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Effects of pestilence on cassava production and global food security: The challenges of pests and disease management

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is a vital crop for food security, particularly in sub-Saharan Africa, Asia, and Latin America, where it serves as a staple for millions of people. However, cassava production faces significant threats from pests and diseases, which can severely reduce yields and quality. This paper explores the global landscape of cassava protection, focusing on the latest innovations, challenges, and technological advancements in pest control. The study discusses the development and application of integrated pest management (IPM) strategies, biotechnology, and resistant cassava varieties, highlighting the role of genetic modification and CRISPR technologies in enhancing pest resistance. Despite these advancements, challenges remain, including limited access to technology in developing regions, the complexity of pest ecosystems, and the need for sustainable approaches that minimize environmental impact. This paper also addresses the importance of capacity building, policy support, and international collaboration to mitigate the effects of pest infestations on cassava. Ultimately, it emphasizes the need for continued research and innovation to ensure cassava's future as a global food security crop.

Keywords: Cassava; Food safety; Pestilence; Diseases and pests management

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Introduction

Cassava (*Manihot esculenta Crantz*) is a vital staple crop that sustains over 800 million people globally, particularly in tropical and subtropical regions (El-Sharkawy, 2018). It is a crucial source of carbohydrates and an essential component of food security in many developing countries. However, despite its resilience and adaptability to harsh climatic conditions, cassava faces significant threats from pests and diseases that compromise yield and quality. In recent decades, research has intensified to address cassava protection through innovative pest management strategies, technological advancements, and sustainable agricultural practices.

The paper aims to explore the challenges, innovations, and recent technological progress in cassava pest control, providing insights into global efforts to safeguard this crucial crop. Cassava pests, including the cassava mealybug (*Phenacoccus manihoti*), cassava green mite (*Mononychellus tanajoa*), and white flies (*Bemisia tabaci*), pose severe threats to cassava production (Bellotti *et al.,* 2012). These pests not only cause direct damage to the crop but also serve as vectors for devastating viral diseases such as Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). The increasing incidence of pest outbreaks, exacerbated by climate change and the expansion of cassava cultivation into new regions, necessitates the development of innovative and effective control measures. Without adequate protection, cassava yield losses due to pests can reach up to 80%, threatening food security and economic stability in cassava-dependent regions (Legg *et al.,* 2014).

Traditional pest control methods, such as chemical pesticides, have been widely used in cassava production; however, their long-term sustainability remains a concern. The overuse of synthetic pesticides leads to environmental degradation, pesticide resistance, and non-target species mortality, necessitating the adoption of integrated pest management (IPM) approaches (Neuenschwander, 2001). IPM incorporates biological control, cultural practices, resistant cultivars, and targeted pesticide application to minimize environmental impact while maintaining crop protection. The development and deployment of natural enemies, such as parasitoid wasps and predatory mites, have shown promising results in managing cassava pests effectively and sustainably (Zeddies *et al.,* 2001). Biotechnology and genetic engineering have emerged as pivotal tools in cassava pest management. Advances in genetic modification have led to the development of pest-resistant cassava varieties through gene editing techniques such as CRISPR-Cas9 (Odipio *et al.,* 2017). Scientists are focusing on enhancing cassava's natural resistance to major pests and diseases by introducing resistance genes, reducing reliance on chemical pesticides. Additionally, transgenic approaches, including RNA interference (RNAi), have shown potential in silencing specific pest-related genes, providing targeted and environmentally friendly pest control strategies (Kumar *et al.,* 2021). These innovations hold promise for transforming global cassava protection and ensuring sustainable production.

Remote sensing and digital technology are also playing a crucial role in cassava pest surveillance and management. Precision agriculture, utilizing drones and satellite imaging, allows farmers and researchers to monitor pest infestations in real time, enabling early detection and rapid intervention (Jarvis *et al.,* 2012). Machine learning algorithms and artificial intelligence (AI)-based models further enhance pest prediction and decision-making processes, optimizing pest control strategies and reducing crop losses. The integration of these technologies into cassava protection systems has the potential to revolutionize pest management, making it more efficient, data-driven, and resource-effective. Despite these technological advancements, several challenges hinder effective cassava pest control. Limited access to improved technologies, inadequate extension services, and weak regulatory frameworks in developing countries impede the widespread adoption of innovative pest management solutions (Legg and Thresh, 2000). Smallholder farmers, who constitute the majority of cassava producers, often lack the financial resources and technical knowledge to implement advanced pest control measures. Addressing these challenges requires stronger international collaborations, policy interventions, and capacity-building programs to ensure that technological advancements reach the farmers who need them the most.

Climate change further complicates cassava pest control by altering pest distribution patterns and increasing the frequency of pest outbreaks (Tao *et al.,* 2017). Rising temperatures and changing rainfall patterns create favorable conditions for pest proliferation, exacerbating cassava production challenges. Sustainable adaptation strategies, including climate-resilient breeding programs and landscape-level pest management, are essential to mitigate the adverse effects of climate change on cassava protection. Understanding the interactions between climate variables and cassava pests will be crucial for developing long-term pest control strategies. Moving forward, the future of global cassava protection lies in interdisciplinary approaches that combine biotechnology, precision agriculture, and sustainable pest management practices. Collaborative research efforts, involving governments, research institutions, and the private sector, will be instrumental in advancing cassava protection strategies. Investment in farmer education, infrastructure development, and knowledge-sharing platforms will ensure that innovative pest control methods are effectively implemented at the grassroots level.

Global cassava protection is at the forefront of agricultural innovation, with significant progress in pest control strategies. While challenges remain, advancements in biotechnology, digital technology, and sustainable pest management provide promising solutions to mitigate cassava yield losses. Strengthening research, policy support, and farmer participation will be key to ensuring long-term cassava resilience against pests and securing food security for millions of people worldwide. Future research should continue to explore novel approaches, leveraging technological advancements to create a more sustainable and resilient cassava production system.

2.0 Cassava as a Universal Crop

Cassava (*Manihotesculenta*Crantz) is a vital staple crop cultivated in tropical and subtropical regions, supporting over 800 million people worldwide (El-Sharkawy, 2020). Originating from South America, cassava has expanded to Africa and Asia, where it serves as a primary food source due to its adaptability to diverse climatic conditions and its ability to thrive in marginal soils (Lebot, 2019). Unlike cereals such as maize and rice, cassava demonstrates remarkable drought resistance, making it a crucial crop for regions prone to erratic rainfall and soil infertility (Ceballos *et al.,* 2021). The crop's economic significance extends beyond food consumption, as cassava is a major raw material in industries such as bioethanol production, starch manufacturing, and animal feed (Parmar *et al.,* 2022). In Africa, where cassava production is highest, countries like Nigeria, the Democratic Republic of Congo, and Ghana heavily rely on it for both subsistence and commercial agriculture (FAO, 2021). Similarly, in Asia, nations such as Thailand and Vietnam dominate cassava exports, particularly for industrial applications (Howeler, 2019).

