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Current Status and Future Prospects of the Distribution and Risk Assessment of Fall Armyworm (*Spodoptera frugiperda*)

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ABSTRACT

The fall armyworm (*Spodoptera frugiperda*) is a significant pest threatening crop production, particularly in tropical and subtropical regions. Beyond its native range, it has invaded most African countries and parts of Asia, with the potential to spread further in tropical climates. Its biological adaptability, combined with geo-ecological diversity and human activities such as trade and poor management, complicates control efforts and promotes global distribution. Effective management requires understanding migration routes, climate patterns, host interactions, and strain-specific behaviors. Coordinated regional strategies, monitoring systems, and collaborative research, especially in Africa, are essential to develop farmer-accessible solutions and improve pest management practices. The objective is to analyze the current distribution of *S. frugiperda*, assess its associated risks to agriculture, and explore future perspectives on its management and mitigation strategies. This includes evaluating its potential spread under changing climatic and ecological conditions.

KEYWORDS

Spodoptera frugiperda, pest threatening, crop production, agriculture, climatic and ecological conditions

INTRODUCTION

The fall armyworm (FAW) (*Spodoptera frugiperda* Smith), (Lepidoptera: Noctuidae) is a polyphagous pest native to the tropical and subtropical parts of the western hemisphere, viz., America, and in 2016, the first outbreak was reported in Africa (Central and Western)[1]. At the beginning of 2018, it was reported that the insect had spread into almost all of Sub-Saharan African countries, causing extensive damage, especially to maize fields, and had become resistant[2]. Surprisingly, transcontinental distribution has been reported from India in maize[3]. Afterwards, it has been reported from more than twenty locations in India[4].

Based on the evidence of distribution in Africa and India, it is predicted that if appropriate global and local measures are not taken, the migration of the pest into the rest of the world will take place quickly, causing considerable crop losses. The global change, crop farming diversity, seed export and import system, may hasten the speed of the spread of FAW. From the view of its host range, it is a polyphagous insect, though the species of the family Poaceae (maize, rice, and sorghum) are the riskiest crops. This can be one of the factors that enable the insect pest to survive all seasons and multiply easily. This factor could make the development of management options complex. Therefore, the objective of this study focused on analyzing the potential distribution and related risks to mitigate the distribution of FAW in Africa.

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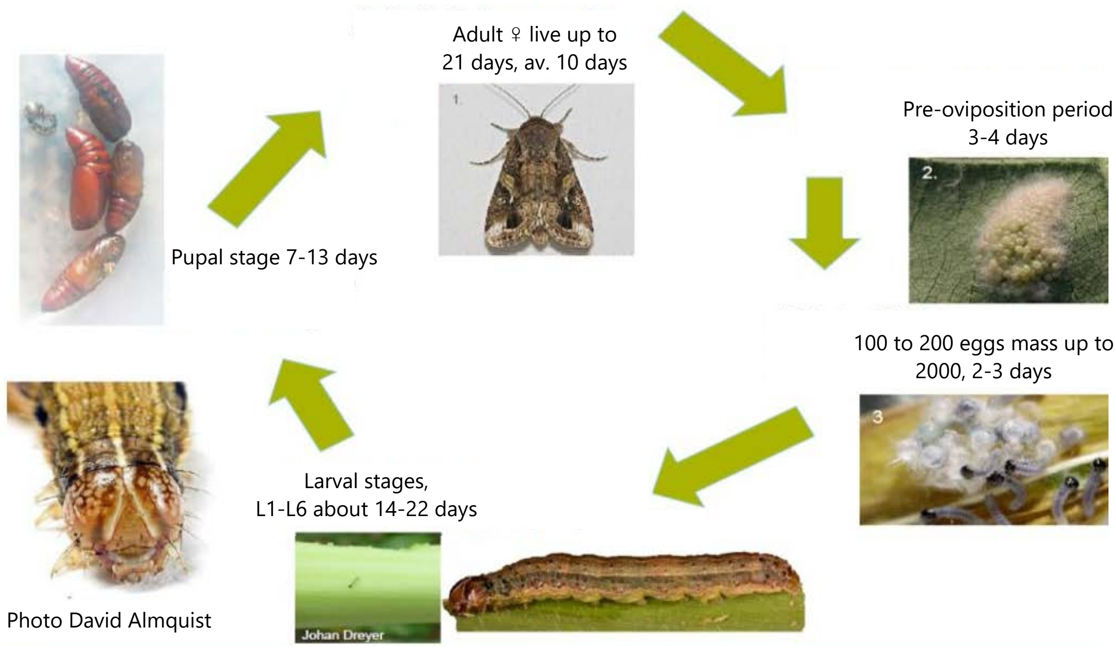


Fig. 1: Life cycle of fall armyworm (Adapted[5])

Biology and ecology of fall armyworm: Understanding of the biology and ecology of insect pests in general, FAW in particular, plays a paramount role in the study of the distribution and population dynamics of the pest. The detailed biology, ecology, and population dynamics of FAW in Africa have yet to be investigated. However, it is well established in its native area, in America shown in Fig. 1.

