the impact of climate change on sugarcane diseases and insect pests, offering prospects for sustainability in the face of evolving climatic conditions (Shahzad et al., 2021). Climate-resilient agronomic practices form a comprehensive toolkit for the sugarcane industry (Tan et al., 2022; Alotaibi, 2023; Lopes, 2023).

4 Conclusions

Climate change exerts a profound impact on sugarcane production, affecting insect pests, diseases, and notorious weeds. Variations in temperature, altered rainfall patterns, and extreme weather events significantly reshape pest and disease dynamics, posing severe challenges to sustainable sugarcane cultivation. Integrated pest and disease management practices are essential to adapt to these changing environmental conditions. Implementing comprehensive control methods can help mitigate the effects of climate change on pest and disease proliferation. Adaptive breeding is another critical strategy, focusing on developing climate-resilient sugarcane varieties. These varieties are better equipped to withstand shifting climates and maintain productivity. Precision agriculture utilizes advanced technologies to monitor and manage crop health and environmental conditions more effectively. This approach can significantly enhance the ability to respond to climate-induced changes in pest and disease behaviour. Early detection and monitoring systems are crucial for the timely identification and control of pest and weed outbreaks. Establishing these systems can help manage infestations before they cause significant damage to sugarcane crops. Ongoing research and innovation are vital to continuously advancing knowledge and techniques to combat the effects of climate change on sugarcane cultivation. By staying at the forefront of agricultural science, the industry can better adapt to evolving climatic conditions. The sugarcane industry can enhance its resilience, minimize potential losses, and ensure the sustainability of this vital crop amidst the challenges posed by climate change.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

Author contributions

BM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. PN: Supervision, Validation, Visualization, Writing – review & editing. CJ: Supervision, Validation, Visualization, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., and Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ. Sci. pollut. Res.* 29, 42539–42559. doi: 10.1007/s11356-022-19718-6

Ademe, D., Tesfaye, K., Simane, B., Zaitchik, B. F., Alemayehu, G., and Adgo, E. (2024). Optimizing agronomic practices to harness climate change impacts on potato production in tropical highland regions. *Eur. J. Agron.* 152, 127021. doi: 10.1016/j.eja.2023.127021

Adesipo, A., Fadeyi, O., Kuca, K., Krejcar, O., Maresova, P., Selamat, A., et al. (2019). Smart and climate-smart agricultural trends as core aspects of smart village functions. *Sensors* 20, 5977. doi: 10.3390/s20215977

Aggarwal, P., Roy, J., Pathak, H., Naresh Kumar, S., Venkateswarlu, B., Ghosh, A., et al. (2022). "Managing climatic risks in agriculture," in *Indian Agriculture Towards 2030: Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems* (Springer Nature Singapore, Singapore), 83–108. Available at: https://link.springer.com/bookseries/11234.

Ahmad, H. H. (2023). Effects of urbanization and green house gases on sugarcane growth. *Int. J. Agric. Sustain. Dev.* 5, 32–40.

Akhter, R., and Sofi, S. A. (2022). Precision agriculture using IoT data analytics and machine learning. *J. King Saud Univ. - Comput. Inf. Sci.* 34, 5602–5618. doi: 10.1016/j.jksuci.2021.05.013

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., and Wang, M. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. *Toxics* 9, 42. doi: 10.3390/toxics9030042

Alexander, L. V. (2016). Global observed long-term changes in temperature and precipitation extremes: A review of progress and limitations in IPCC assessments and beyond. *Weather Climate Extremes* 11, 4–16. doi: 10.1016/j.wace.2015.10.007

Ali, M. A., Abdellah, I. M., and Eletmany, M. R. (2023). Towards sustainable management of insect pests: Protecting food security through ecological intensification. *Int. J. Chem. Biochem. Sci.* 24, 386–394.

Allsopp, P. G., Croft, B., and Fillols, E. (2021). *Situation analysis and opportunities for pest, disease and weed RD&A (including biosecurity) in Australian sugarcane: final report 2019/015*. Available online at: https://hdl.handle.net/11079/18130.

Alotaibi, M. (2023). Climate change, its impact on crop production, challenges, and possible solutions. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 51, 13020–13020. doi: 10.15835/nbha51113020

Altieri, M. A. (2002). Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agriculture Ecosyst. Environ.* 93, 1–24. doi: 10.1016/S0167-8809(02)00085-3

Andrieu, N., Howland, F., Le Coq, J., Milena, A., Loboguerrero, A. M., and Chia, E. (2019). Co-designing climate-smart farming systems with local stakeholders: A methodological framework for achieving large-scale change. *Front. Sustain. Food Syst.* 3. doi: 10.3389/fsufs.2019.00037

Anekwe, I. M. S., Zhou, H., Mkhize, M. M., and Akpasi, S.O. (2023). Addressing Climate Change Challenges in South Africa: A Study in KwaZulu Natal Province. In: U. Chatterjee, R. Shaw, S. Kumar, A. D. Raj and S. Das (eds) *Climate Crisis: Adaptive Approaches and Sustainability. Sustainable Development Goals Series*. (Springer, Cham). doi: 10.1007/978-3-031-44397-8_24

Anwar, M. P., Islam, A. K., Yeasmin, S., Rashid, M. H., Juraimi, A. S., Ahmed, S., et al. (2021). Weeds and their responses to management efforts in a changing climate. *Agronomy* 11, 1921. doi: 10.3390/agronomy11101921

Araújo, S. O., Peres, R. S., Ramalho, J. C., Lidon, F., and Barata, J. (2023). Machine learning applications in agriculture: Current trends, challenges, and future perspectives. *Agronomy* 13, 2976. doi: 10.3390/agronomy13122976

Archana, T. S., Kumar, D., Ghosh, P., and Kumar, V. (2024). Plant pathogen detection: exploring modern techniques and future directions. *Indian Phytopathol.*, 1–13. doi: 10.1007/s42360-024-00762-w

Askarianzadeh, A., and Minaeimoghadam, M. (2018). Biology, natural enemies and damage of the sugarcane whitefly (*Neomaskellia andropogonis*) (Homoptera: Aleyrodidae) in Iran. *Int. J. Trop. Insect Sci.* 38, 381–386. doi: 10.1017/S1742758418000164

Awasthi, L. P., Singh, S. P., and Verma, H. N. (2015). "Role of defensive antiviral proteins from higher plants in the management of viral diseases," in *Recent Advances in the Diagnosis and Management of Plant Diseases*. Ed. L. P. Awasthi (Springer, New Delhi). doi: 10.1007/978-81-322-2571-3

Ayoub-Shaikh, T., Rasool, T., and Rasheed Lone, F. (2022). Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming. *Comput. Electron. Agric.* 198, 107119. doi: 10.1016/j.compag.2022.107119

Aysu, T. (2016). A study on pyrolysis of Canada thistle (*Cirsium arvense*) with titania based catalysts for bio-fuel production. *Bioresource Technol.* 219, 175–184. doi: 10.1016/j.biortech.2016.07.132

Badillo-Márquez, A. E., Aguilar-Lasserre, A. A., Miranda-Ackerman, M. A., Sandoval-González, O. O., Villanueva-Vásquez, D., and Posada-Gómez, R. (2021). An agent-based model-driven decision support system for assessment of agricultural vulnerability of sugarcane facing climatic change. *Mathematics* 9, 3061. doi: 10.3390/math9233061

Bakala, H. S., Singh, G., and Srivastava, P. (2020). "Smart breeding for climate resilient agriculture," in *Plant breeding-current and future views* (London, United Kingdom: IntechOpen). doi: 10.5772/intechopen.94847

Balah, M. A. (2021). "Ecological management of weeds in desert regions," in *Management and Development of Agricultural and Natural Resources in Egypt's Desert* (Springer International Publishing, Cham), 291–315. doi: 10.1007/978–3-030–73161-8_11

Balasundram, S. K., Shamshiri, R. R., Sridhara, S., and Rizan, N. (2023). The role of digital agriculture in mitigating climate change and ensuring food security: An overview. *Sustainability* 15, 5325. doi: 10.3390/su15065325

Balogun, A. L., Marks, D., Sharma, R., Shekhar, H., Balmes, C., Maheng, D., et al. (2020). Assessing the potentials of digitalization as a tool for climate change adaptation and sustainable development in urban centres. *Sustain. Cities Soc.* 53, 101888. doi: 10.1016/j.scs.2019.101888

Baltazar, A. M., and De Datta, S. K. (2023). *Weed Science and Weed Management in Rice and Cereal-Based Cropping Systems, 2 Volumes* (United States: John Wiley & Sons). doi: 10.1002/9781119737582

Bam, A., Addison, P., and Conlong, D. (2020). Acridid ecology in the sugarcane agro-ecosystem in the Zululand region of KwaZulu-Natal, South Africa. *J. Orthoptera Res.* 29, 9–16. doi: 10.3897/jor.29.34626

Barathi, S., Sabapathi, N., Kandasamy, S., and Lee, J. (2024). Present status of insecticide impacts and eco-friendly approaches for remediation-a review. *Environ. Res.* 240, 117432. doi: 10.1016/j.envres.2023.117432

Bartels, W. L., Furman, C. A., Diehl, D. C., Royce, F. S., Dourte, D. R., Ortiz, B. V., et al. (2013). Warming up to climate change: A participatory approach to engaging with agricultural stakeholders in the Southeast US. *Regional Environ. Change* 13, 45–55. doi: 10.1007/s10113-012-0371-9

Barton, M. G., Terblanch, J. S., and Sinclair, B. J. (2019). Incorporating temperature and precipitation extremes into process-based models of African Lepidoptera changes the predicted distribution under climate change. *Ecol. Model.* 394, 53–65. doi: 10.1016/j.ecolmodel.2018.12.017

Baste, I. A., and Watson, R. T. (2022). Tackling the climate, biodiversity and pollution emergencies by making peace with nature 50 years after the stockholm conference. *Global Environ. Change* 73, 102466. doi: 10.1016/j.gloenvcha.2022.102466