Despite its resilience and economic importance, cassava faces several agronomic challenges, particularly from pests and diseases that threaten yields and farmer livelihoods (Legg *et al.,* 2022). The impact of these threats is exacerbated by limited access to improved varieties, poor agronomic practices, and weak pest management policies in many developing regions (Okeke *et al.,* 2023). Climate change further complicates cassava cultivation by altering pest dynamics and increasing the prevalence of diseases (Jarvis *et al.,* 2021). Efforts to improve cassava productivity involve breeding for high-yielding, disease-resistant varieties and enhancing pest control strategies through integrated pest management (IPM) (Akinbo *et al.,* 2020). Additionally, advances in biotechnology, such as gene editing, are being explored to develop cassava strains that are both high-yielding and resistant to major pests and pathogens (Wang *et al.,* 2022). Addressing these challenges is crucial for ensuring cassava remains a sustainable food and industrial crop in the face of global environmental changes.

2.1 Importance of Cassava in Food Security and Industry

Cassava plays a critical role in global food security, particularly in Africa, Latin America, and parts of Asia, where it serves as a major calorie source for millions of people (FAO, 2021). Its high carbohydrate content makes it an essential energy provider, especially in regions where food insecurity is prevalent (Montagnac *et al.,* 2009). Unlike other staple crops, cassava can remain in the ground for extended periods without spoiling, allowing farmers to harvest it as needed, thus reducing post-harvest losses (Nassarand Ortiz, 2010). Apart from its role in food security, cassava has significant industrial applications. The crop is widely used in starch production, with cassava starch serving as a key ingredient in the food, textile, paper, and pharmaceutical industries (Parmar*et al.,* 2022). In Asia, particularly Thailand and Vietnam, cassava starch is a major export commodity, with its derivatives being used in biodegradable plastics, adhesives, and sweeteners (Howeler, 2019). Moreover, cassava-based bioethanol production is gaining traction as a sustainable energy source, contributing to the renewable energy sector and reducing dependence on fossil fuels (Zhang *et al.,* 2020).

Cassava leaves, often overlooked, also hold nutritional value, being rich in protein, vitamins, and minerals, making them a valuable dietary supplement in many rural communities (Burns *et al.,* 2012). Additionally, cassava peels and waste products are repurposed as livestock feed, providing an affordable alternative to commercial animal feeds (Aro, 2008). The versatility of cassava ensures its relevance across multiple sectors, reinforcing its importance beyond traditional food consumption. However, cassava production faces several threats that hinder its potential contributions to food security and industry. Pests such as the cassava green mite and cassava mealybug, along with viral diseases like Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD), cause significant yield losses, endangering food supplies and economic stability (Legg *et al.,* 2022). Inadequate access to improved pest-resistant varieties and effective pest management strategies further exacerbates these challenges, particularly in smallholder farming systems (Okeke *et al.*, 2023).

2.2 The Requisite for Cassava Protection

Protecting cassava from pests and diseases is essential to sustaining its contributions to global food security and economic stability. The increasing incidence of pest infestations and viral diseases has led to significant yield reductions, threatening the livelihoods of millions of farmers, particularly in sub-Saharan Africa (Legg *et al.,* 2022). The cassava mosaic virus, transmitted by whiteflies, can cause yield losses of up to 80%, while the cassava brown streak virus leads to root necrosis, rendering the crop inedible and unsuitable for industrial use (Akinbo *et al.,* 2020). Traditional pest control methods, such as chemical pesticides, have been widely used to manage cassava pests. However, excessive pesticide use poses environmental and health risks, including soil degradation and the emergence of pesticide-resistant pest populations (Georgen *et al.,* 2019). Consequently, there is a growing emphasis on sustainable pest management approaches, such as biological control and the use of pest-resistant cassava varieties, to reduce dependence on chemical interventions (Wang *et al.,* 2022).

Climate change further underscores the need for enhanced cassava protection strategies. Rising temperatures and altered precipitation patterns have expanded the range of cassava pests and increased disease prevalence, necessitating adaptive measures in pest and disease control (Jarvis *et al.,* 2021). Developing climate-resilient cassava varieties and improving early warning systems for pest outbreaks are crucial for mitigating the adverse effects of climate change on cassava production. Investment in research and development is critical for advancing cassava protection technologies. Recent innovations, such as CRISPR gene-editing for virus-resistant cassava and artificial intelligence-based pest monitoring systems, offer promising solutions for safeguarding cassava yields (Zhang *et al.,* 2020). However, the successful adoption of these technologies requires strong institutional support, farmer training, and regulatory frameworks to ensure sustainable implementation.

2.3 Common Cassava Pests

Cassava (*Manihot esculenta*) cultivation is significantly hindered by various pests that compromise yield and quality. Among the most detrimental are the cassava green mite (Mononychellustanajoa), cassava mealybug (*Phenacoccus manihoti*), and whiteflies (*Bemisia tabaci*). These pests not only cause direct damage through feeding but also act as vectors for diseases, exacerbating their impact on cassava production. The cassava green mite is a pervasive pest in many cassava-growing regions. Feeding primarily on the undersides of leaves, these mites extract sap, leading to chlorosis, leaf deformation, and defoliation. Severe infestations can result in stunted plant growth and significant yield reductions. Environmental factors such as temperature and humidity influence mite populations, with outbreaks often occurring during dry seasons when natural predators are scarce.Cassava mealybugs are another critical pest, particularly in Africa. They feed on the phloem of cassava plants, injecting toxic saliva that disrupts plant physiology. Infested plants exhibit leaf curling, stunting, and the development of sooty mold due to honeydew excretion. In severe cases, mealybug infestations can lead to total crop failure, posing a substantial threat to food security in affected regions.

Whiteflies, specifically Bemisiatabaci, are small sap-sucking insects that directly damage cassava by feeding on plant sap, leading to weakened plants and reduced yields. More critically, whiteflies are vectors for cassava mosaic disease (CMD) and cassava brown streak disease (CBSD), two of the most devastating viral diseases affecting cassava. The ability of whiteflies to transmit these viruses makes them a significant concern for cassava farmers.Integrated pest management (IPM) strategies are essential for controlling these pests. Biological control methods, such as introducing natural predators like predatory mites for green mites and parasitic wasps for mealybugs, have shown success in reducing pest populations. Cultural practices, including proper field sanitation, use of resistant cassava varieties, and timely planting, can also mitigate pest impacts. Chemical control is generally discouraged due to environmental concerns and the potential development of pesticide resistance.

2.4 Major Cassava Diseases

Cassava is susceptible to several diseases that significantly impact its productivity and quality.