The number of generations occurring in an area varies with geography. In general, the insect is holometabolous in which means it passes through four life stages, i.e., eggs, larvae, pupae, and adult stage. Eggs are generally laid in batches on the underside of the leaves close to the junction of the leaf and the stem. Larval instars feed on different parts of the host plant. For instance, in maize, early instars feed superficially, usually on the undersides of leaves, leading to the formation of symptomatic semitransparent patches on the leaves. The young larvae (6-14 days old) reach the reproductive part (tassel, silk, and cob) and cause serious damage to the plant. One generation in a year during August has been reported from Minnesota and New York, one to two in Kansas, three in South Carolina, and four in Louisiana; whereas, in coastal areas of North Florida, continuously abundant from April to December. In Africa, where it is an invasive insect pest, an area-based insect biology and population dynamics study is highly needed.

Taxonomy and genetic difference of fall armyworm: Genus *Spodoptera* consists of 25 species; some economically important species are listed in Appendix 1. Fall armyworm (*Spodoptera frugiperda*) was first described in 1797 as *Phaleana frugiperda*, but in 1852, S. *frugiperda* was placed under the genus *Laphygma*. In 1958, *Laphygma* was synonymized with *Spodoptera*[5].

The FAW has a very wide host range, with over 80 plants recorded, but it prefers grasses. Based on the host preferences, two strains of FAW have been confirmed in the native area[6-8]. The first strain is the maize strain, which predominantly feeds on maize, cotton, and sorghum, and the second strain is the rice strain, which prefers rice and grasses. In Africa, it is not well known whether a single strain is introduced or both the strains are introduced; however, some investigations have been done on comparison of the specimens of the introduced populations with native species in Togo infestations and similarity of mitochondrial haplotype in Caribbean Region and the eastern coast of the United States has been reported by Nagoshi *et al.*[9]. They confirmed from the DNA barcoding that the specimens are of the subgroup that

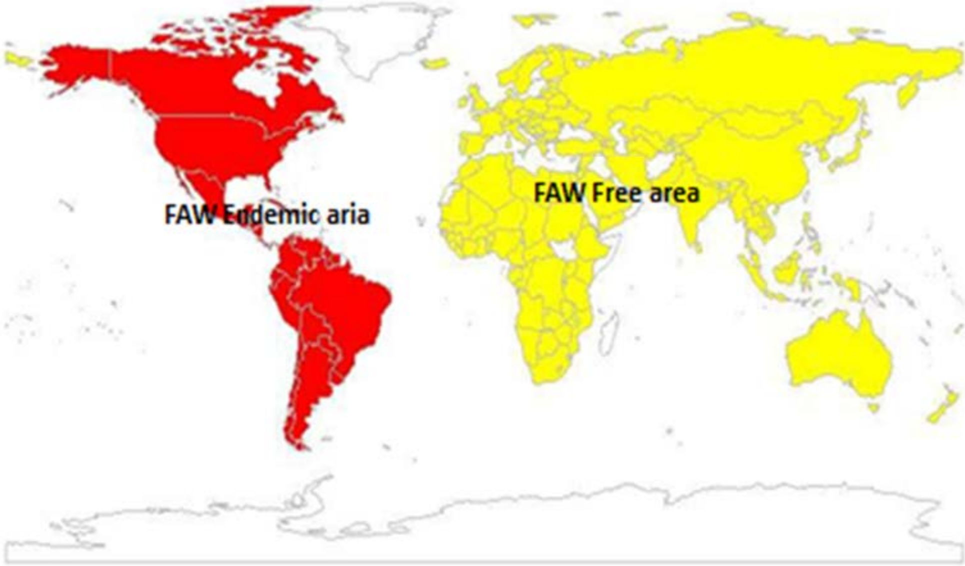
Appendix 1: Different species in the Genus *Spodoptera*, current distribution and economic importance

