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Research progress on climate change adaptation strategies to control invasive crop pest in sub-Saharan Africa: a bibliometric and systematic review

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This bibliometric and systematic review assesses research progress and climate change adaptation strategies to control invasive crop pests in sub-Saharan Africa. Scientific publications on crop pest management in sub-Saharan Africa in a context of climate change adaptation were extracted from papers published between 1991 and 2024. A literature search was conducted on Scopus, dimension, and google scholar, followed by screening and data extraction in compliance with ROSES standards. Findings indicated that pests such as armyworms, fruit flies and coffee berry borer cause huge losses. Communities are adopting integrated pest management, water harvesting, drip irrigation, resistant varieties, and improving production efficiency. Agro-ecological practices reduce pest invasions while preserving the environment. Meanwhile, chemical insecticide use remains an emergency solution as its effects on pest control would be more efficient. However, promising approaches emerge around biocontrol, agroforestry integrating pest management, and gender-tailored strategies. Nevertheless, regional disparities persist in scientific output. In conclusion, while invasive pests represent a major plant health crisis in sub-Saharan Africa, this review highlights innovative adaptation strategies. Their development will require coordinated mobilization to catalyze the sustainable agro-ecological transition that sub-Saharan Africa needs to address these multidimensional challenges. Future research should assess farmer's perception on the effectiveness of the existing pest management practices for invasive crop pests.

KEYWORDS

agro-ecological practices, agroforestry, crop pest, biocontrol, gender approaches

1 Introduction

The agricultural sector in sub-Saharan Africa is the cornerstone of economic development for 1.094 billion people as of 2020, with a strong dependance of around 80% of the rural population (World Population Prospects, 2019; Assèdé et al., 2023). This agricultural sector employs more than 50% of the total labor force of the region, which accounts for 15.3% of the GDP (World Bank, 2020). Sub-Saharan Africa's agricultural sector is fundamental not only as an economic driver but also as a foundation of rural livelihoods and cultural practices. Cash crops in Mozambique, Malawi and Tanzania, include flue-cured tobacco, ground-nuts, maize and cotton (Timberlake and Chidumayo, 2011), while in most of the Western countries, land clearing for cotton fields is widespread (CENAGREF, 2016) and the non-timber forest products make up 39% of the annual income (Vodouhê et al., 2009, 2011). However, pervasive poverty, limited access to agricultural inputs, and infrastructural challenges create vulnerabilities that amplify the impact of invasive crop pests. The rural poverty rate remains high across much of sub-Saharan Africa, with over 40% of the population in extreme poverty, which affects the ability of households to adopt resilient agricultural practices or absorb economic shocks from crop losses. Furthermore, agricultural productivity in the region is also challenged by low mechanization levels, with much of the labor force still relying on manual labor and traditional farming methods. Climate change exacerbates these challenges, as frequent droughts, floods, and unpredictable weather patterns disrupt planting and harvesting cycles, making farming even more precarious.

Invasive crop pests (ICP) are among the most important challenges in the agricultural sector and seriously threaten agricultural yields and people's livelihoods (Mango et al., 2018; Shah et al., 2023). These ICP are responsible for more than USD 65.5 billion of agricultural losses in Africa annually (Eschen et al., 2021). In addition, climate change and changes in agricultural practices have created an environment conducive to the emergence of new pests and the expansion of existing ones (Chakraborty and Newton, 2011; Tonnang et al., 2017). Given this worrying situation, integrated crop pest management (ICPM) is emerging as a sustainable and comprehensive approach to controlling pests, while minimizing the risks to human health and the environment for a resilient agricultural production (Mengistu et al., 2015). While ICPM intends to reduce impacts of pests on crop yield, its effective implementation remains a major challenge in many parts of sub-Saharan Africa. Several constraints contribute to this situation, including insufficient financial resources, inadequate infrastructures, shortage of qualified personnel, and lack of awareness (Sekabira et al., 2022).

Among the crop pests of greatest concern in sub-Saharan Africa are the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuoidae) (Figures 1A–D), the cotton aphid, *Aphis gossypii* Glower (Hemiptera: Aphididae) (Figure 1E) and the fruit fly *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) (Figures 1F–H) (Goergen et al., 2016; Tambo et al., 2020a). Armyworms are for instance responsible for up to 58% of maize losses in the region (Kansiime et al., 2023). These pests, which are often accidentally introduced into new regions, cause considerable damage to crops (Figures 1B–D), leading to substantial yield losses and thus compromising food security and farmers' incomes (Day et al., 2017; Shah et al., 2024). Their rapid proliferation and ability to adapt to different environments make them particularly difficult to manage, requiring intervention strategies tailored to local contexts. Meanwhile, aphids are responsible for more than 35% of yield losses in Africa (Annan et al., 2000).

Climate change is exacerbating the challenges associated with crop pests, necessitating the adoption of effective and sustainable adaptation strategies (Rodenburg et al., 2019; Shah et al., 2024). These strategies must include local specificities, traditional knowledge and the integration of the gender dimension. Gender disparities add another layer of complexity. Women play a crucial role in agriculture in sub-Saharan Africa but face specific obstacles in accessing resources, information and decision-making processes (Perelli et al., 2024). About 30% of the land in sub-Saharan Africa is owned by women (Wamboye, 2024). Cultural norms and policies that restrict women's access to resources reduce their capacity to adapt to challenges like pest invasions effectively. Including women's perspectives and needs in the development and implementation of pest management strategies is essential to ensure their effectiveness and sustainability.

Under these complex challenges, this bibliometric and systematic review aims to assess research progress and climate adaptation strategies for the management of invasive crop pests in sub-Saharan Africa. It specifically intends to: (i) Trace research development on invasive crop pests, and their impact; (ii) Identify the main impacts of invasive crop pests in the context of climate change; (iii) Assess adaptation strategies among communities impacted by invasive crop pests; (iv) Isolate gender-based adaptation approaches for invasive crop pest management; (v) Assess the effectiveness of the identified adaptation strategies for crop pest management and; (vi) Provide insights into research perspectives.

2 Materials and methods

2.1 Literature search

The bibliometric search was conducted on the Scopus database in May 2024 to identify relevant publications on crop management in sub-Saharan Africa in the context of climate change and adaptation. Scopus is a vast reference database, comprising nearly 70 million high-level scientific publications from around the world (Djalante, 2018). It includes a wide range of high-impact international academic journals (Caviggioli and Ughetto, 2019), lists the leading high-impact international academic journals (Leydesdorff et al., 2010) and contains almost all Web of Science Core Collection articles (Visser et al., 2021). Scopus is recognized as a reliable source for accessing bibliometric information, citations (Martín-Martín et al., 2018; Wraith et al., 2020) and key article metadata, such as keywords, authors, affiliations, year of publication and journal (Noyons, 2001).