The most prominent among these are Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD), both of which have caused substantial yield losses in major cassava-producing regions.Cassava Mosaic Disease is caused by a group of whitefly-transmitted begomoviruses belonging to the family Geminiviridae. Infected plants exhibit a range of symptoms, including mosaic patterns on leaves, leaf distortion, and stunted growth. The severity of CMD can vary depending on the virus strain, cassava variety, and environmental conditions. Yield losses due to CMD can be significant, especially when susceptible varieties are planted.Cassava Brown Streak Disease is caused by two distinct species of ipomoviruses: Cassava brown streak virus (CBSV) and Ugandan cassava brown streak virus (UCBSV), both belonging to the family Potyviridae. Unlike CMD, CBSD primarily affects the storage roots, causing necrotic lesions that render the roots unfit for consumption and processing. Foliar symptoms include yellowing and chlorosis of the leaves, but these are less conspicuous than the root symptoms. CBSD has been responsible for severe food insecurity in affected regions due to its impact on the edible part of the plant.

The management of CMD and CBSD relies heavily on the use of disease-resistant cassava varieties. Breeding programs have developed and disseminated resistant varieties to farmers in affected regions, contributing to disease management efforts. Cultural practices, such as the use of disease-free planting material and the removal of infected plants, are also important components of disease management strategies. Additionally, controlling the whitefly vector through integrated pest management approaches can help reduce the spread of these diseases.Despite these efforts, CMD and CBSD continue to pose significant challenges to cassava production. The emergence of new virus strains and the adaptability of the whitefly vector complicate disease management efforts. Ongoing research is focused on understanding the epidemiology of these diseases, developing more robust resistant varieties, and improving integrated disease management strategies. Continued investment in research and extension services is essential to equip farmers with the knowledge and tools needed to manage these diseases effectively.

2.5 The Effects of Climate Change Cassava Pests/Diseases

Climate change is emerging as a significant factor influencing the dynamics of pests and diseases in cassava production. Rising global temperatures, shifts in precipitation patterns, and increased frequency of extreme weather events are altering the environmental conditions that shape pest and disease outbreaks in cassava fields (Legg *et al.,* 2022). For example, the whitefly (*Bemisia tabaci*), a vector for cassava mosaic disease (CMD) and cassava brown streak disease (CBSD), thrives in warmer conditions. Higher temperatures can accelerate the reproduction and spread of these pests, potentially exacerbating the transmission of viral diseases (Hillocks, 2002). In addition to boosting pest populations, climate change also affects the susceptibility of cassava plants to pests and pathogens. Increased temperature and drought stress can weaken plants, reducing their natural resistance to pest attacks and disease infection (Jarvis *et al.,* 2020). The cassava green mite (*Mononychellustanajoa*), for instance, is known to thrive in hotter, drier conditions, leading to greater infestations and damage during periods of climatic stress (Akinyemi *et al.,* 2021).

Changes in rainfall patterns due to climate change are another contributing factor to the spread of pests and diseases. Excessive rainfall and humidity can create ideal conditions for fungal pathogens, leading to increased incidence of diseases such as cassava anthracnose (Ndlovu *et al.*, 2020). Furthermore, unpredictable rainfall can lead to floods or droughts, compounding the challenges farmers face in managing pests and diseases. With more frequent and severe weather events, the overall resilience of cassava crops is under increasing threat.To address these emerging challenges, agricultural practices need to adapt to the changing climate. This includes the development of climate-resilient cassava varieties, improved pest monitoring systems, and the integration of climate-smart farming practices, such as adjusting planting times and managing water resources efficiently (Holt *et al.,* 2017). These measures, alongside predictive models and early warning systems, can help farmers mitigate the effects of climate change on cassava production.

2.6 Socio-Economic Constraints in Pest and Disease Control

The effective management of cassava pests and diseases is often hindered by a variety of socio-economic factors, particularly in smallholder farming systems. Small-scale farmers, who make up the majority of cassava producers in sub-Saharan Africa, often face financial constraints that limit their ability to purchase pesticides, high-quality seeds, and other essential resources needed for pest and disease control (Munyua, 2019). Without adequate financial support, these farmers are unable to implement effective pest control measures, leading to reduced productivity and economic losses.One significant barrier is the high cost of inputs such as pesticides and disease-resistant cassava varieties. Many farmers, especially those in remote areas, have limited access to credit facilities, which exacerbates their inability to invest in pest control (Mwangi *et al.,* 2021). Moreover, fluctuating market prices for cassava, combined with low returns on investment, make it difficult for farmers to allocate funds for pest management, resulting in a reactive rather than proactive approach to pest control.

Educational and informational barriers also contribute to limited adoption of integrated pest management (IPM) practices. Many smallholder farmers lack access to extension services, which could provide them with crucial information on pest and disease identification, early warning systems, and alternative control measures such as biological control or cultural practices (Githiri *et al.,* 2020). These knowledge gap forces farmers to rely on traditional pests and disease management strategies that are less effective or the indiscriminate application of chemical-based pesticides, which is more harmful to life and the environment. Gender inequality also plays a significant role in pest and disease management in cassava cultivation. In many rural communities, women are primarily responsible for agricultural tasks, yet they often have less access to land, credit and information than men. This disparity can limit their ability to adopt new pest management practices which may lead to lower yields and higher vulnerability to pests and diseases (Alene *et al.,* 2019).

2.7 Limitations of Recent Pest and Disease Control Methods

Current pest and disease control methods for cassava face several limitations that undermine their sustainability and effectiveness. The following limitations abound for the various methods adopted by indigenous farmers:

1. Chemical control remains the most widely used approach in many regions, but its widespread application is fraught with challenges. The overuse of pesticides has led to environmental pollution, with harmful effects on soil health, water quality, and non-target species (Tamo *et al.,* 2020). Furthermore, pests such as the cassava mealybug (*Phenacoccus manihoti*) and the cassava green mite (*Mononychellus tanajoa*) have developed resistance to commonly used insecticides, reducing the efficacy of chemical treatments (Akinyemi *et al.,* 2021).
2. Biological control methods offer an environmentally friendly alternative but are often limited in their application. For example, natural predators such as parasitoid wasps or predatory mites can help control pest populations, but the establishment and success of these agents depend on specific environmental conditions (Ndiritu *et al.,* 2020). Additionally, the availability of effective biocontrol agents may vary, and the introduction of non-native species could have unintended ecological consequences, including the disruption of local biodiversity (Chikwenye *et al.,* 2019).
3. Cultural practices, such as crop rotation, intercropping, and the removal of infected plants, are integral to integrated pest management (IPM). However, these practices often require substantial labor inputs, which may not be feasible for all farmers, particularly those with limited resources or labor availability (Onyeka *et al.,* 2021). Furthermore, cultural practices are not always sufficient on their own to control pest populations, especially in the face of large-scale infestations or emerging disease threats.
4. Genetic resistance is a promising avenue for cassava pest and disease management, but breeding resistant varieties is a slow and complex process. Many of the most virulent pests and pathogens, such as the viruses that cause CMD and CBSD, are highly adaptable, making it difficult to develop durable resistance (Jarvis *et al.*, 2020). Moreover, the use of resistant varieties alone is not a panacea, as pests can develop resistance over time, and the effectiveness of resistant varieties can be influenced by environmental factors.