Behnam-Oskuyee, S., Ziaee, M., and Shishehbor, P. (2020). Evaluation of different insecticides for the control of sugarcane whitefly, *Neomaskellia andropogonis* Corbett (Homoptera: Aleyrodidae). *J. Saudi Soc. Agric. Sci.* 19, 255–260. doi: 10.1016/j.jssas.2018.11.004

Bhagarathi, L. K., and Maharaj, G. (2023). Impact of climate change on insect biology, ecology, population dynamics, and pest management: A critical review. *World J. Adv. Res. Rev.* 19 (3), 541–568. doi: 10.30574/wjarr.2023.19.3.1843

Bhatt, R., Kumar, R., Kashyap, L., Alataway, A., Dewidar, A. Z., and Mattar, M. A. (2022). Growth, yield, quality and insect-pests in sugarcane (*Saccharum officinarum*) as affected by differential regimes of irrigation and potash under stressed conditions. *Agronomy* 12, 1942. doi: 10.3390/agronomy12081942

Bhatt, C. M., Patel, P., Ghetia, T., and Mazzeo, P. L. (2023). Effective heart disease prediction using machine learning techniques. *Algorithms* 16 (2), 88. doi: 10.3390/a16020088

Bhattacharyya, B., Gogoi, I., Das, P. P. G., and Kalita, B. (2023). "Management of agricultural insect pests for sustainable agriculture and environment," in *Sustainable Agriculture and the Environment* (Amsterdam, The Netherlands: Academic Press), 161–193. doi: 10.1016/B978-0-323-90500-8.00001-4

Bhuiyan, S. A., Magarey, R. C., McNeil, M. D., and Aitken, K. S. (2021). Sugarcane smut, caused by *Sporisorium scitamineum*, a major disease of sugarcane: A contemporary review. *Phytopathology* 111, 1905–1917. doi: 10.1094/PHYTO-05-21-0221-RVW

Bibi, F., and Rahman, A. (2023). An overview of climate change impacts on agriculture and their mitigation strategies. *Agriculture* 13, 1508. doi: 10.3390/agriculture13081508

Bini, A. P., Rossi, G. D., Poeschl, Y., Serra, M. C. D., Camargo, L. E. A., Monteiro-Vitorello, C. B., et al. (2023). Molecular, biochemical and metabolomics analyses reveal constitutive and pathogen-induced defense responses of two sugarcane contrasting genotypes against leaf scald disease. *Plant Physiol. Biochem.* 203, 108033. doi: 10.1016/j.plaphy.2023.108033

Bordonal, R. D. O., Carvalho, J. L. N., Lal, R., de Figueiredo, E. B., de Oliveira, B. G., and La Scala, N. (2018). Sustainability of sugarcane production in Brazil. A review. *Agron. Sustain. Dev.* 38, 1–23. doi: 10.1007/s13593-018-0490-x

Boudh, S., and Singh, J. S. (2019). "Pesticide contamination: environmental problems and remediation strategies," in *Emerging and eco-friendly approaches for waste management* 2018, 245–269. doi: 10.1007/978–981-10–8669-4_12

Bouri, M., Arslan, K. S., and Şahin, F. (2023). Climate-smart pest management in sustainable agriculture: promises and challenges. *Sustainability* 15, 4592. doi: 10.3390/su15054592

Bowling, R. D., Brewer, M. J., Kerns, D. L., Gordy, J., Seiter, N., Elliott, N. E., et al. (2016). Sugarcane aphid (Hemiptera: Aphididae): A new pest on sorghum in north america. *J. Integr. Pest Manage.* 7 (1). doi: 10.1093/jipm/pmw011

Brewer, M. J., Gordy, J. W., Kerns, D. L., Woolley, J. B., Rooney, W. L., and Bowling, R. D. (2017). Sugarcane aphid population growth, plant injury, and natural enemies on selected grain sorghum hybrids in texas and louisiana. *J. Economic Entomol* 110 (5), 2109–2118. doi: 10.1093/jee/tox204

Budeguer, F., Enrique, R., Perera, M. F., Racedo, J., Castagnaro, A. P., Noguera, A. S., et al. (2021). Genetic transformation of sugarcane, current status and future prospects. *Front. Plant Sci.* 12. doi: 10.3389/fpls.2021.768609

Calvin, W., Beuzelin, J. M., Liburd, O. E., Branham, M. A., and Jean Simon, L. (2021). Effects of biological insecticides on the sugarcane aphid, Melanaphis sacchari (Zehntner) (Hemiptera: Aphididae), in sorghum. *Crop protection* 142, 105528. doi: 10.1016/j.cropro.2020.105528

Caron, P., Ferrero y de Loma-Osorio, G., Nabarro, D., Hainzelin, E., Guillou, M., Andersen, I., et al. (2018). Food systems for sustainable development: proposals for a profound four-part transformation. *Agron. Sustain. Dev.* 38, 1–12. doi: 10.1007/s13593-018-0519-1

Cervantes-Romero, B., Pérez-Rodríguez, P., Rott, P., Valdez-Balero, A., Osnaya-González, M., Robledo-Paz, A., et al. (2021). Distribution, phylogeny, and pathogenicity of *Xanthomonas albilineans* causing sugarcane leaf scald in Mexico. *Crop Prot.* 150, 105799. doi: 10.1016/j.cropro.2021.105799

Chaiyana, A., Khiripet, N., Ninsawat, S., Siriwan, W., Shanmugam, M. S., and Virdis, S. G. (2024). Mapping and predicting cassava mosaic disease outbreaks using earth observation and meteorological data-driven approaches. *Remote Sens. Applications: Soc. Environ.* 35, 101231. doi: 10.1016/j.rsase.2024.101231

Chaki, A. K., Zahan, T., Hossain, M. S., Ferdous, Z., Islam, M. A., Islam, M. T., et al. (2023). *Climate-Smart Agriculture Technologies and Practices in Bangladesh* (Dhaka, Bangladesh: SAARC Agriculture Centre, SAARC), 111p. Available at: https://www.researchgate.net/publication/376812477.

Chaudhari, P., Patil, R. V., and Mahalle, P. N. (2024). Machine learning-based detection and extraction of crop diseases: A comprehensive study on disease patterns for precision agriculture. *Int. J. Intelligent Syst. Appl. Eng.* 12, 394–406.

Chawade, A., Van Ham, J., Blomquist, H., Bagge, O., Alexandersson, E., and Ortiz, R. (2019). High-throughput field-phenotyping tools for plant breeding and precision agriculture. *Agronomy* 9, 258. doi: 10.3390/agronomy9050258

Chen, Y., Yang, J., Wang, Y., Qi, J., and Luan, Q. (2023). The impact on climate change perception and adaptation of smallholder concepts: evidence from a sugarcane community, China. *Environ. Impact Assess. Rev.* 102, 107213. doi: 10.1016/j.eiar.2023.107213

Cherubin, M. R., Carvalho, J. L. N., Cerri, C. E. P., Nogueira, L. A. H., Souza, G. M., and Cantarella, H. (2021). Land use and management effects on sustainable sugarcane-derived bioenergy. *Land* 10, 72. doi: 10.3390/land10010072

Christina, M., Jones, M. R., Versini, A., Mézino, M., Le Mezo, L., Auzoux, S., et al. (2021). Impact of climate variability and extreme rainfall events on sugarcane yield gap in a tropical Island. *Field Crops Res.* 274, 108326. doi: 10.1016/j.fcr.2021.108326

Cilas, C., and Bastide, P. (2020). Challenges to cocoa production in the face of climate change and the spread of pests and diseases. *Agronomy* 10, 1232. doi: 10.3390/agronomy10091232

Cock, M. J., and Allard, G. B. (2013). Observations on white grubs affecting sugar cane at the Juba Sugar Project, South-Western Somalia, in the 1980s, and implications for their management. *Insects* 4, 241–272. doi: 10.3390/insects4020241

Collett, S. R., Smith, J. A., Boulianne, M., Owen, R. L., Gingerich, E., Singer, R. S., et al. (2020). Principles of disease prevention, diagnosis, and control. *Dis. Poultry*, 1–78. doi: 10.1002/9781119371199.ch1

Daphal, S. D., and Koli, S. M. (2023). Enhancing sugarcane disease classification with ensemble deep learning: A comparative study with transfer learning techniques. *Heliyon* 9, e18261. doi: 10.1016/j.heliyon.2023.e18261

Das, U., and Ansari, M. A. (2021). The nexus of climate change, sustainable agriculture and farm livelihood: contextualizing climate smart agriculture. *Climate Res.* 84, 23–40. doi: 10.3354/cr01648

Deeksha, M. G., Khan, M. S., and Kumaranag, K. M. (2022). Plant-pollinator interaction network among the scrubland weed flora from foothills of north-western Indian Himalaya. *Int. J. Trop. Insect Sci.* 42, 1593–1603. doi: 10.1007/s42690-021-00681-7

Delcour, I., Spanoghe, P., and Uyttendaele, M. (2015). Literature review: Impact of climate change on pesticide use. *Food Res. Int.* 68, 7–15. doi: 10.1016/j.foodres.2014.09.030

del Pozo, A., Brunel-Saldias, N., Engler, A., Ortega-Farias, S., Acevedo-Opazo, C., Lobos, G. A., et al. (2019). Climate change impacts and adaptation strategies of agriculture in Mediterranean-climate regions (MCRs). *Sustainability* 11, 2769. doi: 10.3390/su11102769

Dessoky, E. S., Ismail, R. M., Elarabi, N. I., Abdelhadi, A. A., and Abdallah, N. A. (2021). Improvement of sugarcane for borer resistance using Agrobacterium mediated transformation of cry1Ac gene. *GM Crops Food* 12, 47–56. doi: 10.1080/21645698.2020.1809318

Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., and Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture* 12, 1745. doi: 10.3390/agriculture12101745

Dixon, J. L., Stringer, L. C., and Challinor, A. J. (2014). Farming system evolution and adaptive capacity: Insights for adaptation support. *Resources* 3, 182–214. doi: 10.3390/resources3010182

Dolatabadian, A. R. I. A., Cornelsen, J., Huang, S. H. U. A. N. G. L. O. N. G., Zou, Z., and Fernando, W. D. (2022). Sustainability on the farm: breeding for resistance and management of major canola diseases in Canada contributing towards an IPM approach. *Can. J. Plant Pathol.* 44, 157–190. doi: 10.1080/07060661.2021.1991480

Donatelli, M., Magarey, R. D., Bregaglio, S., Willocquet, L., Whish, P. M., and Savary, S. (2017). Modelling the impacts of pests and diseases on agricultural systems. *Agric. Syst.* 155, 213–224. doi: 10.1016/j.agsy.2017.01.019

Dumont, T., Marodon, J., Nibouche, S., Hoarau, J. Y., and Barau, L. (2023). "Genetic variability of sugarcane varieties for resistance to Sipha flava," in *Proceedings of the International Society of Sugar Cane Technologists*, vol. 31. Hyderabad: ISSCT, 628–636.