The search strategy consisted of combining the key terms "crop management," "climate change" and "adaptation" in the title, abstract and keywords fields, without restricting the publication period. The results were then refined to include only scientific articles written in English or French and relating specifically to sub-Saharan African countries. Terms were linked using the Boolean operators OR and AND (Garcia-Yi et al., 2014; Petrokofsky et al., 2015) to broaden or narrow the search. In total, 263 documents (183 and 40 documents recorded in Scopus and dimension, respectively) were retrieved,

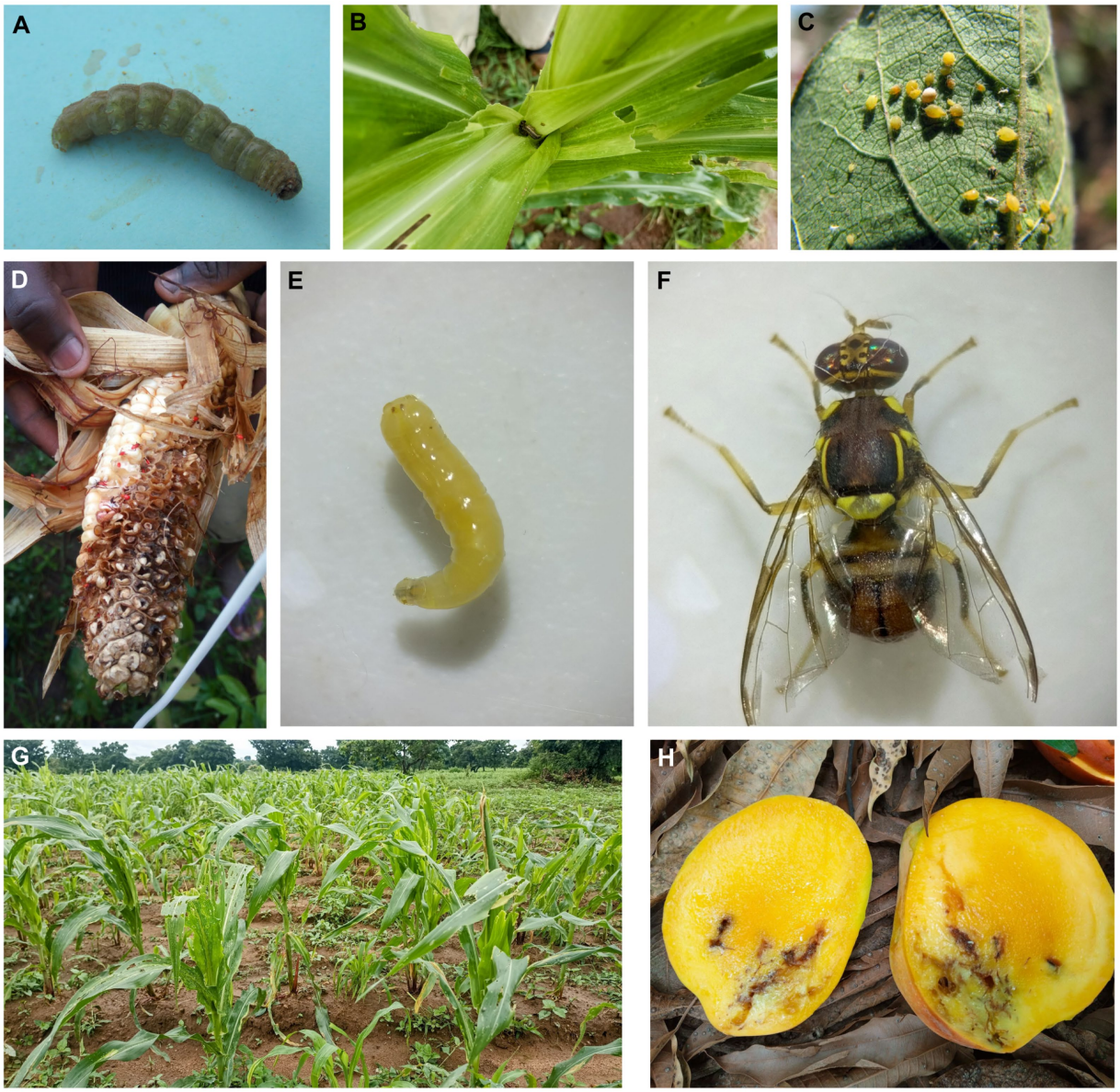

FIGURE 1
Three crop pests of greatest concern in sub-Saharan Africa: **(A)** *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuoidae) larva; **(B, C)**: damages caused by *S. frugiperda* larva on maize plants, and **(D)** on maize corn in Benin, West Africa (@SANNI WOROGO and Zadji); **(E)** *Aphis gossypii* Glower (Hemiptera: Aphididae) on cotton leaf in Benin, West Arica (@ASSOU and YOKOSSI); **(F)** *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) adult female; **(G)** *Bactrocera dorsalis* larva, and **(H)** damages caused by larvae of *B. dorsalis* on mango fruit (@ LDLI Lab).

covering the period from 1991 to 2024. Thirty seven of them were review papers, while the remaining documents were research papers. Bibliographic data were exported for screening and analysis.

2.2 Screening

Documents exported from databases were imported into the CADIMA platform,[1] designed to facilitate the systematic review process in accordance with RepOrting standards for Systematic Evidence Syntheses (ROSES) (Kohl et al., 2018).

The predefined inclusion criteria were applied to identify relevant studies. These criteria required that studies are conducted in sub-Saharan Africa and focus on integrated pest management and climate change adaptation. The documents that did not meet these criteria were excluded. The first inclusion/exclusion phase assessed the papers eligibility based on titles and abstracts (Petrokofsky et al., 2015; Latterini et al., 2023), resulting in the selection of 103 eligible papers.

The second step involved a full-text review of the articles, after which 39 documents were deemed relevant and selected for data extraction. To ensure a comprehensive coverage, an additional

1 www.cadima.info

manual search was carried out on Google Scholar. Additional 42 documents meeting the eligibility criteria were added to the final set of documents to be included in the study for a total of 81 documents (Figure 2).