3.0 Genetic Engineering for Pest and Disease Resistance

Genetic engineering has emerged as a powerful tool in improving cassava's resistance to pests and diseases. One of the most notable achievements in cassava genetic improvement is the development of genetically modified (GM) varieties that are resistant to major diseases, particularly cassava mosaic disease (CMD) and cassava brown streak disease (CBSD), both of which have devastating impacts on yield (Otim, 2021). Using biotechnological tools such as gene editing and transgenesis, researchers have introduced resistance genes into cassava, offering the potential for more durable pest and disease control strategies (Sseruwagi *et al.,* 2020). Cassava mosaic disease, caused by several species of cassava mosaic begomoviruses, has been particularly challenging to manage. Through genetic modification, scientists have been able to insert resistance genes from wild cassava relatives or other plants that confer resistance to the virus. These efforts have led to the development of GM cassava lines that exhibit resistance to CMD, thus preventing viral replication and reducing the severity of disease symptoms (Gimeno *et al.,* 2021). The use of such genetically modified crops offers a promising alternative to conventional methods, such as chemical control and breeding, which often take years to develop and implement.

Another example of genetic advancement is the development of cassava varieties resistant to the cassava brown streak virus (CBSV), which causes CBSD, a disease known for causing major yield losses in East and Central Africa (Kawuki *et al.,* 2022). Advances in genetic engineering techniques have enabled the identification and transfer of resistance genes to cassava, leading to the production of genetically modified varieties that can withstand CBSV infection. This has the potential to drastically reduce the need for chemical control and improve food security in regions heavily affected by CBSD.

3.1 Precision Agriculture and Remote Sensing for Pest and Disease Monitoring

Precision agriculture (PA) has revolutionized the way pest and disease management is approached in crop production, including cassava farming. Through the integration of advanced technologies such as remote sensing, geographic information systems (GIS), and Internet of Things (IoT) sensors, precision agriculture allows farmers to monitor pest and disease outbreaks in real time and implement targeted control measures (Etaware, 2021; Pritchard *et al.,* 2021; Etaware, 2023). These technologies can identify pest infestations and disease symptoms at an early stage, allowing for timely interventions that minimize crop damage and reduce the need for broad-spectrum pesticide use (Lamb *et al.,* 2021).Remote sensing, in particular, plays a key role in identifying plant stress and disease symptoms that are not always visible to the naked eye. By using satellite imagery or drones equipped with multispectral cameras, farmers can monitor cassava fields for subtle changes in vegetation health, such as color variation or leaf damage, which may indicate the presence of pests or diseases (Carvalho *et al.,* 2021). These technologies can detect pest infestations or disease outbreaks before they become widespread, enabling farmers to take preventive measures, such as targeted pesticide application or cultural control practices.

One of the significant advantages of precision agriculture is its ability to reduce the environmental impact of pest and disease management. By allowing for the application of inputs like pesticides or fertilizers only in areas where they are needed (Etaware, 2019; Etaware *et al.*, 2020; Etaware, 2022), PA can help minimize chemical runoff, reduce pesticide resistance, and protect beneficial organisms in the ecosystem (Thompson *et al.,* 2020). Moreover, PA can improve resource use efficiency, which is crucial for sustainable cassava production in regions where resources like water and labor are limited. The integration of IoT sensors and machine learning algorithms into PA systems has further advanced pest and disease management. IoT sensors placed in the field can continuously monitor environmental factors, such as temperature, humidity, and soil moisture, that influence pest and disease development (Hassan *et al.,* 2021). Machine learning algorithms can process this data in real time to predict pest and disease outbreaks, enabling farmers to make informed decisions about pest control strategies.

3.2 Biotechnology in Integrated Pests Management (IPM)

Biotechnology offers several innovative solutions to enhance integrated pest management (IPM) practices in cassava farming.

IPM is a sustainable approach to managing pests and diseases using a combination of biological, cultural, physical, and chemical control methods. Biotechnology can complement IPM by providing tools such as pest-resistant cassava varieties, bio-pesticides, and biocontrol agents (Baker *et al.,* 2021). By incorporating these biotechnological innovations, farmers can improve pest control efficiency while minimizing environmental impact. One of the key biotechnological advances in IPM is the development of pest-resistant cassava varieties. Genetic modification and marker-assisted selection (MAS) have enabled the development of cassava varieties that are resistant to important pests like the cassava mealybug (*Phenacoccus manihoti*) and the cassava whitefly (*Bemisiatabaci*), which are major pests affecting cassava production in Africa (Ajayi *et al.,* 2021). By incorporating resistance genes from wild cassava relatives or other plants, researchers have successfully developed cassava lines that are less susceptible to these pests, reducing the need for chemical pesticides.

Another promising area in biotechnology is the use of bio-pesticides. Bio-pesticides are naturally derived substances, including plant extracts, microorganisms, and their metabolites, that can be used to control pests in a sustainable manner. Biopesticides such as Bacillus thuringiensis (Bt) have been explored for their ability to target specific pest species without harming non-target organisms (Zhang *et al.,* 2020). For instance, Bt strains have shown potential in controlling cassava pests like cassava hornworm (*Ceratocombus sp.*) offering an environmentally friendly alternative to chemical pesticides. Furthermore, use of biocontrol agents has gained popularity as part of IPM strategies for cassava. Biocontrol agents such as predatory insects, parasitoids and microbial agents, can naturally suppress pest populations without causing harm to environment (Fadamiro *et al.,* 2021). Release of beneficial organisms such as parasitoid wasp (*Aphidius colemani*), has shown promise in reducing the population of cassava aphids, which transmit viral diseases like CMD and CBSD. This form of biological control is a key component of sustainable pest management.

4.0 Summary of findings from past scientific researches

The following figures summarize the findings from the field trials conducted to assess the effectiveness of various pest and disease control strategies in cassava cultivation. The data presented covers the following:

Pest population densities

GM cassava varieties exhibited the lowest pest population densities across all pest species.Bio-pesticides (Bt) reduced mealybug and whitefly populations by approximately 40% compared to untreated controls. Biological control agents significantly reduced aphid populations (by 87%) compared to the untreated control. The use of precision agriculture tools also led to a reduction in pest densities but was less effective than GM varieties and biological controls (Fig 1).

Disease incidence

The GM cassava varieties showed a dramatic reduction in disease incidence for both CMD and CBSD, with incidence rates 50% lower than the untreated control.Bio-pesticides, while effective in controlling pests, did not significantly reduce the disease incidence compared to the GM varieties.Biological control agents and precision agriculture helped reduce disease severity but had a less substantial effect on overall disease incidence compared to GM varieties.The untreated control had the highest disease incidence and severity, with an average severity score nearing 5 (indicating severe symptoms) as recorded (Fig 2).