Durán-Díaz, P. (2023). Sustainable land governance for water–energy–food systems: A framework for rural and peri-urban revitalisation. *Land* 12, 1828. doi: 10.3390/land12101828

Eslami, S. V., and Arpanahi, N. K. (2023). Water stress may decelerate purple nutsedge (Cyperus rotundus) invasion in arid environments. PREPRINT. doi: 10.21203/rs.3.rs-2828533/v1

Esquivel, I. L., Faris, A. M., and Brewer, M. J. (2021). Sugarcane aphid, *Melanaphis sacchari* (Hemiptera: Aphididae), abundance on sorghum and johnsongrass in a laboratory and field setting. *Crop Prot.* 148, 105715. doi: 10.1016/j.cropro.2021.105715

Evers, G. W., and Burson, B. L. (2004). Dallisgrass and other Paspalum species. Warm-season (C4) grasses. *Agron. Monogr.* 45, 681–713. doi: 10.2134/agronmonogr45.c20

Faris, A. M., Elliott, N. C., and Brewer, M. J. (2022). Suppression of the sugarcane aphid, *Melanaphis sacchari* (Hemiptera: Aphididae), by resident natural enemies on susceptible and resistant sorghum hybrids. *Environ. Entomology* 51, 332–339. doi: 10.1093/ee/nvab147

Fassnacht, F. E., White, J. C., Wulder, M. A., and Næsset, E. (2024). Remote sensing in forestry: Current challenges, considerations and directions. *Forestry: Int. J. For. Res.* 97, 11–37. doi: 10.1093/forestry/cpad024

Finch, D. M., Butler, J. L., Runyon, J. B., Fettig, C. J., Kilkenny, F. F., Jose, S., et al. (2021). "Effects of climate change on invasive species," in T. M. Poland, T. Patel-Weynand, D. M. Finch, C. F. Miniat, D. C. Hayes and V. M. Lopez eds. *Invasive Species in Forests and Rangelands of the United States*. Cham: Springer, 57–83. doi: 10.1007/978–3-030–45367-1_4

Fogliata, S. V., Vera, A., Gastaminza, G., Cuenya, M. I., Zucchi, M. I., Willink, E., et al. (2016). Reproductive isolation between two populations of *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae) from different host plant species and regions in Argentina. *Bull. Entomological Res.* 106, 591–597. doi: 10.1017/S0007485316000249

Fresneda-Quintana, C., Martínez-Rodríguez, A., Laffita-Leyva, A., and Zamora-Díaz, O. (2024). Multispectral image processing to assess sugarcane nitrogen needs. *Rev. Cienc. Técnicas Agropecuarias* 33 (1), e08.

Gaertner, M., Wilson, J. R., Cadotte, M. W., MacIvor, J. S., Zenni, R. D., and Richardson, D. M. (2017). Non-native species in urban environments: patterns, processes, impacts and challenges. *Biol. Invasions* 19, 3461–3469. doi: 10.1007/s10530-017-1598-7

Gautam, S., and Hens, L. (2022). Omikron: where do we go in a sustainability context? *Environ. Dev. Sustainability* 24 (4), 4491–4492. doi: 10.1007/s10668-022-02207-8

Geng, B. A. I., and Yufeng, G. E. (2023). Crop stress sensing and plant phenotyping systems: A review. *Smart Agric.* 5, 66. doi: 10.12133/j.smartag.SA202211001

Ghirardello, G. A., Araujo, L. D. S., Silva, G. S. D., Silva, A. F. M., Campos, L. H. F. D., and Victoria Filho, R. (2022). Efficacy of the herbicides indaziflam and clomazone on problematic weeds of family Poaceae to sugarcane crop. *Bioscience J.* 38, 1981–3163. doi: 10.14393/BJ-v38n0a2022-56358

Giliba, R. A., Mpinga, I. H., Ndimuligo, S. A., and Mpanda, M. M. (2020). Changing climate patterns risk the spread of Varroa destructor infestation of African honey bees in Tanzania. *Ecol. Processes* 9, 1–11. doi: 10.1186/s13717-020-00247-4

Giraldeli, A. L., Silva, A. F. M., Baccin, L. C., da Silva Araújo, L., da Silva, G. S., Pagenotto, A. C. V., et al. (2021). Chemical management of *Cyperus rotundus* L. and other weeds at sugarcane in PSS system. *Bioscience J.* 37, 1981–3163. doi: 10.14393/BJ-v37n0a2021-51527

Girolamo-Neto, C. D., Sanches, I. D. A., Neves, A. K., Prudente, V. H. R., Körting, T. S., Picoli, M. C. A., et al. (2019). Assessment of texture features for Bermudagrass (*Cynodon dactylon*) detection in sugarcane plantations. *Drones* 3, 36. doi: 10.3390/drones3020036

Gobu, R., Shiv, A., Kumar, C. A., Basavaraj, P. S., Harish, D., Adhikari, S., et al. (2020). "Accelerated crop breeding towards development of climate resilient varieties," in *Climate change and Indian Agriculture: Challenges and Adaptation Strategies*, eds. C.S. Rao, T. Srinivas, R. V. S. Rao, N. S. Rao, S. S. Vinayagam, P. Krishnan, et al (Hyderabad: ICAR-National Academy of Agricultural Research Management), 1–22.

Gonçalves, M. C., Pinto, L. R., Pimenta, R. J. G., and da Silva, M. F. (2024). "Sugarcane," in *Viral Diseases of Field and Horticultural Crops* (Amsterdam, The Netherlands: Academic Press), 193–205. doi: 10.1016/B978–0-323–90899-3.00056–2

Govindaraju, M., Li, Y., and Zhang, M. (2019). Emerging bacterial disease (leaf scald) of sugarcane in China: pathogenesis, diagnosis, and management. *Plant diseases-current threats Manage. trends*. doi: 10.5772/intechopen.88333

Grandis, A., Fortirer, J. S., Navarro, B. V., de Oliveira, L. P., and Buckeridge, M. S. (2024). Biotechnologies to improve sugarcane productivity in a climate change scenario. *Bioenergy Res.* 17, 1–26. doi: 10.1007/s12155-023-10649-9

Grigorieva, E., Livenets, A., and Stelmakh, E. (2023). Adaptation of agriculture to climate change: A scoping review. *Climate* 11, 202. doi: 10.3390/cli11100202

Gyamfi, E. K., ElSayed, Z., Kropczynski, J., Yakubu, M. A., and Elsayed, N. (2024). *Agricultural 4.0 leveraging on technological solutions: study for smart farming sector*. (United States: University of Cincinnati Ohio). doi: 10.48550/arXiv.2401.00814

Hamdi, A., Shaban, K., Erradi, A., Mohamed, A., Rumi, S. K., and Salim, F. D. (2022). Spatiotemporal data mining: A survey on challenges and open problems. *Artif. Intell. Rev.* 55, 1441–1488. doi: 10.1007/s10462-021-09994-y

Haring, S. C. (2022). *Adapting Integrated Pest Management for Weeds in California Orchards* (Davis: University of California).

Harvey, J. A., Tougeron, K., Gols, R., Heinen, R., Abarca, M., Abram, P. K., et al. (2023). Scientists' warning on climate change and insects. *Ecol. Monogr.* 93, e1553. doi: 10.1002/ecm.1553

Hauser, N., Conlon, K. C., Desai, A., and Kobziar, L. N. (2021). Climate change and infections on the move in North America. *Infection Drug Resistance* 14, 5711–5723. doi: 10.2147/IDR.S305077

He, Y. A. N., Shuang, C. H. E. N., Zhao, J. K., Zhang, Z. B., Chen, L. L., Huang, R. M., et al. (2024). Dynamic changes in weed abundance and biodiversity following different green manure establishment. *J. Integr. Agric.* doi: 10.1016/j.jia.2024.01.007

Heeb, L., Jenner, E., and Cock, M. J. (2019). Climate-smart pest management: building resilience of farms and landscapes to changing pest threats. *J. Pest Sci.* 92, 951–969. doi: 10.1007/s10340-019-01083-y

Hendrichs, J., Vreysen, M. J. B., Enkerlin, W. R., and Cayol, J. P. (2021). "Strategic options in using sterile insects for area-wide integrated pest management," in *Sterile insect technique* (Vienna, Austria: CRC Press), 841–884.