2.3 Data extraction and analysis

The data exported from the Scopus database were subjected to a bibliometric analysis using the R software. Bibliometric analysis is a rigorous and objective approach to analyzing the literature, allowing the identification, evaluation, and interpretation of studies (Derviş, 2019). Thus, the analysis of publication trends and countries or regions contribution in the studied field was carried out using the bibliometrix R-Tool via the biblioshiny interface (Aria and Cuccurullo, 2017), a recent R package that facilitates a more comprehensive bibliometric analysis by employing specific tools for quantitative bibliometric and scientometric research. A descriptive bibliometric analysis was conducted, involving the examination of publications and citations over time, the evaluation of the quality of publications, and the impact of authors on the studied subject. The collaboration network analyses between authors and between countries, as described by Galvagno (2022) was developed. Using biblioshiny, a thematic analysis was conducted to highlight the major thematic groups and their evolution

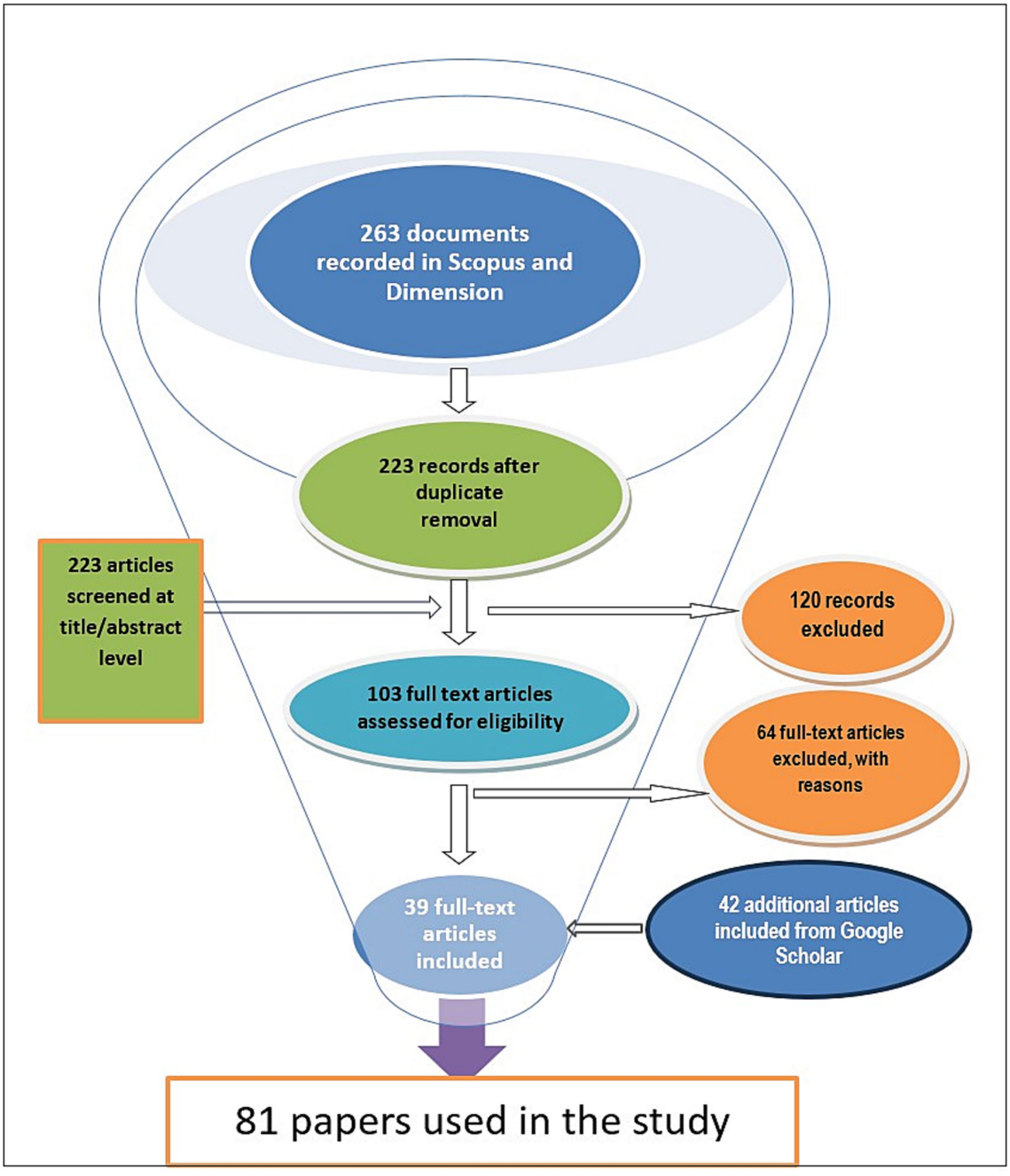

FIGURE 2
Flow diagram for inclusion criteria compliant with ROSES standards for the systematic review.

over time on crop pest management. The importance of the thematic was evaluated using Callon's centrality index, while their degree of development was assessed by Callon's density (Callon et al., 1991). These two indicators were used to construct the strategic diagram to appreciate the temporal performance of the identified thematic.

To identify the main impacts of invasive crop pests, assess strategies developed and their effectiveness, the qualitative data were extracted according to the extraction columns defined in Table 1. The extraction columns include the objectives of the study, the main crops concerned, the problems addressed, the extent of the damage, the most important pests, the adaptation strategies developed, their effectiveness and the implications for a sustainable agricultural system (Table 1).

3 Results

3.1 Progress in scientific publications on ICP and climate change adaptation in sub-Saharan Africa

The results of the analysis of trends in studies on the ICP and their management in sub-Saharan Africa between 1991 and 2023 (Figure 3) reveal a complex dynamic, characterized by two distinct periods. The 1991–2008, is characterized by a moderate academic output, suggesting limited interest in crop pest management. However, this initial phase can also be seen as a period of early discovery, where the scientific community timidly explored this specific area with a quiet high publication citation in 2000 (around 7 in average per year) and 2002 (around 5 in average per year).

The second period, from 2008 to 2023, demonstrates a progressive development of research interest on crop pests management in sub-Saharan Africa. This period is marked by a significant increase in the influence of articles on the subject, highlighting a growing interest over the years. The slow but steady evolution of research suggests a positive shift in the perception and importance attributed to crop pest management.

3.2 Most influential authors and specific contributions from African countries and institutions on ICP

3.2.1 Influential author

Table 2 highlights researchers who have made a significant impact on crop pest management. The h and g indices, as well as the total citations (TC), provide indications of the impact and scope of each author's work. The author YAN G stands out as the most visible with the highest total citation, reflecting a notable influence in the field. Similarly, researchers such as DOUMBIA S, GITHEKO AK, and KWEKA EJ display recorded important citation indicating substantial influence.

3.2.2 Countries contribution

At the international level, the America emerges as the leader with 47 articles, followed by South Africa and Kenya with 20 and 17 articles, respectively. However, the distribution of articles by Single Country Publication (SCP) and Multiple Country Publication (MCP) reveals significant disparities in the level of international collaboration (Figure 4). Meanwhile some countries, such as Nigeria and India, show no MCP, suggesting their limited involvement in the global research on crop pest management and emphasize the local nature of their collaboration on the subject. These results underline the importance of cooperation between nations in scientific production and highlight the gaps between developing and developed countries

TABLE 1 Variables and description of data extraction columns.