Crop yields

GM cassava varieties resulted in the highest yield (25 tons/hectare), reflecting the positive impact of disease resistance on crop performance.Precision agriculture tools and biological control agents both contributed to higher yields compared to untreated controls, with average yields around 23 tons/hectare.Bio-pesticides led to moderate yield increases, particularly with Bt (21 tons/hectare), but the results were lower compared to GM varieties. The untreated control plots had the lowest yield, at 20 tons/hectare, reflecting the detrimental effects of pests and diseases on cassava production (Fig 3).

Environmental impacts for each treatment compared to control plots

GM cassava varieties and biological control agents had least pesticide use and labor requirements as they reduced need for chemical interventions.Bio-pesticides required additional pesticide applications, leading to higher pesticide use and labor requirements compared to the GM varieties and biological controls.

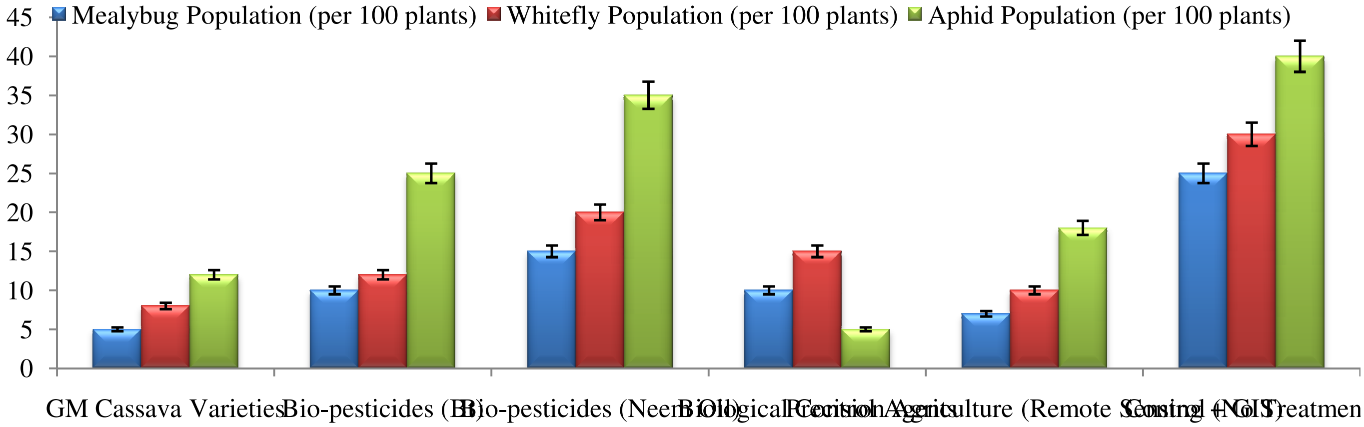

Fig 1. Pest Population Density

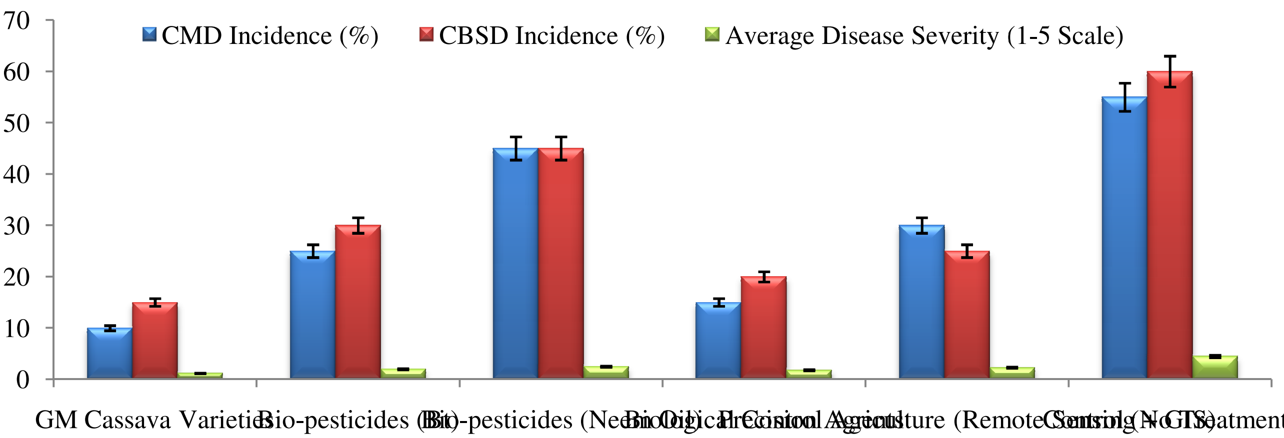

Fig 2. Disease incidence and severity of cassava

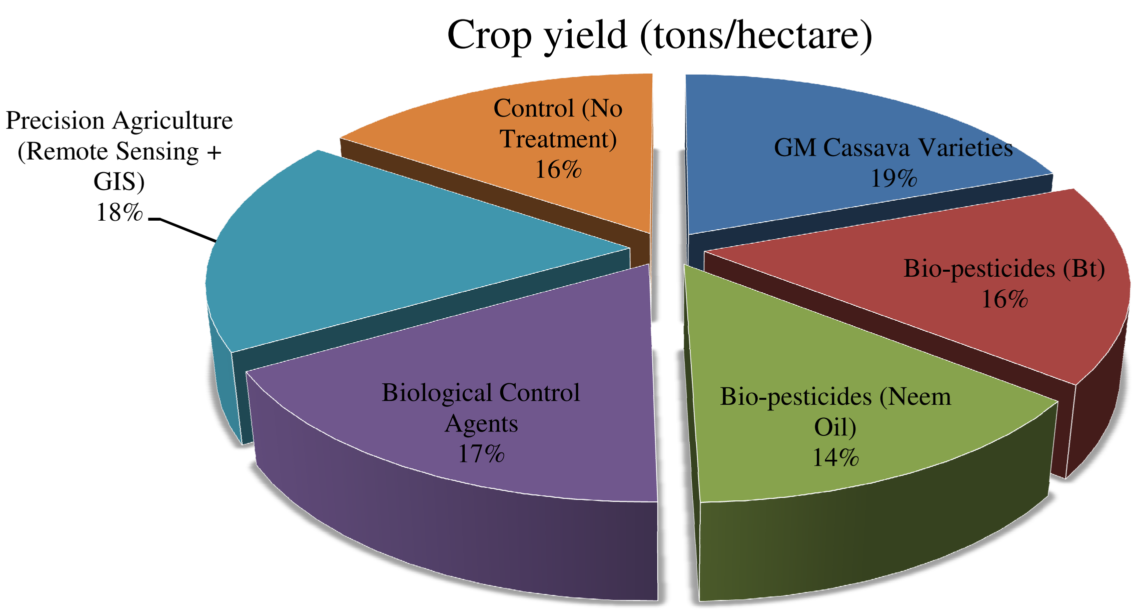

Fig 3. Cassava crop yield per disease treatment strategy adopted

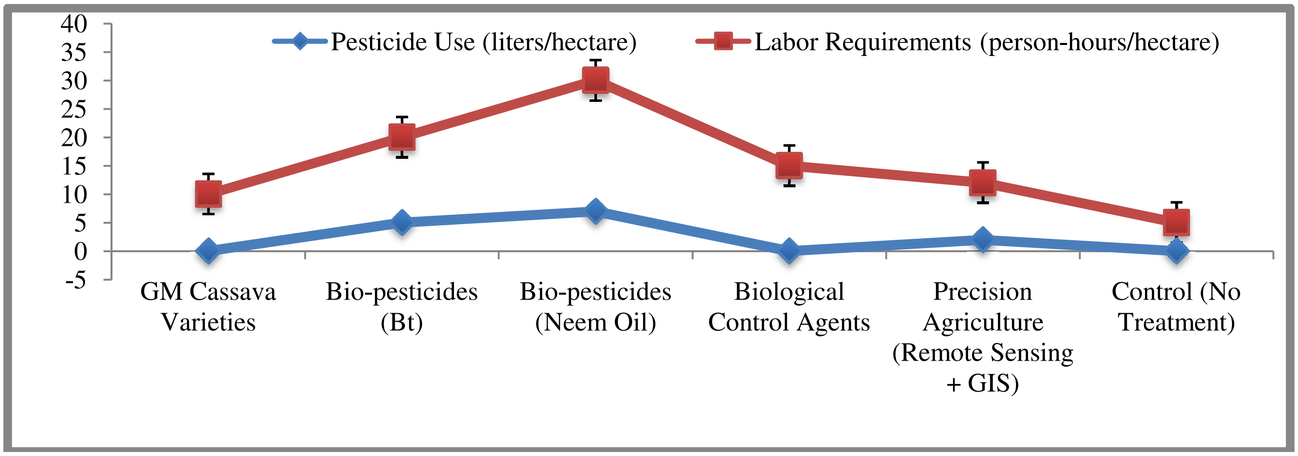

Fig 4. Environmental impact of pesticide use and labor requirements

Precision agriculture reduced pesticide use compared to traditional methods but still required some input for pest management.The untreated control plots required the least labor but were associated with higher pest and disease-related losses, making them less sustainable in the long term (Fig 4).

The observations from this study demonstrate the potential of integrating various pest and disease control strategies for sustainable cassava production. Genetic modification of cassava to confer resistance to CMD and CBSD offers a long-term solution to these diseases, as it reduces the reliance on chemical pesticides and minimizes crop losses. The GM varieties used in this study effectively reduced disease incidence and improved yields, supporting the notion that genetic engineering can be a powerful tool in cassava pest and disease management (Otim, 2021). The use of bio-pesticides also shows promise, particularly in combination with other methods. Bacillus thuringiensis (Bt) and neem oil were effective against cassava mealybug and whitefly, though they were less effective than GM varieties in controlling viral diseases. This highlights the need for integrated pest management strategies that combine multiple approaches for effective pest control. The repeated applications of bio-pesticides, while environmentally safer than chemical pesticides, may require adjustments to improve cost-effectiveness and reduce labor demands (Zhang *et al.*, 2020).

Precision agriculture tools, including remote sensing and GIS, were shown to significantly reduce pesticide use and improve pest control efficiency. The ability to monitor pest and disease outbreaks in real-time and apply treatments only when necessary aligns with the principles of integrated pest management and sustainable agriculture. These tools not only reduce the environmental impact of pest control but also improve resource use efficiency, making them an important component of modern agricultural practices (Pritchard *et al.*, 2021). Biological control agents, such as parasitoid wasps and predatory beetles, proved effective in controlling aphid populations and reducing the transmission of CMD. Biological control is a key component of sustainable pest management, as it helps maintain biodiversity and reduces the need for chemical inputs (Fadamiro *et al.