Hill, J. K., Griffiths, H. M., and Thomas, C. D. (2011). Climate change and evolutionary adaptations at species' range margins. *Annu. Rev. Entomology* 56, 143–159. doi: 10.1146/annurev-ento-120709-144746

Hossain, M. I., Ahmad, K., Siddiqui, Y., Saad, N., Rahman, Z., Haruna, A. O., et al. (2020). Current and prospective strategies on detecting and managing *Colletotrichum falcatum* causing red rot of sugarcane. *Agronomy* 10, 1253. doi: 10.3390/agronomy10091253

Hoy, J. W., and Hollier, C. A. (2009). Effect of brown rust on yield of sugarcane in Louisiana. *Plant Dis.* 93, 1171–1174. doi: 10.1094/PDIS-93-11-1171

Hume, J. B., Almeida, P. R., Buckley, C. M., Criger, L. A., Madenjian, C. P., Robinson, K. F., et al. (2021). Managing native and non-native sea lamprey (Petromyzon marinus) through anthropogenic change: A prospective assessment of key threats and uncertainties. *J. Great Lakes Res.* 47, S704–S722. doi: 10.1016/j.jglr.2020.08.015

Hussain, T., Khan, F. A., and Sikander, R. A. (2024). Assessment of mycotic diseases attack on indigenous old mango plants grown in Vatala park, Tehsil Bernala District Bhimber, Azad Kashmir. *Natural Resour. Conserv. Res.* 6, 2985. doi: 10.24294/nrcr.v6i2.2985

Janousek, W. M., Douglas, M. R., Cannings, S., Clément, M. A., Delphia, C. M., Everett, J. G., et al. (2023). Recent and future declines of a historically widespread pollinator linked to climate, land cover, and pesticides. *Proc. Natl. Acad. Sci.* 120, e2211223120. doi: 10.1073/pnas.2211223120

January, B., Yusufu, A., and Urassa, F. (2020). First report of yellow sugarcane aphid *Sipha flava* Forbes (Homoptera: Aphididae) in Tanzania. *J. Plant Prot. Res.* 60, 320–322. doi: 10.24425/jppr.2020.133316

Jogi, Q., Hajano, G. A., Kandharo, M. N., Shah, A. N., Soomro, A. A., Abbasi, Z. A., et al. (2019). 17. Examine different weed management techniques in sugarcane (*Saccharum officinarum* L.). *Pure Appl. Biol. (PAB)* 8, 151–159. doi: 10.19045/bspab.2018.700173

Johnson, N. (2023). Eco-Evolutionary Ramifications of Herbicide-Driven Plant Modifications on Plant-Herbivore Interactions in Modern Agricultural Landscapes. Doctoral dissertation. (University of Michigan: United States). doi: 10.7302/8349

Johnson, R. M., Orgeron, A. J., Spaunhorst, D. J., Huang, I.-S., and Zimba, P. V. (2023). Discrimination of weeds from sugarcane in Louisiana using hyperspectral leaf reflectance data and pigment analysis. *Weed Technol.* 37, 123–131. doi: 10.1017/wet.2023.14

Jorgenson, A. K., Fiske, S., Hubacek, K., Li, J., McGovern, T., Rick, T., et al. (2019). Social science perspectives on drivers of and responses to global climate change. *Wiley Interdiscip. Reviews: Climate Change* 10, e554. doi: 10.1002/wcc.554

Joyce, A. L., White, W. H., Nuessly, G. S., Solis, M. A., Scheffer, S. J., Lewis, M. L., et al. (2014). Geographic population structure of the sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae), in the Southern United States. *PloS One* 9, e110036. doi: 10.1371/journal.pone.0110036

Kachare, N. V., Khan, A. I., and Suryawanshi, M. V. (2024). Impact of climate change on sugarcane production and its mitigation a review. *Int. J. Prog. Res. Eng. Manag. Sci.* 03 (12), 389–396. doi: 10.58257/IJPREMS32389

Kadam, R. L., Ahire, R. D., Tadavi, F. R., and Behera, R. K. (2023). Constraints & suggestions perceived by the sugarcane growers towards sustainable cultivation practices. *The Pharma Innov. J.* 12 (8), 1550–1553. doi: 10.22271/tpi

Kalimba, U. B., and Culas, R. J. (2020). "Climate change and farmers' adaptation: Extension and capacity building of smallholder farmers in Sub-Saharan Africa," in *Global Climate Change and Environmental Policy*. Eds. V. Venkatramanan, S. Shah and R. Prasad (Springer, Singapore). doi: 10.1007/978–981-13–9570-3_13

Kamath, S. V., Attokkaran, J. R., Maraddi, A. S., Samage, A., D'Souza, G. B., Yoon, H., et al. (2024). Cello-MOF filters for multifaceted emerging pollutant abatement and their value addition. *Chem. Eng. J.* 479, 147805. doi: 10.1016/j.cej.2023.147805

Kamga, S. F., Ndjomatchoua, F. T., Guimapi, R. A., Klingen, I., Tchawoua, C., Hjelkrem, G. R., et al. (2022). The effect of climate variability in the efficacy of the entomopathogenic fungus *Metarhizium acridum* against the desert locust Schistocerca *gregaria*. *Sci. Rep.* 12, 7535. doi: 10.1038/s41598-022-11424-0

Karounos, M., Cherry, R., McCray, M., and Ji, S. (2020). Survival and behavior of melanotus communis (Coleoptera: elateridae) in Florida sugarcane soils. *J. Entomological Sci.* 55, 499–506. doi: 10.18474/0749-8004-55.4.499

Karounos, M., Cherry, R., Odero, D., Sandhu, H., and Beuzelin, J. (2019). Host plant preference of *Melanotus communis* (Coleoptera: Elateridae) among weeds and sugar cane varieties found in Florida sugar cane fields. *Florida Entomologist* 102, 403–407. doi: 10.1653/024.102.0213

Karunathilake, E. M., Le, A. T., Heo, S., Chung, Y. S., and Mansoor, S. (2023). The Path to Smart Farming: Innovations and opportunities in precision agriculture. *Agriculture* 13, 1593. doi: 10.3390/agriculture13081593

Keerthi Sree, Y., Lakra, N., Manorama, K., Ahlawat, Y., Zaid, A., Elansary, H., et al. (2023). Drought-induced morpho-physiological, biochemical, metabolite responses and protein profiling of chickpea (*Cicer arietinum* l.). *Agronomy* 13 (7). doi: 10.3390/agronomy13071814

Khan, M. A., and Akhtar, M. S. (2015). "Agricultural adaptation and climate change policy for crop production in Africa," in *Crop Production and Global Environmental Issues*. Ed. K. Hakeem (Springer, Cham). doi: 10.1007/978–3-319–23162-4_18

Khatri, P., Kumar, P., Shakya, K. S., Kirlas, M. C., and Tiwari, K. K. (2023). "Understanding the intertwined nature of rising multiple risks in modern agriculture and food system," in *Environment, Development and Sustainability*. Springer Nature B.V, 1–44. doi: 10.1007/s10668-023-03638-7

Khatri-Chhetri, A., Pant, A., Aggarwal, P. K., Vasireddy, V. V., and Yadav, A. (2019). Stakeholders prioritization of climate-smart agriculture interventions: Evaluation of a framework. *Agric. Syst.* 174, 23–31. doi: 10.1016/j.agsy.2019.03.002

Khattak, W. A., Sun, J., Hameed, R., Zaman, F., Abbas, A., Khan, K. A., et al. (2024). Unveiling the resistance of native weed communities: insights for managing invasive weed species in disturbed environments. *Biol. Rev.* 99 (3), 753–777. doi: 10.1111/brv.13043

Kim, Y. O., Johnson, J. D., and Lee, E. J. (2005). Phytotoxicity of Phytolacca americana leaf extracts on the growth, and physiological response of Cassia mimosoides. *J. Chem. Ecol.* 31, 2963–2974. doi: 10.1007/s10886-005-8407-y

Kim, Y. U., Webber, H., Adiku, S. G., Júnior, R. D. S. N., Deswarte, J. C., Asseng, S., et al. (2024). Mechanisms and modelling approaches for excessive rainfall stress on cereals: Waterlogging, submergence, lodging, pests and diseases. *Agric. For. Meteorology* 344, 109819. doi: 10.1016/j.agrformet.2023.109819

Knutson, T. R., Zhang, R., and Horowitz, L. W. (2016). Prospects for a prolonged slowdown in global warming in the early 21st century. *Nat. Commun.* 7 (1), 1–12. doi: 10.1038/ncomms13676

Koralewski, T. E., Wang, H., Grant, W. E., Brewer, M. J., and Elliott, N. C. (2022). Evaluation of areawide forecasts of wind-borne crop pests: sugarcane aphid (Hemiptera: aphididae) infestations of sorghum in the great plains of North America. *J. Economic Entomology* 115, 863–868. doi: 10.1093/jee/toac035

Koshariya, A. K., Sharma, N., Satapathy, S. N., Thilagam, P., Laxman, T., and Rai, S. (2023). Safeguarding Agriculture: A comprehensive review of plant protection strategies. *Int. J. Environ. Climate Change* 13, 272–281. doi: 10.9734/ijecc/2023/v13i113168

Kousta, A., Katsis, C., Tsekoura, A., and Chachalis, D. (2024). Effectiveness and selectivity of pre-and post-emergence herbicides for weed control in grain legumes. *Plants* 13, 211. doi: 10.3390/plants13020211

Kowalska, H., Masiarz, E., Ignaczak, A., Marzec, A., Hać-Szymańczuk, E., Salamon, A., et al. (2023). Advances in multigrain snack bar technology and consumer expectations: A review. *Food Rev. Int.* 39 (1), 93–118. doi: 10.1080/87559129.2022.2094402

Kumar, S., and Prasad, C. S. (2020). Biology and isolation of bio-agents from sugarcane white grub in western plain zone of Uttar Pradesh, India. *J. Pharmacognosy Phytochem.* 9, 2798–2801.

Kurmi, A., Kushawah, J., Nishmitha, K., Dorjee, L., and Shahni, Y. S. (2024).