No	Variables of extraction column	Descriptions information in extraction column
1	Aim_of_the_study	The main objectives of the study
2	Main_crop_of_interest	List of the types of crop under discussion in the paper
3	Main_problem_addressed_by_the_paper	What is the main problem stated in the paper
4	Extent_of_the_problem_stated_damages	What was the extent of the problem caused by the pest invasion and extent of damage
5	The_most_important_crop_pests_discussed	Data to be analyzed in order to determine the three most common crop pests whatever the crop in Sub-Saharan Africa
6	Adaptation_strategies_impact	What was the Adaptation strategies developed by local population to mitigate impact of crop pests whatever the crop and the region of Sub-Saharan Africa
7	Efficiency_of_the_strategies_developed	The Efficiency of the strategies developed by local population and also scientists to mitigate crop pest impact in Sub-Saharan Africa
8	Implications_for_sustainable_agricultural_system	Some good ideas in the literature as a base line to write, "the Implications of the efficiency of the strategies developed to mitigate crop pest impact for sustainable agricultural system"
9	Motivation_factors_for_the_use_of_the_adaptation	What motivated the use of the adaptation technique
10	Mitigation_strategies_used_by_the_local_community	Analysis of the mitigation technologies applied by the local communities in the affected areas
11	Measurable_performance_impact_due_to_intervention	What was the measure of change or improvement as a result of the intervention or adaptation used
12	methodology_used_in_the_intervention	Describe the methodology used in the intervention laid
13	Kay_limitataion_and_challenge_encountered	Key limitations and challenges experienced in the study
14	Economic_implications_of_the_adaptation_program	Document the cost and economic implications of the intervention used

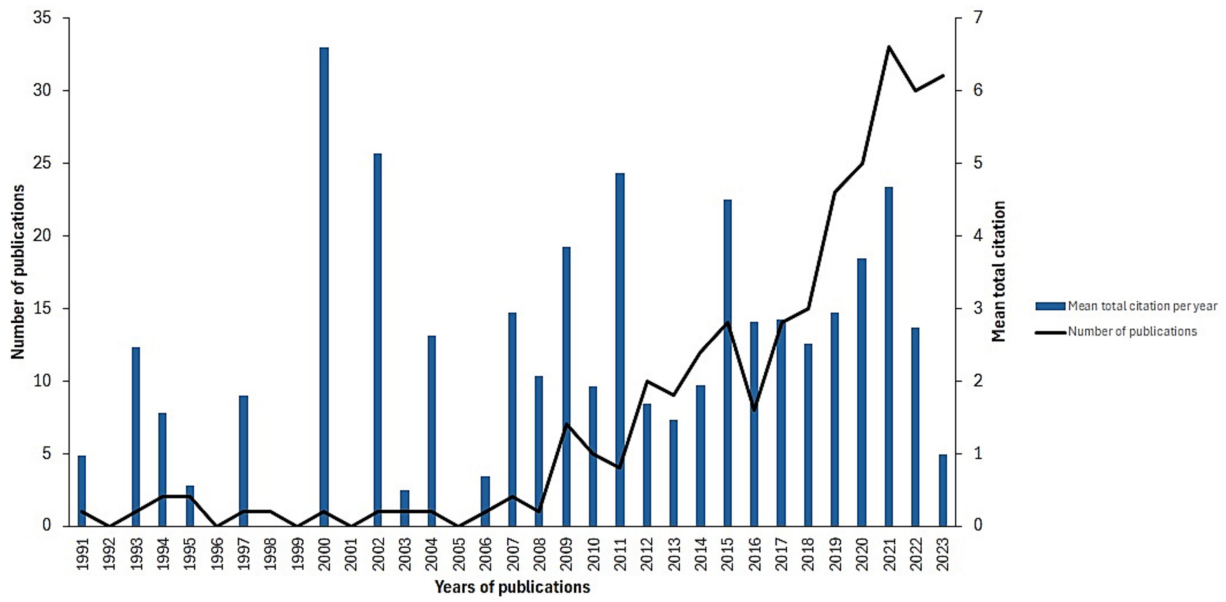

FIGURE 3
Publication trend on crop pest management in sub-Saharan Africa between 1991 and 2023.

TABLE 2 H_index, G_index, total number of citations and number of publications of the first 10 authors.

Authors	H_ index	G_ index	Total citations	NP (Fr)
Yan G	6	7	113	7 (2.66%)
Doumbia S	4	4	56	4 (1.52%)
Githeko AK	4	4	161	4 (1.52%)
Kweka EJ	4	4	73	4 (1.52%)
Animut A	3	3	39	3 (1.14%)
Aryal JP	3	3	88	3 (1.14%)
Bennett A	3	3	50	3 (1.14%)
Eisele TP	3	3	50	3 (1.14%)
Ferguson HM	3	3	60	3 (1.14%)
Koudou BG	3	3	95	3 (1.14%)

in terms of participation in global research on crop pest management. Although the focus is on the sub-Saharan African agriculture system, researchers with greater interest or access to better financial resources are often located outside the African continent.

3.2.3 African country production

The Figure 5 presents an overview of scientific production in sub-Saharan African countries, measured with the number of articles published on crop pest management. The distribution of articles is not uniform among countries with some countries, such as Namibia and Botswana, showing relatively low number of publications. This disparity may reflect differences in research and funding capabilities among countries. Research interest in a specific area is often driven by local needs, suggesting that agricultural systems in those countries may face relatively limited crop pest issues. Kenya stands out as the lead with 112 items, followed closely by South Africa and Tanzania. This high scientific production can be attributed to factors such as investment in research, academic infrastructure and policies supporting science.

Clearly, Kenya and Tanzania play a leading role in research on pest crop management. Their sustained publication activity suggests significant engagement in the development of agricultural pest management strategies. It would be interesting to explore the types of research being conducted, particularly regarding biological control methods, alternatives to chemical pesticides, and integrated pest management approaches.

In Kenya, studies focused on coffee berry borer distribution, factors affecting this distribution and impact on coffee production and local economy (Mosomtai et al., 2021). Like many coffee producer countries, Kenya is also facing coffee leaf rust and has conducted studies to understand and manage coffee-diseases. This includes cultural control, the use of fungicide spray, the development and implementation of biological control agents and breeding for resistant coffee varieties (Gichuru et al., 2021) with sometimes limited results. In Tanzania, main studies focused on Antestia bug distribution and showed that the severity of the impact increases with the shade and elevation (Zani and Rwegasira, 2023). These researches have the potential to have a significant impact on the food and economic security of the region, by improving agricultural productivity and reducing losses caused by pests, which could benefit the local population and strengthen the economy of the countries concerned. However, the development and transfer of crop pest management technologies must be carried out in close collaboration with farmers to enhance both their effectiveness in improving crop yields and their adoption by the farming community.