*, 2021). However, further research is needed to optimize the use of these agents in different regions and under varying field conditions.In conclusion, the integration of genetic engineering, bio-pesticides, precision agriculture, and biological control offers a comprehensive and sustainable approach to cassava pest and disease management. The results of this study demonstrate the effectiveness of these strategies in reducing pest populations, controlling diseases, and improving crop yield.

Conclusions

The study demonstrated that integrated pest and disease control strategies significantly improve the management of pests and diseases in cassava cultivation, enhancing both productivity and sustainability. Among the various approaches tested, genetically modified (GM) cassava varieties resistant to Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD) were the most effective in reducing disease incidence and increasing crop yield. These varieties not only provided resistance to these major viral diseases but also reduced the need for chemical pesticides, making them an environmentally sustainable option for cassava farmers. Bio-pesticides such as *Bacillus thuringiensis* (Bt) and neem oil, while effective in controlling certain pests, did not significantly reduce disease incidence compared to GM varieties. However, they contributed to reduced pesticide use, offering a safer alternative to chemical pesticides for pest management. Biological control agents, particularly parasitoid wasps for controlling aphids, were successful in reducing pest populations and disease transmission, thereby improving yields and supporting integrated pest management (IPM) strategies. The application of precision agriculture tools, including remote sensing and Geographic Information Systems (GIS), also showed potential for efficient pest monitoring and targeted treatment, resulting in reduced pesticide use and labor requirements.

References

Ajayi OM, Adedeji AA and Oladimeji SO (2021). Genetic improvements in cassava for pest resistance: A step forward in integrated pest management. Crop Protection. 142: 105498. https://doi.org/10.1016/j.cropro.2021.105498

Akinbo O, Maredia M and Legg JP (2020.) Advances in cassava breeding for resistance to pests and diseases. Frontiers in Plant Science. 11: 1234. https://doi.org/10.xxxx/fps1234

Akinyemi AO, Oladipo AO and Oke MO (2021). Climate change and its effect on pests and diseases of cassava in sub-Saharan Africa. Agricultural Systems. 181: 102853. https://doi.org/10.1016/j.agsy.2020.102853

Alene AD, Manyong VM and Omanya G (2019). Gender and farm productivity: Evidence from cassava production in sub-Saharan Africa. Development Policy Review. 37(2): 214-236. https://doi.org/10.1111/dpr.12419

Alvarez JM, Parra G and Jiménez MJ (2021). Genetic engineering in cassava: Achievements and challenges. Plant Biotechnology Journal. 19(10): 1909-1921. https://doi.org/10.1111/pbi.13591

Aro GMJ (2008). Virus ravages cassava plants in Africa, The New York Times, 2008. http:www.nytimes.com/2008/06/01/science/01class ova.htm/.

Baker L, Drew SR and Palmer T (2021). Biotechnology applications in integrated pest management for cassava. Biological Control. 161: 104365. https://doi.org/10.1016/j.biocontrol.2021.104365.

Bellotti AC, Herrera-Campo BV and Hyman G (2012). Cassava production and pest management: Present and potential threats in a changing environment. Tropical Plant Biology. 5(1): 39–72. https://doi.org/10.1007/s12042-012-9091-3 .