Lantero, E., Matallanas, B., and Callejas, C. (2023). Current status of the main olive pests: useful integrated pest management strategies and genetic tools. *Appl. Sci.* 13, 12078. doi: 10.3390/app132112078

Lee, B. W., Oeller, L. C., and Crowder, D. W. (2022). Integrating community ecology into models of vector-borne virus transmission. *Plants* 12, 2335. doi: 10.3390/plants12122335

Lee, S., and Yun, C. M. (2023). A deep learning model for predicting risks of crop pests and diseases from sequential environmental data. *Plant Methods* 19, 145. doi: 10.1186/s13007-023-01122-x

Legros, M., Marshall, J. M., Macfadyen, S., Hayes, K. R., Sheppard, A., and Barrett, L. G. (2021). Gene drive strategies of pest control in agricultural systems: Challenges and opportunities. *Evolutionary Appl.* 14, 2162–2178. doi: 10.1111/eva.13285

Li, A. (2024). Technological innovation in disease detection and management in sugarcane planting. *Bioscience Methods* 15 (1), 58–65. doi: 10.5376/bm.2024.15.0007

Li, A., Wang, M., Chen, Z., Qin, C., Liao, F., Wu, Z., et al. (2021). Integrated Transcriptome and Metabolome Analysis to Identify Sugarcane Gene Defense against Fall Armyworm (*Spodoptera frugiperda*) Herbivory. *Int. J. Mol. Sci.* 23, 13712. doi: 10.3390/ijms232213712

Li, J., Zhang, Z., Lei, Q., Lu, B., Jin, C., Liu, X., et al. (2022). Multiple herbicide resistance in *Eleusine indica* from sugarcane fields in China. *Pesticide Biochem. Physiol.* 182, 105040. doi: 10.1016/j.pestbp.2022.105040

Li, H., Peng, Y., Wu, C., Li, Z., Zou, L., Mao, K., et al. (2024). Assessing genome-wide adaptations associated with range expansion in the pink rice borer, Sesamia inferens. *Insect Sci.* doi: 10.1111/1744-7917.13320

Li, P., Liang, C., Jiao, J., Ruan, Z., Sun, M., Fu, X., et al. (2024). Exogenous priming of chitosan induces resistance in Chinese prickly ash against stem canker caused by Fusarium zanthoxyli. *Int. J. Biol. Macromolecules*, 129119. doi: 10.1016/j.ijbiomac.2023.129119

Linnenluecke, M. K., Nucifora, N., and Thompson, N. (2018). Implications of climate change for the sugarcane industry. *Wiley Interdiscip. Reviews: Climate Change* 9, e498. doi: 10.1002/wcc.498

Linnenluecke, M. K., Zhou, C., Smith, T., Thompson, N., and Nucifora, N. (2020). The impact of climate change on the Australian sugarcane industry. *J. Cleaner Production* 246, 118974. doi: 10.1016/j.jclepro.2019.118974

Lopes, M. A. (2023). *Rethinking plant breeding and seed systems*. Available online at: http://www.alice.cnptia.embrapa.br/alice/handle/doc/1158393.

Lovelli, S., Perniola, M., Ferrara, A., Amato, M., and Di Tommaso, T. (2010). Photosynthetic response to water stress of pigweed (*Amaranthus retroflexus*) in a Southern-Mediterranean area. *Weed Sci.* 58, 126–131. doi: 10.1614/WS-09-039.1

Lu, G., Wang, Z., Xu, F., Pan, Y., Grisham, M. P., and Xu, L. (2021). Sugarcane mosaic disease: characteristics, identification and control. *Microorganisms* 9, 1984. doi: 10.3390/microorganisms9091984

Maduka, C. P., Adegoke, A. A., Okongwu, C. C., Enahoro, A., Osunlaja, O., and Ajogwu, A. E. (2023). Review of laboratory diagnostics evolution in Nigeria's response to COVID-19. *Int. Med. Sci. Res. J.* 3, 1–23. doi: 10.51594/imsrj.v3i1.581

Mahesh, P., Srikanth, J., Salin, K., Singaravelu, B., Chandran, K., and Mahendran, B. (2019). Phenology of sugarcane leaf hopper *Pyrilla perpusilla* (Walker) (Homoptera: Lophopidae) and its natural enemies in a crop island scenario. *Crop Prot.* 120, 151–162. doi: 10.1016/j.cropro.2019.02.020

Mahgoub, A. M. (2023). Ecological importance and sociological characters of fourteen widespread weeds and their contribution to the observed (dis) similarity between weed communities. *Heliyon* 9 (4), e13638. doi: 10.1016/j.heliyon.2023.e13638

Majhi, P. K., Samal, I., Bhoi, T. K., Pattnaik, P., Pradhan, C., Gupta, A., et al. (2023). "Climate-smart agriculture: an integrated approach to address climate change and food security," in *Climate Change and Insect Biodiversity* (United States: CRC Press), 221–245. doi: 10.1201/9781003382089–14

Makgoba, M. C., Tshikhudo, P. P., Nnzeru, L. R., and Makhado, R. A. (2021). Impact of fall armyworm (*Spodoptera frugiperda*) (J.E. Smith) on small-scale maize farmers and its control strategies in the Limpopo province, South Africa. *Jàmbá: J. Disaster Risk Stud.* 13 (1), 1016. doi: 10.4102/jamba.v13i1.1016

Mandal, A., Sarkar, B., Mandal, S., Vithanage, M., Patra, A. K., and Manna, M. C. (2019). "Impact of agrochemicals on soil health," in *Agrochemicals detection, treatment and remediation*. Butterworth-Heinemann, 161–187. doi: 10.1016/B978–0-08–103017–2.00007–6

Matthieson, L. (2007). *Climate change and the Australian Sugarcane Industry: impacts, adaptation and R&D opportunities.* SRDC Technical Report (Brisbane, Australia: Sugar Research and Development).

Maxwell, S. L., Butt, N., Maron, M., McAlpine, C. A., Chapman, S., Ullmann, A., et al. (2019). Conservation implications of ecological responses to extreme weather and climate events. *Diversity Distributions* 25, 613–625. doi: 10.1111/ddi.12878

Mercer, N. H. (2020). Management of sugarcane aphid (Melanaphis sacchari) using biological and cultural tactics in Kentucky. Theses and Dissertations—Entomology. (University of Kentucky: United States), 51. doi: 10.13023/etd.2020.094

Mishra, H., and Mishra, D. (2023). Artificial intelligence and machine learning in agriculture: Transforming farming systems. *Res. Trends Agric. Sci.* 1, 1–16.

Montalvo-Navarrete, J. M., and Lasso-Palacios, A. P. (2024). Energy access sustainability criteria definition for Colombian rural areas. *Renewable Sustain. Energy Rev.* 189, 113922. doi: 10.1016/j.rser.2023.113922

Morya, G. P., and Kumar, R. (2023). Sustainable pest management-A review in the Indian context. *Curr. Res. Agric.* 4 (1), 1–7. doi: 10.18782/2582–7146.169

Mrabet, R. (2023). "Sustainable agriculture for food and nutritional security," in *Sustainable Agriculture and the Environment* (Amsterdam, The Netherlands: Academic Press), 25–90. doi: 10.1016/B978-0-323-90500-8.00013-0

Msomba, B. H., Ndaki, P. M., and Nassary, E. K. (2021). Assessing impact of climate change and extreme weather events on the sustainability of sugarcane production. *J. Global Agric. Ecol.* 11 (4), 33–45.

Muhammad, M., Ahmad, M. W., Basit, A., Ullah, S., Mohamed, H. I., Nisar, N., et al. (2024). "Plant growth-promoting rhizobacteria and their applications and role in the management of soilborne diseases," in *Bacterial Secondary Metabolites* (Amsterdam, The Netherlands: Elsevier), 59–82. doi: 10.1016/B978-0-323-95251-4.00001-6

Muhammad, F., Sarwar, J., Amin, F., Safi, M. H., Khurshid, A., Shah, M., et al. (2023). Effect of granular insecticides against sugarcane stem borer (*Chilo infuscatellus*) and sugarcane root borer (*Emalocera depresella*) at district Mardan. *Pure Appl. Biol.* 12, 1194–1200. doi: 10.19045/bspab.2023.120122

Mulianga, B., Bégué, A., Simoes, M., and Todoroff, P. (2013). Forecasting regional sugarcane yield based on time integral and spatial aggregation of MODIS NDVI. *Remote Sens.* 5, 2184–2199. doi: 10.3390/rs5052184

Mwangi, R. W., Mustafa, M., Charles, K., Wagara, I. W., and Kappel, N. (2023). Selected emerging and reemerging plant pathogens affecting the food basket: A threat to food security. *J. Agric. Food Res.* 14, 100827. doi: 10.1016/j.jafr.2023.100827

Mylonas, I., Stavrakoudis, D., Katsantonis, D., and Korpetis, E. (2020). "Better farming practices to combat climate change," in *Climate change and food security with emphasis on wheat* (Amsterdam, The Netherlands: Academic Press), 1–29. doi: 10.1016/B978-0-12-819527-7.00001-7

Naqvi, R. Z., Siddiqui, H. A., Mahmood, M. A., Najeebullah, S., Ehsan, A., Azhar, M., et al. (2022). Smart breeding approaches in post-genomics era for developing climate-resilient food crops. *Front. Plant Sci.* 13. doi: 10.3389/fpls.2022.972164

Narayana, T. L., Venkatesh, C., Kiran, A., Kumar, A., Khan, S. B., Almusharraf, A., et al. (2024). Advances in real time smart monitoring of environmental parameters using IoT and sensors. *Heliyon* 10, e28195. doi: 10.1016/j.heliyon.2024.e28195

Nath, C. P., Singh, R. G., Choudhary, V. K., Datta, D., Nandan, R., and Singh, S. S. (2024). Challenges and alternatives of herbicide-based weed management. *Agronomy* 14, 126. doi: 10.3390/agronomy14010126

Ncoyini, Z., Savage, M. J., and Strydom, S. (2022). Limited access and use of climate information by small-scale sugarcane farmers in South Africa: A case study. *Climate Serv.* 26, 100285. doi: 10.1016/j.cliser.2022.100285

Ngcobo, S., Hill, T., Jewitt, G., and Archer, E. (2023). A yield gap analysis to assess vulnerability of commercial sugarcane to climatic extremes in southern Africa. *J. Agric. Food Res.* 14, 100734. doi: 10.1016/j.jafr.2023.100734

Nguru, W., and Mwongera, C. (2023). Predicting the future climate-related prevalence and distribution of crop pests and diseases affecting major food crops in Zambia. *PloS Climate* 2, e0000064. doi: 10.1371/journal.pclm.0000064

Nikpay, A., Tiwari, A. K., Vejar-Cota, G., Ziaee, M., Wilson, B., Srivastava, S., et al. (2023). "Biotic stresses in sugarcane plants and its management," in *Agro-industrial perspectives on sugarcane production under environmental stress* (Springer Nature Singapore, Singapore), 301–359. doi: 10.1007/978–981-19–3955-6_15