3.3 Thematic group developed on ICP based on author keywords

The analysis of the database revealed 12 major thematic groups developed on ICP distributed in four distinct quadrants (Figure 6). The

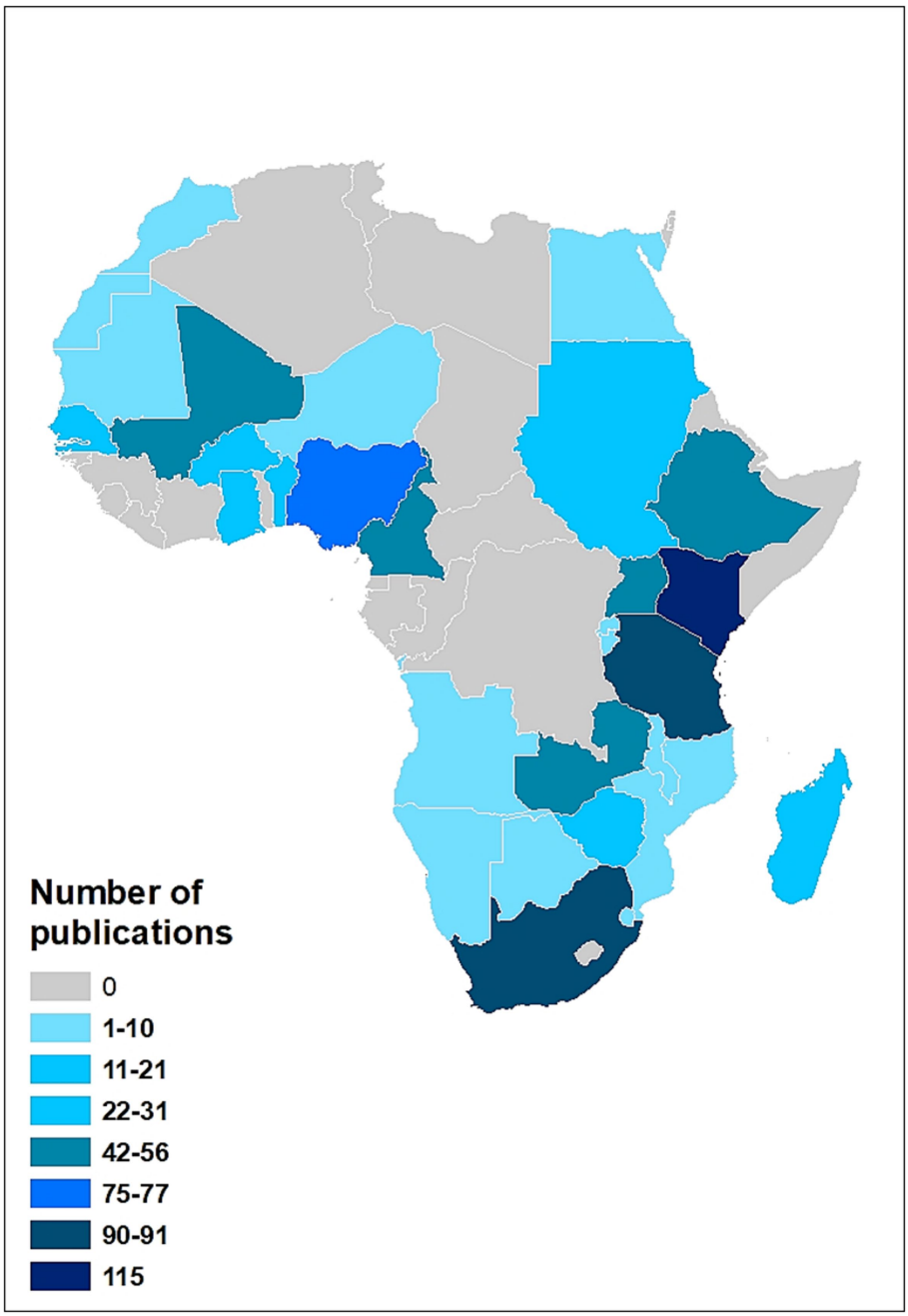

FIGURE 4
Scientific publication of the most productive country using corresponding author nationality. SCP, Single Contribution Publication; MCP, Multiple contribution publication; N, Number; USA, America.

Motor themes quadrant presents the current scientific development focused on three major topics: pest management and agroforestry, dengue and climate change, as well as control vectors. The focus of these themes in the driving quadrant underlines the strategic importance actually given to pest management as one of the major challenges driving the agriculture system in sub-Saharan Africa. Emerging themes aim to connect biodiversity and crop pest management through the promotion of biological control. These themes reflect a growing concern and the pressing need to integrate biodiversity conservation into crop pest management strategies. For a long time, the indiscriminate use of chemical pest control has contributed significantly to biodiversity loss. It is therefore crucial to explore in greater depth the interactions and synergies between biodiversity and pest management, as well as the challenges and opportunities associated with their practical implementation in crop production.

3.4 Main invasive crop pests and effects

Invasive Crop Pests (ICP) are having a devastating impact in many sub-Saharan African countries, causing substantial yield losses and threatening household food security (Eschen et al., 2021).