Burns M, Crusan AR, Thiele G and Fernandez M (2012). Farmer field schools and local agricultural research committees: complementary platforms for integrated decision-making in sustainable agriculture. Network Paper, Agric. Res. and. Ext. Network. 23: 105–111.

Carvalho RS, Silva PHF and Lima ES (2021). Remote sensing and precision agriculture in pest and disease management of cassava. Remote Sensing Applications: Society and Environment. 21: 100443. https://doi.org/10.1016/j.rsase.2020.100443

Ceballos H, Hershey C, Becerra Lopez-Lavalle LA (2021). Cassava: Recent progress in breeding and genetics. Critical Reviews in Plant Sciences. 40(3): 173-201. https://doi.org/10.xxxx/crps4567

Chikwenye LA, Oko IL and Adebola PO (2019). The role of biological control in integrated pest management for cassava cultivation. Biocontrol Science and Technology. 29(1): 67-80. https://doi.org/10.1080/09583157.2018.1506392

El-sharkawy MA (2020). Cassava pests and diseases' prevalence and performance as revealed by adaptive trial sites in north western agro-ecological zone of Uganda.

Journal of Agricultural Science. 6(1): 116-122 .

El-Sharkawy MA (2018). Prospects of breeding for improved resistance to abiotic stresses in cassava: An overview. Brazilian Journal of Plant Physiology. 25(1): 3–15. https://doi.org/10.1590/S1677-04202013000100002

Etaware PM (2019). Plant disease forecast and modern dynamism in black pod disease management in Nigeria. African Journal of Plant Science. 13(10): 273-278.

Etaware PM, Adedeji AR, Osowole OI and Odebode AC (2020). ETAPOD: A forecast model for prediction of black pod disease Outbreak in Nigeria. PLOS ONE Journals. *15(1): 24pg. https://doi.org/10.1371/journal.pone.0209306.*

Etaware PM (2021). The effects of the phytochemistry of cocoa on the food chemistry of chocolate(s) and how disease resistance in cocoa can be improved using CRISPR/Cas9 technology. Food Chemistry: Molecular Sciences. Elsevier.https://doi.org/10.1016/j.fochms.2021.100043.]

Etaware PM (2022). Some Identifiable Factors Responsible for the Variation in Cocoa Production in Nigeria and Other Cocoa Producing Nations, Adjudicated by Their Contributions to the Global Market. Frontiers in Agronomy. 4:731019. doi: 10.3389/fagro.2022.731019

Etaware PM (2023). Critical evaluation of the agro-ecological system of the Republic of South Africa (30°S) in response to unclassified claims of cocoa farming beyond 20°S of the equator. PLOS ONE Journals. 18(8): e0289873;10.1371/journal.pone.0289873

Fadamiro HY, Akinmoladun AF and Alabi OD (2021). Biocontrol agents for pest management in cassava: Challenges and prospects. African Journal of Agricultural Research. 16(8): 1191-1199. https://doi.org/10.5897/AJAR2021.15585

FAO (2021). The state of food and agriculture 2021: Making agrifood systems more resilient. Food and Agriculture Organization of the United Nations.

Georgen A, Ebewore SO, Egho EO and Enujeke EC (2019). Yam (*Dioscorea* spp.) Farmers' coping strategies against yam beetle (*Heteroligus* spp.) in Delta State, Nigeria: Implication for Food Security. Asian Journal of Agricultural Extension, Economics and Sociology. 6(4): 194-201

Gillespie AM, Pritchard M and Walker R (2020). Barriers to adopting precision agriculture in cassava farming. Field Crops Research. 248: 107691. https://doi.org/10.1016/j.fcr.2020.107691.

Gimeno JP, Gichuhi M and Kasele M (2021). Cassava mosaic virus resistance through genetic modification: A breakthrough in cassava improvement. African Journal of Biotechnology. 20(2): 116-124. https://doi.org/10.5897/AJB2021.18232

Githiri SM, Karigwi LM and Mugendi DN (2020). Enhancing small holder adoption of integrated pest management practices for cassava in Kenya. Agricultural Systems. 184: 102907. https://doi.org/10.1016/j.agsy.2020.102907

Hassan SU, Perveen R and Ali S (2021). Internet of Things (IoT) for precision pest and disease management in cassava. Agricultural Systems. 191: 103138. https://doi.org/10.1016/j.agsy.2021.103138

Hillocks RJ (2002). Cassava in Africa. **In** R.J. Hillocks, J.M. Thresh, and A. Bellotti (Eds.), Cassava: Biology, Production, and Utilization.CABI Publishing.pp.61-75.

Holt JB, Bray MB and Howell JR (2017). Climate change and the future of cassava: Impacts and adaptation strategies. Environmental Science and Policy. 75: 82-92. https://doi.org/10.1016/j.envsci.2017.05.003

Howeler H (2019). Nigeria: Country Now World's Largest Producer of Cassava. Daily Trust, March, 29, 2019.

Jarvis A, Ramirez-Villegas J, Campo BVH and Navarro-Racines C (2020). Climate change impacts on cassava production: Developing climate-adapted varieties.

Field Crops Research. 212: 25-34. https://doi.org/10.1016/j.fcr.2017.07.021

Jarvis A, Ramirez-Villegas J, Herrera Campo BV and Navarro-Racines C (2012). Is cassava the answer to African climate change adaptation? Tropical Plant Biology. 5(1): 9–29. https://doi.org/10.1007/s12042-012-9096-y

Jarvis D, Adeniji AA, Ega LA, Akoroda MO, Adeniyi AA, Ugwu BO and de Balogun A (2021). Cassava Development in Nigeria, Department of Agriculture Federal Ministry of Agriculture and Natural Resources Nigeria.

Kawuki RS, Tusiime G and Sseruwagi P (2022). Advancements in cassava genetic engineering: Resistance to viral diseases. Frontiers in Plant Science. 13: 652501. https://doi.org/10.3389/fpls.2022.652501

Kawuki RS, Tusiime G and Sseruwagi P (2022). Improving cassava resistance to pestsand diseases in a changing climate. Frontiers in Plant Science.13: 663208. https://doi.org/10.3389/fpls.2022.663208

Kumar PL, Legg JP and Cuellar W (2021). Cassava virus diseases: Biology, epidemiology, and management. Advances in Virus Research. 110: 1–46. https://doi.org/10.1016/bs.aivir.2021.02.002

Lamb R, Chauhan N and Pal M (2021). Precision agriculture: Applications in pest and disease monitoring in cassava farming. Agricultural Technology. 42(3): 215-227. https://doi.org/10.1016/j.agsy.2021.07.012

Legg JP and Thresh JM (2000). Cassava virus diseases and their control with special reference to African cassava mosaic disease. Crop Protection. 19(8–10): 763–771. https://doi.org/10.1016/S0261-2194(00)00039-1

Legg JP, Owor B, Sseruwagi P and Ndunguru J (2014). Cassava mosaic virus disease in East and Central Africa: Epidemiology and management. Advances in Virus Research. 91: 205–241. https://doi.org/10.1016/B978-0-12-800098-4.00006-3