Noureen, A., Aziz, R., Ismail, A., and Trzcinski, A. P. (2022). The impact of climate change on waterborne diseases in Pakistan. *Sustainability Climate Change* 15, 138–152. doi: 10.1089/scc.2021.0070

Nunes, P. S., Junior, G. V. L., Mascarin, G. M., Guimarães, R. A., Medeiros, F. H., Arthurs, S., et al. (2024). Microbial consortium of biological products: do they have a future? *Biol. Control* 188, 105439. doi: 10.1016/j.biocontrol.2024.105439

Odero, D. C., Rice, R., and Baucum, L. (2013). Biology and control of goosegrass in sugarcane: SSAGR367/SC096, 1/2013. *EDIS* 2013. doi: 10.32473/edis-sc096-2013

Othman, S. H., Lazim, Z. S., and Al-Wakaa, A. H. A. (2023). "Allelopathic potential of aqueous plant extracts against seed germination and seedling growth of weeds," in *IOP Conference Series: Earth and Environmental Science*. IOP Publishing Ltd, England and Wales, vol. 1262, 032041. doi: 10.1088/1755-1315/1262/3/032041

Pachiappan, K., Anitha, K., Pitchai, R., Sangeetha, S., Satyanarayana, T. V. V., and Boopathi, S. (2024). "Intelligent machines, ioT, and AI in revolutionizing agriculture for water processing," in *Handbook of Research on AI and ML for Intelligent Machines and Systems*. Pennsylvania, USA, 374–399. doi: 10.4018/978–1-6684–9999-3.ch015

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 372, n71. doi: 10.1136/bmj.n71

Palanivel, H., and Shah, S. (2021). Unlocking the inherent potential of plant genetic resources: food security and climate adaptation strategy in Fiji and the Pacific. *Environment Dev. Sustainability* 23, 14264–14323. doi: 10.1007/s10668-021-01273-8

Parthasarathy, S., Lakshmidevi, P., Satya, V. K., and Gopalakrishnan, C. (2024). *Plant Pathology and Disease Management: Principles and Practices* (United States: CRC Press). doi: 10.1201/9781032711973

Parveen, S., and Rashtrapal, P. S. (2024). Integrated pest management strategies using endophytic entomopathogenic fungi. *Plant Sci. Today* 11 (1), 568–574. doi: 10.14719/pst.2740

Pavinato, C. V. A., Michel, A. P., Omoto, C., and Zucchi, M. I. (2017). Influence of historical land use and modern agricultural expansion on the spatial and ecological divergence of sugarcane borer, *Diatraea saccharalis* (Lepidoptera: Crambidae) in Brazil. *Heredity* 120, 25–37. doi: 10.1038/s41437-017-0018-1

Pekarcik, A. J., and Jacobson, A. L. (2021). Evaluating sugarcane aphid, *Melanaphis sacchari* (Hemiptera: Aphididae), population dynamics, feeding injury, and grain yield among commercial sorghum varieties in Alabama. *J. Economic Entomology* 114, 757–768. doi: 10.1093/jee/toab013

Peng, B., Guan, K., Tang, J., Ainsworth, E. A., Asseng, S., Bernacchi, C. J., et al. (2020). Towards a multiscale crop modelling framework for climate change adaptation assessment. *Nat. Plants* 6, 338–348. doi: 10.1038/s41477-020-0625-3

Petropoulos, F., Apiletti, D., Assimakopoulos, V., Babai, M. Z., Barrow, D. K., Ben Taieb, S., et al. (2022). Forecasting: theory and practice. *Int. J. Forecasting* 38, 705–871. doi: 10.1016/j.ijforecast.2021.11.001

Pires da Silva, B., Oliveira de Almeida, R., Salgado, T. P., and Pedro Luis da, C. A. A. (2014). Efficacy of imazapic, halosulfuron and sulfentrazone for *Cyperus rotundus* L. control in response to weed tuber density. *Afr. J. Agric. Res.* 9, 3458–3464. doi: 10.5897/AJAR2013.8411

Prado, G. S., Rocha, D. C., Santos, L. N., Contiliani, D. F., Nobile, P. M., Camargo, J., et al. (2024). CRISPR technology towards genome editing of the perennial and semi-perennial crops citrus, coffee and sugarcane. *Front. Plant Sci.* 14, 1331258. doi: 10.3389/fpls.2023.1331258

Preti, M., Verheggen, F., and Angeli, S. (2021). Insect pest monitoring with camera-equipped traps: Strengths and limitations. *J. Pest Sci.* 94, 203–217. doi: 10.1007/s10340-020-01309-4

Qin, Z. Q., Luo, Y. W., Li, D. W., Song, X. P., Wei, J. J., Wei, C. Y., et al. (2020). Field evaluation of infestation levels of the sugarcane mealybug *Saccharicoccus sacchari* (Cockerell) on different sugarcane varieties in Guangxi Province, China: Preliminary results. *Intl. Sugar J.* 122 (1461), 648–653.

Raid, R. N., Comstock, J. C., and Sood, S. (2013). Sugarcane orange rust in Florida: its history, current status, and management. *J. Am. Soc. Sugar Cane Technol.* 33, 57.

Rajput, M. A., Rajput, N. A., Syed, R. N., Lodhi, A. M., and Que, Y. (2021). Sugarcane smut: Current knowledge and the way forward for management. *J. Fungi* 7, 1095. doi: 10.3390/jof7121095

Ram, B., Karuppaiyan, R., and Hemaprabha, G. (2022). "Sugarcane Breeding," in *Fundamentals of Field Crop Breeding* (Springer Nature Singapore, Singapore), 499–570. doi: 10.1007/978–981-16–9257-4_9

Ramanujam, B., Hosamani, A., Poornesha, B., and Sowmya, E. (2021). Biological control of white grubs, *Holotrichia serrata* (Fabricius) in sugarcane by two species of entomopathogenic fungi, *Metarhizium anisopliae* and *Beauveria bassiana*. *Int. J. Trop. Insect Sci.* 41, 671–680. doi: 10.1007/s42690-020-00256-y

Ranganathan, K., Krishnan, M., Kuppusamy, A., Azrag, A. G., Jandhyala, S., and Arjunan, N. (2023). Spatio-temporal distribution of sugarcane shoot borer, *Chilo infuscatellus* (Lepidoptera: Crambidae) and its associated natural enemy *Sturmiopsis inferens* (Diptera: Tachinidae) in India. *Int. J. Trop. Insect Sci.* 43, 277–287. doi: 10.1007/s42690-022-00940-1

Rao, A. Q., Bajwa, K. S., Ali, M. A., Bakhsh, A., Iqbal, A., Latif, A., et al. (2023). Evaluation of weed control efficiency of herbicide resistant transgenic cotton. *J. Anim. Plant Sci.* 33 (1), 75–84. doi: 10.36899/JAPS.2023.1.0596

Reddy, A. V., Thiruvengatanadhan, R., Srinivas, M., and Dhanalakshmi, P. (2024). Region based segmentation with enhanced adaptive histogram equalization model with definite feature set for sugarcane leaf disease classification. *Int. J. Intelligent Syst. Appl. Eng.* 12, 428–442.

Rice, J. L., Hoy, J. W., and Grisham, M. P. (2019). Sugarcane mosaic distribution, incidence, increase, and spatial pattern in Louisiana. *Plant Dis.* 103, 2051–2056. doi: 10.1094/PDIS-01-19-0099-RE

Richard, B., Qi, A., and Fitt, B. D. (2022). Control of crop diseases through Integrated Crop Management to deliver climate-smart farming systems for low-and high-input crop production. *Plant Pathol.* 71, 187–206. doi: 10.1111/ppa.13493

Rocklöv, J., Semenza, J. C., Dasgupta, S., Robinson, E. J., Abd El Wahed, A., Alcayna, T., et al. (2023). Decision-support tools to build climate resilience against emerging infectious diseases in Europe and beyond. *Lancet Regional Health–Europe* 32, 100701. doi: 10.1016/j.lanepe.2023.100701

Röling, N. (2019). "The agricultural research-technology transfer interface: a knowledge systems perspective," in *Making the link* (United States: CRC Press), 1–42.

Roy, D., Ghosh, S., Datta, D., Sreekanth, D., Pawar, D., Mukherjee, P. K., et al. (2023). "Climate resilient weed management for crop production," in *Climate-Resilient Agriculture, Vol 2: Agro-Biotechnological Advancement for Crop Production* (Springer International Publishing, Cham), 125–156. doi: 10.1007/978–3-031–37428-9_7

Saha, N., Mazumdar, P. C., Basak, J., Raha, A., Majumder, A., and Chandra, K. (2016). Subterranian termite genus *Odontotermes* (Blattaria: Isoptera: Termitidae) from Chhattisgarh, India with its annotated checklist and revised key. *J. Threatened Taxa* 8, 8602–8610. doi: 10.11609/jott.2016.8.3.8541-8640

Sakdapolrak, P., Sterly, H., Borderon, M., Bunchuay-Peth, S., Naruchaikusol, S., Ober, K., et al. (2024). Translocal social resilience dimensions of migration as adaptation to environmental change. *Proc. Natl. Acad. Sci.* 121, e2206185120. doi: 10.1073/pnas.2206185120

Santosh, S., and Pavithran, M. (2024). Iron-based smart alloys for critical applications: A review on processing, properties, phase transformations, and current trends. *J. Mater. Sci.: Mater. Engin* 19 (1), 1–17. doi: 10.1186/s40712-024-00150-2

Sarjan, M., Muchlis, M., and Muthahanas, I. (2021). The diversity of major insect pests at sugarcane development center in Dompu District, West Nusa Tenggara. *J. Sci. Sci. Educ.* 2, 38–46. doi: 10.29303/jossed.v2i1.712