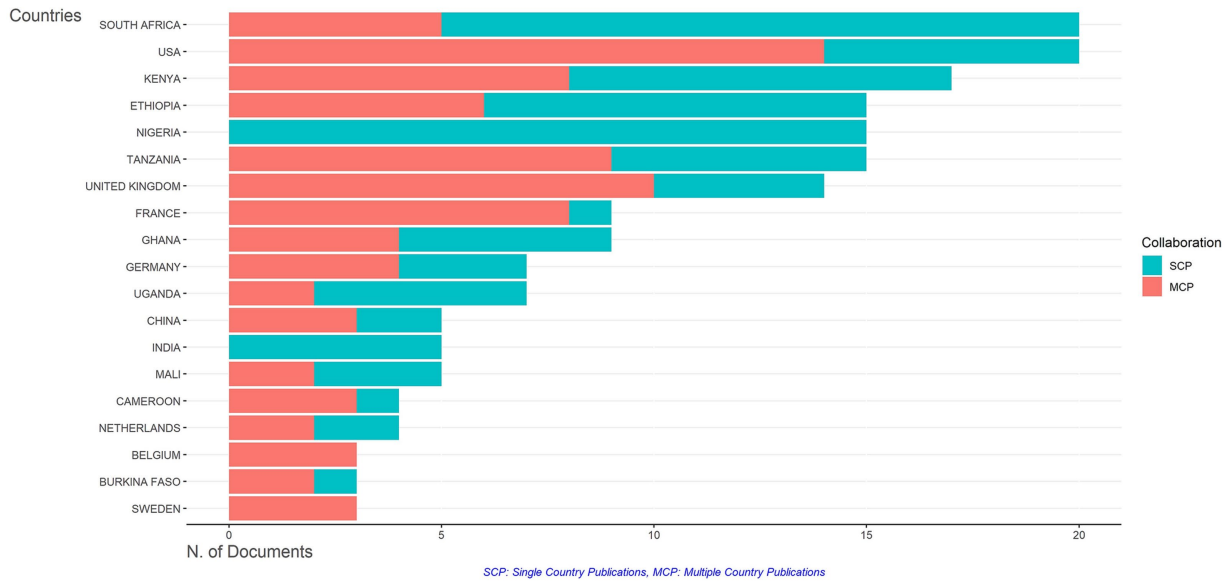

FIGURE 5
Spatial distribution of the number of publications.

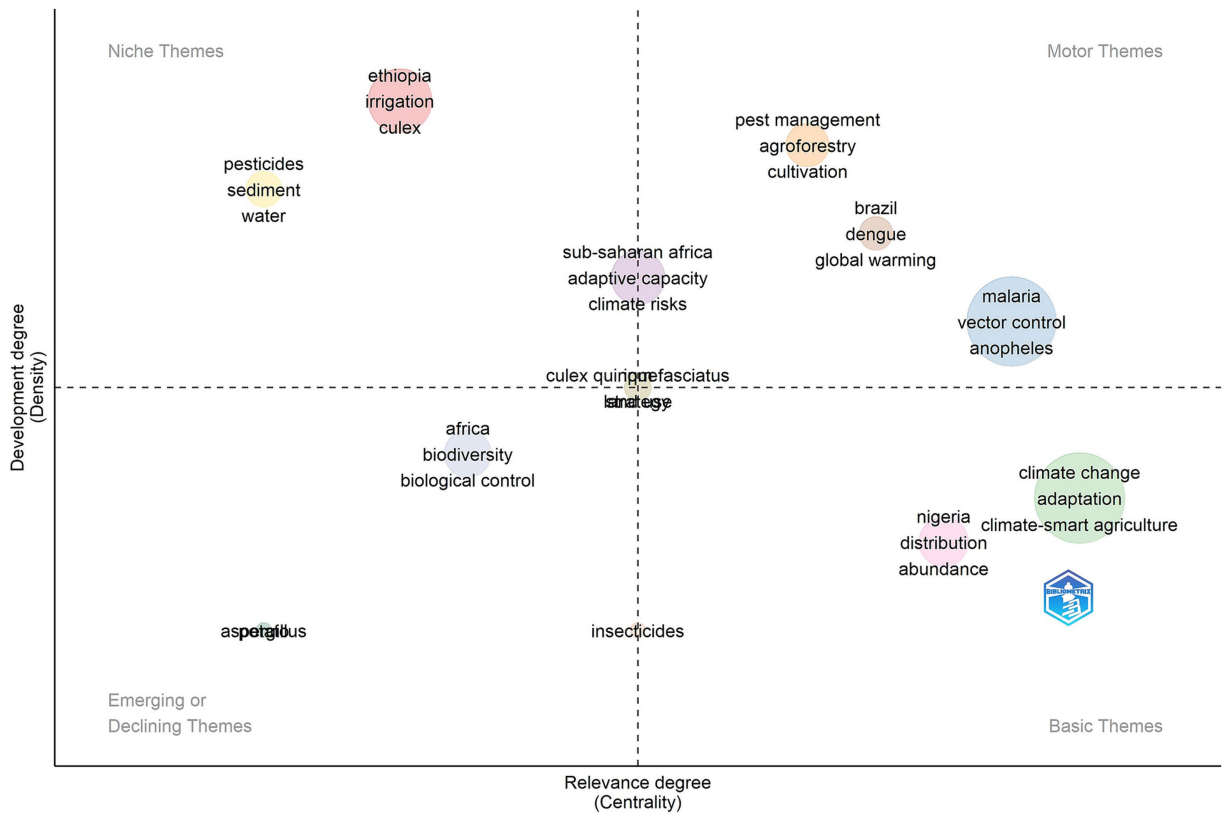

FIGURE 6
Thematic map of the research development on crop pest management.

Considered as the most harmful sucking pest insect on cotton, *A. gossypii* is described as the most common and highly polyphagous aphid in sub-Saharan Africa since the past three decades (Mursal, 1993). This invasive crop pest has a major negative impact on the economy of the region including both the loss of seed cotton production and the decline of cotton fiber quality (Deguine et al., 2007). According to Matova et al. (2020), De Groote et al. (2020), and Tambo et al. (2020a), the fall armyworm (*S. frugiperda*), a

polyphagous pest native to the Americas, has rapidly invaded sub-Saharan Africa since 2016, causing significant damage to crops (corn, rice, sorghum, cane sugar) and other food and cash crops. The authors estimate that in 12 maize-producing countries in Africa, the fall armyworm could cause yield losses of 8.3–20.6 million tonnes per year, worth 2.5–6.2 billion dollars, which would be enough to feed 40–100 million people. Similarly, Eschen et al. (2021) estimated that the fall armyworm was the pest causing the highest yield losses (USD 9.4 Bn) in the region. Even native insect pests such as the coffee berry borer (*Hypothenemus hampei*) has increased its expansion area. Jaramillo et al. (2011) and Tambo et al. (2020a) highlighted that, over the 35 diseases and pathogens recorded as major pests of coffee plants, the coffee berry borer, has benefited from increased temperatures in East Africa, leading to increased damage on coffee crops and an expansion of its distribution area. Brévault et al. (2014) mentioned that fruit flies (*B. invadens* Drew, Tsuruta & White) can infest more than 40 fruit species in Benin and Cameroon, and more than 30 fruit species in Senegal, significantly reducing yields. All these researches demonstrate an increasing challenges of ICPM in sub-Saharan Africa agriculture systems and their growing impact on food security and poverty alleviation. Adaptation strategies are need to reduce the impact of these pests on farmers livelihood.

3.5 Adaptation strategies and effectiveness to invasive crop pests

Facing a growing invasive crop pests threat on the agriculture system, the communities in sub-Saharan Africa developed effective strategies to significantly reduce their impacts. Joseph et al. (2021), in their study of citrus growers in South Africa, found widespread adoption of practices such as integrated pest management (92.3%), rainwater harvesting (87.3%), drip irrigation (78.6%) and the use of drought-resistant varieties to combat crop pest infestations. These measures aimed to improve the resilience of crops to climate change and consistently reduced the negative effects of crop pests.