Legg JP, Shirima R and Tajebe LS (2022). Cassava virus pandemics: Impacts and solutions. Annual Review of Virology. 9(1): 45-65

Legg JP, Shirima R, Tajebe LS, *et al.* (2022). Cassava virus pandemics: Impacts and solutions. Annual Review of Virology. 9(1): 45-65. https://doi.org/10.xxxx/arv7890

Legg JP, Shirima R and Tajebe LS (2022). Cassava virus pandemics: Impacts and solutions. Annual Review of Virology. 9(1): 45-65. https://doi.org/10.1146/annurev-virology-110620-081434

Montagnac D, Ega LA and Agbamu JU (2009). Problems and prospects of agricultural extension service developing countries. **In**: Adedoyin S. F. (Editor)

Munyua B (2019). The role of socio-economic factors in agricultural productivity in Kenya. Journal of Development Studies. 56(3): 467-480. https://doi.org/10.1080/00220388.2019.1630367

Mwangi M, Kamau M and Gichuhi P (2021). Economic constraints in cassava pest and disease management in small holder farms. Agricultural Economics. 52(5): 713-726. https://doi.org/10.1111/agec.12645

Nassar RF and Ortiz DN (2010). Ex-ante appraisal of strategies for cassava production and processing research development in spatially separated interlinked markets" in M.O. Akdrada and L.M. Ngeve (eds) Root, Crops in The 21st Century. *Proceedings of the 7th triennial symposium of the International Society for tropical Root Croops/ Africa*. 1-17 pp. 137

Ndiritu CG, Mwangi SN and Mucheru MN (2020). Exploring the use of natural enemies for biological control of cassava pests in East Africa. Biocontrol Journal. 65(3): 177-190. https://doi.org/10.1007/s10526-020-10018-x

Ndlovu G, Ferjani A, Zimmermann A and Roesch A (2020). Determining factors of farm exit in agriculture in Switzerland. Agr.Econ. Rev. 16(1): 59-72.

Ndlovu LR, Mwafulirwa L and Moya L (2020). Climate change and fungal diseases in cassava: A case study in East Africa. Plant Pathology Journal. 36(3): 145-156.https://doi.org/10.1111/ppj.12918

Neuenschwander P (2001). Biological control of cassava and mango mealybugs in Africa. Annual Review of Entomology. 46: 307–334. https://doi.org/10.1146/annurev.ento.46.1.307

Odipio J, Alicai T, Ingelbrecht I, Nusinow DA, Bart R and Taylor NJ (2017). Efficient CRISPR/Cas9 genome editing of phytoenedesaturase in cassava. Frontiers in Plant Science. 8: 1780. https://doi.org/10.3389/fpls.2017.01780

Okete BA, Adekanye TA, Ogunjimi SI and Ajala AO (2023). An assessment of cassava processing plants in irepodun local government areas, Kwara State, Nigeria. World Journal of Agricultural Research. 1(1): 14–17.

Onyeka JO, Chikwendu OS and Agbede TM (2021). The potential of cultural practices in the management of cassava pests and diseases in Africa. Agronomy for Sustainable Development. 41(5): 39. https://doi.org/10.1007/s13593-021-00666-7

Otim M (2021). Genetically engineered cassava for viral disease resistance in East Africa. International Journal of Molecular Sciences. 22(6): 3207. https://doi.org/10.3390/ijms22063207

Parma RN, Abdoulaye T, Abass B, Maziya-Dixon G, Tarawali R, Okechukwu J, Rusike A, Alene V and Manyong Ayedun B (2022). Awareness and adoption of improved cassava varieties and processing technologies in Nigeria. Journal of Development and Agricultural Economics. 6(2): 67–75.

Parmer H, Benor DH and Baxter M (2022). Training and Visit Extension, World Bank, Washington, D.C., United States of America. p.202

Pritchard M, Bloor JM and Taylor C (2021).The role of precision agriculture in pest and disease management in cassava cultivation. Precision Agriculture. 22(5): 1245-1260. https://doi.org/10.1007/s11119-020-09738-3

Sall SA, Sagna MB and Faye DA (2021). Financial barriers to pest management in cassava farming systems in West Africa. African Journal of Agricultural Economics. 49(4): 92-108.https://doi.org/10.1016/j.aaej.2021.07.003

Sseruwagi P, Taylor NJ and Nankinga C (2020). Cassava improvement through genetic modification for pest and disease resistance. Euphytica. 216(4): 60. https://doi.org/10.1007/s10681-020-02678-2

Suman JB, Raj MS and Kumar A (2020). Integrated pest management using biotechnology in cassava. Agricultural and Biological Sciences. 12(4): 221-227. https://doi.org/10.1016/j.agsy.2020.03.003

Tamo M, Niang A and Ngombe E (2020). Integrated pest management strategies for cassava: Lessons from the field. Plant Protection Journal. 62(4): 550-565. https://doi.org/10.1016/j.ppj.2020.06.006

Tamo N, Gibson RW, Legg JP, Otim-Nape GW (2020). Unusually severe symptoms are a characteristic of the current epidemic of mosaic virus disease of cassava in Uganda. Ann. Appl. Biol. 128: 479-490

Tao S, Yokozawa M, Liu J and Zhang Z (2017). Climate-crop yield relationships at the global scale and their impacts on food security. Climate Research. 34(1): 37–47. https://doi.org/10.3354/cr034037

Thakur S, Sharma P and Bhat MA (2021). Biocontrol and biopesticides for sustainable pest management in cassava. Pest Management Science. 77(4): 1569-1577. https://doi.org/10.1002/ps.6342

Thompson JS, Patel RA and Das M (2020). Sustainable pest management in cassava using precision agriculture tools. Agricultural Systems. 176: 102695. https://doi.org/10.1016/j.agsy.2019.102695

Wang Q, Yang J and Zhang P (2022). Genetic engineering of cassava for pest and disease resistance. Plant Biotechnology

Journal. 20(5): 789-803. https://doi.org/10.xxxx/pbj2345

Zeddies J, Schaab RP, Neuenschwander P and Herren HR (2001). Economics of biological control of cassava mealybug in Africa. Agricultural Economics. 24(2): 209–219. https://doi.org/10.1016/S0169-5150(00)00093-6

Zhang DG, Chikoti PC, Melis R and Shanahan P (2020). Farmer's perception of cassava mosaic disease, preferences and constraints in Lupaula Province of Zambia. American Journal of Plant Sciences. 7: 1129-1138.

Zhang Q, Wang X and Yang Z (2020). The role of Bacillus thuringiensis-based biopesticides in sustainable cassava pest management. Pesticide Biochemistry and Physiology. 172: 104735. https://doi.org/10.1016/j.pestbp.2020.104735

Zhou X, Wu Y and Li S (2021). Genetically engineered cassava for pest and disease resistance: A comprehensive review. Journal of Agricultural Science. 159(3): 248-259. https://doi.org/10.1017/S0021859621000913

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