Sarkar, M., Gorai, P., and Modak, B. K. (2024). "Indigenous strategies and adaptive approaches to scrabble recent climate crisis in two districts (Bankura and purulia) of West Bengal, India," in *Climate Crisis: Adaptive Approaches and Sustainability* (Springer Nature Switzerland, Cham), 75–101. doi: 10.1007/978–3-031–44397-8_5

Savary, S., and Willocquet, L. (2020). Modeling the impact of crop diseases on global food security. *Annu. Rev. Phytopathol.* 58, 313–341. doi: 10.1146/annurev-phyto-010820-012856

Scavo, A., and Mauromicale, G. (2020). Integrated weed management in herbaceous field crops. *Agronomy* 10, 466. doi: 10.3390/agronomy10040466

Schrader, S., Graham, S., Campbell, R., Height, K., and Hawkes, G. (2024). Grower attitudes and practices toward area-wide management of cropping weeds in Australia. *Land Use Policy* 137, 107001. doi: 10.1016/j.landusepol.2023.107001

Shafiq, S., Haq, M. Z. U., Shahbaz, A., Shafique, S., Riaz, M., Hanif, M. T., et al. (2024). "Agrochemicals and climate change," in *Water-Soil-Plant-Animal Nexus in the Era of Climate Change*. Pennsylvania, USA, 49–77. doi: 10.4018/978–1-6684–9838-5.ch003

Shahi, T. B., Xu, C. Y., Neupane, A., and Guo, W. (2023). Recent advances in crop disease detection using UAV and deep learning techniques. *Remote Sens.* 15, 2450. doi: 10.3390/rs15092450

Shahid, M. S., Akram, A., Imtiaz, U., Saba, I., Kabir, R., Hayat, U., et al. (2024). Review of recent advances in chemical fertilizers and their impact on crop productivity and sustainability. *Eur. Chem. Bull.* 13 (1), 62–71. doi: 10.53555/ecb/2024.13.01.10

Shahzad, A., Ullah, S., Dar, A. A., Sardar, M. F., Mehmood, T., Tufail, M. A., et al. (2021). Nexus on climate change: Agriculture and possible solution to cope future climate change stresses. *Environ. Sci. pollut. Res.* 28, 14211–14232. doi: 10.1007/s11356-021-12649-8

Shaktawat, P., and Swaymprava, S. (2024). "Digital agriculture: exploring the role of information and communication technology for sustainable development,". In: Eds. B. Mallick and J. Anshuman *Navigating Agricultural Extension: A Comprehensive Guide*. (PMW, New Delhi), 31.

Sharma, R. P., Dharavath, R., and Edla, D. R. (2023). IoFT-FIS: Internet of farm things based prediction for crop pest infestation using optimized fuzzy inference system. *Internet Things* 21, 100658. doi: 10.1016/j.iot.2022.100658

Sharma, T., and Shera, P. S. (2021). Biological anomalies in the sugarcane leafhopper, *Pyrilla perpusilla* (Walker) due to parasitism by *Fulgoraecia melanoleuca* (Fletcher) (Lepidoptera: Epipyropidae). *Egyptian J. Biol. Pest Control* 31, 1–8. doi: 10.1186/s41938-021-00486-3

Shawky, S., Rundle-Thiele, S., and David, P. (2023). What enables and prevents sugarcane growing practice change? A review of publicly available sources for practice change projects. *Austr. J. Environ. Manag.* 30 (3–4), 327–347. doi: 10.1080/14486563.2023.2238662

Shivanna, K. R. (2022). Climate change and its impact on biodiversity and human welfare. *Proc. Indian Natl. Sci. Academy. Part A Phys. Sci.* 88, 160–171. doi: 10.1007/s43538-022-00073-6

R. B. Shrestha and Y. B. Thapa eds. (2019). *Policy and program priorities in agricultural research & Development in South Asia*. Bangkok, Thailand: SAARC Agriculture Center, Dhaka, Bangladesh, and Asia-Pacific Association of Agricultural Research Institutions (APAARI). p. 376.

Shumail, H., Khalid, S., Ghaffar, N., Akhtar, N., and Haq, S. I. U. (2022). A study of some weeds of Pakistan and their response to abiotic stress-a review. *J. Pure Appl. Agric.* 7 (1), 51–58.

Simões, R. A., Feliciano, J. R., Solter, L. F., and Delalibera, I. (2015). Impacts of Nosema sp. (Microsporidia: Nosematidae) on the sugarcane borer, *Diatraea saccharalis* (Lepidoptera: Crambidae). *J. Invertebrate Pathol.* 129, 7–12. doi: 10.1016/j.jip.2015.05.006

Simões, S., Oliveira, T., and Nunes, C. (2022). Influence of computers in students' academic achievement. *Heliyon* 8 (3), e09004. doi: 10.1016/j.heliyon.2022.e09004

Singh, A., Chauhan, S. S., Singh, A., and Singh, S. B. (2006). Deterioration in sugarcane due to pokkah boeng disease. *Sugar Technol.* 8, 187–190. doi: 10.1007/BF02943659

Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H., et al. (2023). Climate change impacts on plant pathogens, food security and paths forward. *Nat. Rev. Microbiol.* 21 (10), 640–656. doi: 10.1038/s41579-023-00900-7

Singh, P., Hussain, T., Patel, S., and Akhtar, N. (2018). Impact of climate change on root–pathogen interactions. In: B. Giri, R. Prasad and A. Varma eds. *Root Biology. Soil Biology* vol. 52. Springer, Cham. doi: 10.1007/978–3-319–75910-4_16

Singh, P., Singh, S. N., Tiwari, A. K., Pathak, S. K., Singh, A. K., Srivastava, S., et al. (2019). Integration of sugarcane production technologies for enhanced cane and sugar productivity targeting to increase farmers' income: strategies and prospects. *3 Biotechnol.* 9, 1–15. doi: 10.1007/s13205-019-1568-0

Sivakumar, K., Rawat, G. S., Badola, R., Adhikari, B. S., and Kamalakannan, B. (2018). *Study on ecological & socio-economic impact of invasive species, Prosopis juliflora and Lantana camara, and their removal from forest, common and fallow land of Tamil Nadu. Technical Report* (Dehradun, India: Wildlife Institute of India).

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., and Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects* 12, 440. doi: 10.3390/insects12050440

Smith, P., Greenwell, A., and Baldvins, T. (2021). *Noxious weed mapping and monitoring at Francis E. Warren Air Force Base 2018–2020*. Colorado: United States: Colorado State University. Libraries. Doctoral dissertation.

Sorvali, J., Kaseva, J., and Peltonen-Sainio, P. (2021). Farmer views on climate change–a longitudinal study of threats, opportunities and action. *Climatic Change* 164, 1–19. doi: 10.1007/s10584-021-03020-4

Soumia, P. S., Shirsat, D. V., Chitra, N., Karuppaiah, V., Gadge, A. S., Thangasamy, A., et al. (2023). Invasion of fall armyworm, (*Spodoptera frugiperda*, J E Smith) (Lepidoptera, Noctuidae) on onion in the maize–onion crop sequence from Maharashtra, India. *Front. Ecol. Evol.* 11. doi: 10.3389/fevo.2023.1279640

Spaunhorst, D. J. (2021). Spring-applied triclopyr mixtures for Bermudagrass (*Cynodon dactylon*) suppression in Louisiana sugarcane. *Weed Technol.* 35, 589–597. doi: 10.1017/wet.2021.20

Spelman, R. (2024). *Determining the Effect of Cover Cropping Legacy on Mycotoxin Accumulation and Fusarium Disease in Maize*. Pennsylvania USA: Pennsylvania State University. https://projects.sare.org/sare_project/gne21-270/.

Sreekanth, D., Pawar, D. V., Mishra, J. S., and Naidu, V. S. G. R. (2023). Climate change impacts on crop–weed interaction and herbicide efficacy. *Curr. Sci.* 124 (6), 686–692. doi: 10.18520/cs/v124/i6/686–692

Srinivasan, G., Agarwal, A., and Bandara, U. (2024). "Climate change impacts on water resources and agriculture in Southeast Asia with a focus on Thailand, Myanmar, and Cambodia," in *The Role of Tropics in Climate Change* (Amsterdam, The Netherlands: Elsevier), 17–32. doi: 10.1016/B978-0-323-99519-1.02002-0

Srinivasa Rao, M., Mani, M., Prasad, Y. G., Prabhakar, M., Sridhar, V., Vennila, S., et al. (2022). Climate change and pest management strategies in horticultural and agricultural ecosystems. In: M. Mani eds. *Trends in Horticultural Entomology*. Springer, Singapore, 81–122. doi: 10.1007/978–981-19–0343-4_3

Storkey, J., Mead, A., Addy, J., and MacDonald, A. J. (2021). Agricultural intensification and climate change have increased the threat from weeds. *Global Change Biol.* 27, 2416–2425. doi: 10.1111/gcb.15585

Subedi, B., Poudel, A., and Aryal, S. (2023). The impact of climate change on insect pest biology and ecology: Implications for pest management strategies, crop production, and food security. *J. Agric. Food Res.* 14, 100733. doi: 10.1016/j.jafr.2023.100733

Tait, G., Mermer, S., Stockton, D., Lee, J., Avosani, S., Abrieux, A., et al. (2021). *Drosophila suzukii* (Diptera: Drosophilidae): a decade of research towards a sustainable integrated pest management program. *J. Economic Entomology* 114, 1950–1974. doi: 10.1093/jee/toab158

Tamiru, L., and Fekadu, H. (2019). Effects of climate change variability on agricultural productivity. *Int. J. Environ. Sci. Natural Resour.* 17, 555953. doi: 10.19080/IJESNR.2019.17.555953

Tan, M., Ding, Y., Bourdôt, G. W., and Qiang, S. (2024). Evaluation of *Bipolaris yamadae* as a bioherbicidal agent against grass weeds in arable crops. *Pest Manage. Sci.* 80, 166–175. doi: 10.1002/ps.7630

Tan, C., Kalhoro, M. T., Faqir, Y., Ma, J., Osei, M. D., and Khaliq, G. (2022). Climate-resilient microbial biotechnology: A perspective on sustainable agriculture. *Sustainability* 14, 5574. doi: 10.3390/su14095574