In the transitional agroecological savanna zones of Ghana, climate-smart agricultural practices have been widely developed and adopted by smallholders (Antwi-Agyei and Nyantakyi-Frimpong, 2021). These are timely harvesting and storage, crop rotation, seed banking, timely weeding, proper planting methods, early maturing varieties, intercrops, cover crops, use of indigenous knowledge, planting of legumes and no-till. Additionally, to control fall armyworm, Ethiopian and Kenyan smallholders have resorted to synthetic insecticides, plant extracts, hand picking of larvae and filling corn cobs with soil as methods of crop pest control (Singh et al., 2022). In Zambia and Ghana, farmers have mainly adopted insecticide spraying and manual collection of larvae (Tambo et al., 2020b).

Several studies have evaluated the effectiveness of the identified adaptation strategies for crop pest management. The integrated pest management, rainwater harvesting, drip irrigation, and the use of drought-tolerant varieties can provide significant improvement of production and profitability to citrus growers in South Africa (Joseph et al., 2021). In the same way, climate-smart agricultural practices adopted by smallholder farmers in Ghana are highly effective in promoting environmental protection, soil health, reduction of pests and diseases, increased yields and agricultural income, erosion control and soil moisture conservation (Antwi-Agyei and Nyantakyi-Frimpong, 2021). Chemical insecticides, because they are cheap, are widely used in Africa and most of them are broad-spectrum insecticides to which the fall armyworm has developed resistance (Tambo et al., 2020b; Singh et al., 2022). The authors instead advocate the use of pest-resistant corn varieties, which have proven effective in the Americas. Diabate et al. (2021) studied a "push-pull" strategy combined with greenhouses to control cowpea pests. They found that this approach was effective in reducing the proliferation of certain harmful insects while improving yields of cowpea pods and grains.

3.6 Gender-based adaptation approaches for controlling invasive crop pests

Recent studies have highlighted the importance of taking into account gender differences in the adoption of coping strategies. For example, Nchanji and Bellwood-Howard (2018), in their study of cabbage farmers in Cameroon, found a negative correlation between farmer experience and the number of pesticide applications, indicating that women, who generally have less experience in agriculture, tend to use more pesticides. The authors emphasize the importance of training on pesticide use, which could particularly benefit women. Similarly, climate smart agricultural practices in Nigeria, mentions that farmers' characteristics, such as gender and age, influence their perception of climate change and their decision to adopt weather and climate information services, which in turn promote the adoption of resilient agricultural practices (Igberi et al., 2022).

3.7 Research perspectives

The results of the bibliometric analysis highlighted promising avenues for future research on ICPM in sub-Saharan Africa. Deep knowledge on biodiversity and biological control appears as a major perspective. These emerging themes reflect an increasing recognition of the need to develop approaches for biological control for ICP by harnessing functional biodiversity within agroecosystems. This path appears strategic as it would progressively reduce dependence on synthetic pesticides, which carry severe negative externalities including soil and water pollution, pest resistance, food poisoning, health effects and declines in biodiversity with cascading consequences on ecosystems (Palaniyappan et al., 2022; Tison et al., 2024). By optimizing the natural regulations carried out by natural enemies of pests (parasitoids, predators like beetles, bugs, spiders, birds) and plant biodiversity within diversified and complex agroecosystems, we have a sustainable alternative in environmental, health and economic terms. The regulation of the microclimate through shading and moisture retention under agroforestry cover creates ecological niches that support the establishment and maintenance of functional biodiversity, thereby enhancing the biological control of ICP populations. There is currently the emergence of pesticide-free agricultural production systems around the world to sustain agriculture systems and maintain biodiversity conservation and ecosystems functioning (Maré et al., 2023; Finger, 2024; Finger and Möhring, 2024; Finger et al., 2024). The main concern is how to scale up these approaches in the context of land shortage, increase demand in agricultural lands and population growth and climate variabilities

in sub-Saharan Africa. Technologies need to be developed in respect to the environment to increase food production in Africa. Studying the interactions and synergies between pest management, agroforestry, and climate change effects, adaptation solutions appear essential. These driving research topics underscore strategic importance, while their combination could lead to major innovations to increase the resilience of African agri-food systems in the face of the multiple challenges. The development of climate-smart agroforestry systems that integrate crop pest management components would represent a transformative advancement.

A crucial cross-cutting perspective lies in strengthening scientific cooperation, both at the regional and international levels. The observed disparities in scientific production and multilateral collaboration are a reminder of inequalities in access to research funds. Promoting knowledge sharing and the emergence of Pan-African and global networks would be a powerful lever to disseminate innovations, pool resources, and collectively address these complex, multidimensional challenges of ICPM in sub-Saharan Africa.

4 Discussion

4.1 Invasive crop pests effects in sub-Saharan Africa

Detrimental effects of ICP on agricultural production and community food security have been reported by scholars in many sub-Saharan African countries (Singh et al., 2022; Maré et al., 2023). These invasive pests, often unintentionally introduced into new regions, have caused significant yield losses and threatened the livelihoods of rural populations dependent on agriculture.

One of the most concerning pests is the fall armyworm (*S. frugiperda*), a polyphagous insect native to the America that has rapidly spread across sub-Saharan Africa since 2016. Even if native to Africa, another major pest is the coffee berry borer (*H. hampei*), considered one of the most significant threats to coffee production globally. These invasive pests have particularly detrimental effects in sub-Saharan Africa agricultural systems, even more than native pests, for several reasons. Firstly, they are introduced into a new environment devoid of natural enemies to control them, allowing them to multiply rapidly (Mafongoya et al., 2019). Secondly, locally cultivated plants have not co-evolved with these invasive pests and have therefore not developed defense mechanisms or resistance against them compared to native pests (Ngowi et al., 2017). Furthermore, many ICP thrive in the tropical and subtropical climatic conditions of sub-Saharan Africa, where high temperatures, humidity, and host plant availability are favorable for their rapid reproduction (Subedi et al., 2023). They also have a great capacity to adapt to new environments and hosts, enabling them to establish and spread rapidly in new regions (Mafongoya et al., 2019). Finally, many African countries lack the resources, knowledge, and surveillance systems to detect and respond quickly to ICP, giving invasive pests an additional advantage before management measures can be implemented (Day et al., 2017).

Thus, the introduction of ICP into naive ecosystems, combined with favorable conditions and a lack of national preparedness, allows these pests to spread rapidly, causing significant damage to crops and threatening food security in sub-Saharan Africa. These findings emphasize the urgency of developing and implementing integrated pest management strategies tailored to local contexts and resilient to climate change.

4.2 Adaptation strategies and effectiveness to invasive crop pests

The observed adaptation strategies to ICP developed by local communities are species and context specific in the global context of climate change. The adoption of agro-ecological practices such as integrated pest management, water harvesting or the use of resistant varieties aims to strengthen the resilience of the production systems aligned with international recommendations (OECD/FAO, 2016).

Agro-ecology, through crop diversification, mulching, intercropping and agroforestry, largely implemented in sub-Saharan Africa can reduce crop pest risks by disrupting pest and disease cycles while promoting natural enemies with a 50% reduction in infestations in diversified systems (Kremen and Miles, 2012; Assèdé et al., 2023). Additionally, techniques such as mulching, ridging or alley cropping optimize water and nutrient regulation in soils, thereby limiting abiotic stresses, with for example 30–60% increases in soil water and organic matter content observed by Araya et al. (2011). The cultivated biodiversity and adjacent semi-natural habitats also strengthen key ecosystem services like pollination or biological control. Finally, the combination of nitrogen-fixing legumes and cover crops, which provide biomass to the soil, sustainably restores soil fertility (Duchene et al., 2017). Through this systemic approach and optimization of natural regulations, agro-ecology increases the overall resilience of agroecosystems to multiple biotic and abiotic disturbances with limited input, justifying its increasing adoption across sub-Saharan Africa.

The use of synthetic insecticides against one of the major ICP, fall armyworm appeared largely adopted by Kenyan and Ethiopian smallholders as an emergency solution because of its quick and severe effect. However, the indirect effects on environmental components are not well documented. The rapid development of resistance would compromise their future effectiveness in controlling ICP (Okuma et al., 2018). The use of resistant maize and Bt cotton varieties has substantially reduced damage in Asia (Marral et al., 2023), advocating for their deployment in sub-Saharan Africa, in combination with integrated pest management. However, most farmers in the sub-Saharan agricultural landscape have low education levels and limited capacity to implement technologies introduced to their environment, particularly when these require specific and complex application processes.

The push-pull systems associating trap crops and repellent plants, tested on cowpea in Burkina Faso, appear promising to reduce the insect pests populations in an agro-ecological way (Diabate et al., 2021). Trap crops attract pest insects through their volatile compounds and serve as host plants for oviposition (Khan and Pickett, 2004). This allows concentrating pest populations on these plants instead of the main crop. Then, repellent plants emit compounds that are repulsive or toxic to insect pests, creating a chemical barrier around the crop (Pickett et al., 2014). Certain plants such as desmodium or jack bean have demonstrated their effectiveness in repelling lepidopteran pests (Reddy, 2017). Additionally, push-pull systems promote the abundance and diversity of natural enemies of crop pests such as parasitoids and predators, due to the more diversified habitat (Midega

et al., 2018). This approach enhances the biological control of pest populations. Successful results (with 82.6% reduction in bug populations on cowpea and 129% increase in yields) were obtained in Burkina Faso using trap crops and repellent plants association in cowpea crop fields (Diabate et al., 2021). Research works in Kenya (Midega et al., 2018) and Ethiopia (Deressa et al., 2024) also confirmed the effectiveness of these push-pull systems in reducing attacks by stem-boring Lepidoptera on cereal crops. However, beyond adaptation, strengthening prevention and preparedness against invasive pests is crucial to sustain crop production in sub-Saharan Africa. The development of early warning systems and accessible seed systems facilitating the rapid deployment of resistant varieties would help limit the initial expansion of ICP (Kumela et al., 2019). Crop diversification, mulching and the maintenance of semi-natural habitats favoring natural enemies of pests are also important levers (Abdullah et al., 2022).

Women' empowerment and their equal access to productive resources such as inputs, land, and training are essential to increase the resilience of African agriculture. Several studies demonstrate that by bridging the gender gaps in the use of fertilizers, improved seeds, and extension services, yields could increase by 16–25% (Arsil et al., 2022), significantly improving African food security. Beyond productivity, women play a pivotal role in preserving natural resources and cultivated biodiversity, which are key assets in the face of biotic and abiotic stresses (Sinthumule, 2022; Büscher et al., 2024). As custodians of traditional ecological knowledge on sustainable resource management, such as water conservation and the selection of resilient local varieties, their expertise is crucial for building more robust agroecosystems. Thus, by removing systemic barriers to accessing innovations and valuing women leadership, adaptation capacities are optimized, strengthening the overall resilience of farms against the growing threats of ICP and climate change.

While crop pests remain important challenges, the adoption of ICPM technologies at the farmers level and through extension services may be valuable in alleviating the challenge. According to Khan et al. (2021), farmers' perspectives and adoption of ICPM concepts is a critical driver in the success of ICPM practices. Extension agencies in Africa could directly assist farmers in identifying and managing pest and disease outbreaks. Their role includes but is not limited to farmers training in technology use, preventive measures and the tools to monitor their farms against ICP. In addition, extension workers usually work to promote farmers' indigenous knowledge and practices into sustainable farming and by facilitating learning and knowledge sharing. More importantly, extension officers monitor the field and identify areas where local agricultural agencies and the government can intervene. Future research should assess sub-Saharan Africa farmer's perception on the effectiveness of the existing ICPM practices. Furthermore, a categorization should be made across the region to classify the ICPM based on criteria such as pathogen classes, effects on pests, biodiversity, and crop yield.

5 Conclusion

This study assessed research progress and climate change adaptation strategies for crop pest management in sub-Saharan Africa. Our analysis revealed that the significant damage caused by major pests, such as the fall armyworm and fruit flies, has resulted in substantial yield losses, directly threatening the food security and livelihoods of millions of farmers. However, local communities have developed diverse adaptation strategies to address this crop health crisis, exacerbated by climate change. Although there are regional disparities in access to research and collaboration, the bibliometric analysis highlighted promising approaches, including biological control through functional biodiversity, agroforestry systems integrating crop pest management, and gender-based strategies. The development of these approaches could be key to sustainably addressing the multidimensional challenges of ICPM. However, achieving this will require coordinated mobilization at all levels to catalyze this essential agro-ecological transition across Africa. Additionally, given the limited research on ICP in most sub-Saharan countries, this study calls for more research to mitigate climate change-induced crop pests and their impacts on production and food insecurity. Future research should also evaluate farmers' perceptions of the effectiveness of current ICPM practices.

Author contributions

EA: Conceptualization, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. CO: Conceptualization, Investigation, Methodology, Writing – review & editing, Writing – original draft. AL: Conceptualization, Investigation, Methodology, Writing – review & editing. GB: Conceptualization, Writing – review & editing. TG: Conceptualization, Writing – review & editing. MZ: Conceptualization, Writing – review & editing. A-JN'g: Conceptualization, Writing – review & editing.

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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.

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