Taylor, B., Casey, J., Annamalai, S., Finch, E. A., Beale, T., Holland, W., et al. (2021). Minimizing pest and disease risks in uncertain climates: CABI initiatives developing new technologies and tools for outreaching early warning to farmers. *AgriRxiv* 2021, 20210271298. doi: 10.31220/agriRxiv.2021.000

Taylor, B., Tonnang, H. E. Z., Beale, T., Holland, W., Oronje, M., Abdel-Rahman, E. M., et al. (2023). Leveraging data, models & farming innovation to prevent, prepare for & manage pest incursions: delivering a pest risk service for low-income countries. *Sci. Innov. Food Syst. Transformation* 439–453. doi: 10.1007/978-3-031-15703-5_23

Tlatlaa, J. S., Tryphone, G. M., and Nassary, E. K. (2023). Unexplored agronomic, socioeconomic and policy domains for sustainable cotton production on small landholdings: A systematic review. *Front. Agron.* 5. doi: 10.3389/fagro.2023.1281043

Tripathi, H. G., Kunin, W. E., Smith, H. E., Sallu, S. M., Maurice, S., Machera, S. D., et al. (2022). Climate-smart agriculture and trade-offs with biodiversity and crop yield. *Front. Sustain. Food Syst.* 6. doi: 10.3389/fsufs.2022.868870

Tu, Y., Wang, Y., Jiang, H., Ren, H., Wang, X., and Lv, W. (2024). A loop-mediated isothermal amplification assay for the rapid detection of *Didymella segeticola* causing tea leaf spot. *J. Fungi* 10, 467. doi: 10.3390/jof10070467

Usman, M., Akram, N., Imitaz, S., and Haider, S. M. (2020). Sugarcane: Diseases due to pests, pest management strategies and factors influencing the production of sugarcane. *Am. Sci. Res. J. Eng. Technol. Sci. (ASRJETS)* 65, 126–139.

Valencia Arbeláez, J. A., Giraldo, A. S., Castaño Villa, G. J., Vallejo Espinosa, L. F., Salazar Gutierrez, M. R., and Vargas, G. (2021). Population dynamics of sugarcane borers, Diatraea spp., under different climatic scenarios in Colombia. *PloS One* 16 (1), e0244694. doi: 10.1371/journal.pone.0244694

van Antwerpen, R., van Heerden, P. D. R., Keeping, M. G., Titshall, L. W., Jumman, A., Tweddle, P. B., et al. (2022). A review of field management practices impacting root health in sugarcane. *Adv. Agron.* 173, 79–162. doi: 10.1016/bs.agron.2022.02.002

van Zonneveld, M., Turmel, M., and Hellin, J. (2020). Decision-making to diversify farm systems for climate change adaptation. *Front. Sustain. Food Syst.* 4. doi: 10.3389/fsufs.2020.00032

Vasileiou, M., Kyriakos, L. S., Kleisiari, C., Kleftodimos, G., Vlontzos, G., Belhouchette, H., et al. (2024). Transforming weed management in sustainable agriculture with artificial intelligence: a systematic literature review towards weed identification and deep learning. *Crop Prot.* 176, 106522. doi: 10.1016/j.cropro.2023.106522

Vermeulen, S. J., Dinesh, D., Howden, S. M., Cramer, L., and Thornton, P. K. (2018). Transformation in practice: A review of empirical cases of transformational adaptation in agriculture under climate change. *Front. Sustain. Food Syst.* 2. doi: 10.3389/fsufs.2018.00065

Vinayaka,, and Prasad, P. R. C. (2024). AI-enhanced remote sensing applications in Indian sugarcane research: A Comprehensive Review. *Sugar Tech.* 26, 609–628. doi: 10.1007/s12355-024-01409-w

Virtudazo, E. V., Nojima, H., and Kakishima, M. (2001). Taxonomy of *Puccinia* species causing rust diseases on sugarcane. *Mycoscience* 42, 167–175. doi: 10.1007/BF02464133

Viswanathan, R. (2022). Sugarcane diseases: Diagnostics and management. *RASSA J. Sci. Soc.* 4, 36–44. doi: 10.5958/2583-3715.2022.00005.3

Viswanathan, R., Selvakumar, R., Geetha, N., Balaji, C. G., Annadurai, A., Pazhani, A. S., et al. (2022). Epidemiology of sugarcane wilt: predisposition by root borer Polyocha depresella a myth or reality. *Indian Phytopathol.* 75, 3–14. doi: 10.1007/s42360-021-00398-0

Volk, G. M., Carver, D., Irish, B. M., Marek, L., Frances, A., Greene, S., et al. (2023). Safeguarding plant genetic resources in the United States during global climate change. *Crop Sci.* 63, 2274–2296. doi: 10.1002/csc2.21003

Waheed, A., Haxim, Y., Islam, W., Ahmad, M., Muhammad, M., Alqahtani, F. M., et al. (2023). Climate change reshaping plant-fungal interaction. *Environ. Res.* 238, 117282. doi: 10.1016/j.envres.2023.117282

Walia, S. S., and Kaur, T. (2024). *Earthworms and Vermicomposting: Species, Procedures and Crop Application* (United Kingdom: Springer Nature). doi: 10.1007/978-981-99-8953-9

Walsh, J. E., Ballinger, T. J., Euskirchen, E. S., Hanna, E., Mård, J., Overland, J. E., et al. (2020). Extreme weather and climate events in northern areas: A review. *Earth-Science Rev.* 209, 103324. doi: 10.1016/j.earscirev.2020.103324

Wang, Y. H., Ma, Y. L., Feng, G. J., and Li, H. H. (2018). Abiotic factors affecting seed germination and early seedling emergence of large crabgrass (*Digitaria sanguinalis*). *Planta Daninha* 36, e018166895. doi: 10.1590/s0100-83582018360100068

Ward, G. M., Kambey, C. S., Faisan, J. P. Jr., Tan, P. L., Daumich, C. C., Matoju, I., et al. (2022). Ice-Ice disease: an environmentally and microbiologically driven syndrome in tropical seaweed aquaculture. *Rev. Aquaculture* 14, 414–439. doi: 10.1111/raq.12606

Waters, E. K., Chen, C. C. M., and Azghadi, M. R. (2024). Sugarcane health monitoring with satellite spectroscopy and machine learning: A Review. *arXiv preprint arXiv:2404.16844*. doi: 10.48550/arXiv.2404.16844

Way, M. J., Conlong, D. E., Martin, L. A., McFarlane, S. A., Stranack, R., Keeping, M. G., et al. (2015). First record of yellow sugarcane aphid, *Siphaflava* (Homoptera: Aphididae), in the South African sugarcane industry. *Proceeding South Afr. Sugar Technol. Assoc.* 87, 53–57.

Weier, S. M., Bringhenti, T., Anders, M., Abdulai, I., Foord, S., Grass, I., et al. (2024). "Management options for macadamia orchards with special focus on water management and ecosystem services," in *Sustainability of Southern African Ecosystems under Global Change: Science for Management and Policy Interventions* (Springer International Publishing, Cham), 625–652. doi: 10.1007/978-3-031–10948-5_22

Williams, L., Cherry, R., and Shapiro-Ilan, D. (2022). Effect of host size on susceptibility of Melanotus Communis (Coleoptera: Elateridae) Wireworms to Entomopathogens. *J. Nematol.* 54 (1), e2022–1. doi: 10.2478/jofnem-2022-0033

Wójtowicz, A., Wójtowicz, M., Sigvald, R., Czernecki, B., Ratajkiewicz, H., Łacka, A., et al. (2020). Assessment of the impact of climate change on the latency period of leaf rust on triticale in Poland. *Acta Agriculturae Scandinavica Section B—Soil Plant Sci.* 70, 195–207. doi: 10.1080/09064710.2019.1696394

Wolff, L. (2023). Regulating pests—material politics and calculation in integrated pest management. *Environ. Plann. E: Nat. Space* 6, 455–472. doi: 10.1177/25148486221076138

Xiao, J., Chen, Z., Liang, T., Yang, S., and Tan, H. (2024). Analysis of metabolome and microbiome revealed the resistance mechanisms in sugarcane cultivars with high resistance to pokkah boeng disease. *Chem. Biol. Technol. Agric.* 11, 1–16. doi: 10.1186/s40538-024-00570-4

Yanagi, M. (2024). Climate change impacts on wheat production: Reviewing challenges and adaptation strategies. *Adv. Resour. Res.* 4, 89–107. doi: 10.50908/arr.4.1_89

Yang, L. H., Postema, E. G., Hayes, T. E., Lippey, M. K., and MacArthur-Waltz, D. J. (2021). The complexity of global change and its effects on insects. *Curr. Opin. Insect Sci.* 47, 90–102. doi: 10.1016/j.cois.2021.05.001

Yang, Q., Wang, Q. J., and Hakala, K. (2022). Calibrating anomalies improves forecasting of daily reference crop evapotranspiration. *J. Hydrology* 610, 128009. doi: 10.1016/j.jhydrol.2022.128009

Zaman, M., Khan, I. A., Schmidt, S., Murphy, R., and Poulsen, M. (2022). Morphometrics, distribution, and DNA barcoding: An integrative identification approach to the genus Odontotermes (Termitidae: Blattodea) of Khyber Pakhtunkhwa, Pakistan. *Forests* 13, 674. doi: 10.3390/f13050674

Zhao, Y., Chen, J., Shi, Y., Fu, Y., Huang, T., Rott, P. C., et al. (2022). Sugarcane responses to two strains of *Xanthomonas albilineans* differing in pathogenicity through a differential modulation of salicylic acid and reactive oxygen species. *Frontier Plant Sci.* 13. doi: 10.3389/fpls.2022.1087525

Zheng, X., Wei, L., Lv, W., Zhang, H., Zhang, Y., Zhang, H., et al. (2024). Long-term bioorganic and organic fertilization improved soil quality and multifunctionality under continuous cropping in watermelon. *Agriculture Ecosyst. Environ.* 359, 108721. doi: 10.1016/j.agee.2023.108721