Species name	Common name	Regions/countries	Status
Spodoptera frugiperda	Fall armyworm	US, South America, Africa, and Asia	Major
Spodoptera littoralis	Egyptian cotton leafworm	Africa, Southern Europe, Western Arabian Peninsula, Islands of Indian ocean, and Islands of Atlantic Ocean	
Spodoptera exempta	Nutgrass armyworm	Africa, Australia, Hawaii, and Western Arabian Peninsula	
Spodoptera litura	Taro caterpillar	Australia, Pacific Islands, and Asia	
Spodoptera mauritia	Lawn armyworm	Madagascar, Saudi Arabia, Asia, Pacific Islands, and Hawaii	
Spodoptera exigua	Beet armyworm	Africa, Western Arabian Peninsula, Islands of Indian Ocean, and Islands of Atlantic Ocean	
Spodoptera pectin	-	Asia	Minor
Spodoptera ochrea	-	Peru	
Spodoptera marima	-	Brazil	
Spodoptera cilium	-	Africa, Western Arabian Peninsula, and Islands of Indian Ocean	
Spodoptera triturata	-	Africa	

Source: Feed the Future, 2017

predominantly exists in the Western Hemisphere. The mitochondrial haplotype configuration showed that these populations are similar to the Caribbean Region and the Eastern Coast of the United States, and speculated the likely originating source of the Togo infestations as the Caribbean Region and the Eastern Coast of the United States. The study on Haplotype profile comparisons of FAW populations from Mexico with those from Puerto Rico, geographically subdivided the C-strain into two (FL-type and TX-type) based on differences in the frequency of mitochondrial haplotypes[10]. Recently, the partial cytochrome oxidase I (coxI) gene sequence confirmed that the FAW population from Tanzania feeding on maize is rice strain[11]. In India, one of the countries where the insect was newly introduced in 2018, the mtCOI (5') based sequence analyses revealed that the FAW populations feeding on maize aligned with rice strain[12]. The study on these strains in two countries in two different continents showed the same result that the rice strain is the suspected strain in both countries. The most surprising point is that in both countries, the insect population is confined to maize, showing no incidence on rice. The question of why rice strains are confined in maize habitat may be the direction of future research. However, the study on the inter-strain hybrid frequency and their distribution in populations from the United States and Brazil confirmed that the hybrid configurations are most often found in corn-dominated habitats[13,14]. The result of this study may give some clues that the new invasive FAW in Africa and India are the hybrid strain, though it needs detailed investigation. Supporting this view, very recently, Nagoshi and Meagher[8] reported the absence of R-strain in Africa based on the study of strain-biased mating behaviors. He also suggested that African FAW populations are dominated by two groups, the C-strain and the descendants of inter-strain hybrids. Overall, there are contradictory reports on the invasive FAW strain in Africa. Therefore, to develop the appropriate management strategies, the exact strains and their abundance need further study in Africa.

Bionomics, overwintering, and dispersal mechanisms: The study on insect ecology plays a great role in the understanding of the insect niche, overwintering mechanism, and its dispersal ability to develop management strategies to mitigate its impact on crops. About this, the understanding of biotic and abiotic factors affecting the insect life cycle is crucial in forecasting the potential distribution. Accordingly, high temperature (over 32°C) has been reported to affect larval and pupal survival and development rates[15,16], as well they cannot survive prolonged freezing[17]. The study in its native area suggested that FAW migrates during the winter season to warm and moist areas where host plants are available to overwinter. The other interesting behavior of FAW is its long-distance seasonal migration potential over the sea. Thus, the infestation in Africa most probably could be suspected of migration along this route. The presence of a year-round host plant, long-distance migration potential of the pest, and the suitability of the ecology may create a conducive environment for the survivability and wide range dispersal of FAW in Africa. However, regional-based ecology and the overwintering mechanism of the insect need further investigation.



Appendix 2: FAW distribution area pre 2016

Table 1: Fall armyworm distribution history in Africa and Asia

Countries	Date of first report
Nigeria, Benin, Togo and São Tomé, and Principe	January, 2016
Ghana, South Africa, Malawi, Mozambique, Zambia, Zimbabwe, and Democratic Republic of Congo	February, 2017
Botswana, Burundi, Cameroon, Ethiopia, Kenya, Rwanda, Tanzania, Uganda, Burkina Faso, Equatorial Guinea, Niger, Sierra Leone, and Swaziland	May, 2017
Angola, Central African Republic, Chad, South Sudan, Republic of Congo, and Guinea	December, 2017
Cape Verde, Côte d'Ivoire, Guinea-Bissau, Madagascar, Mali, Senegal, Seychelles, Sierra Leone, Somalia, Liberiam and Sudan	February, 2018
Mayottem and Reunion	August, 2018
India (Karnataka)	May, 2018
India (Andhra Pradesh, Maharashtra, Tamil Nadu, and Telangana)	August, 2018

Origin and distribution history of fall armyworm: The FAW has a history of over 200 years in the United States (Appendix 2). The first recorded outbreak of FAW was on grains and grasses in Georgia during 1797. Since its first identification, its outbreaks were recorded as sporadic in limited areas of the United States for about 100 years. The most serious outbreaks were observed in 1899 and 1912 in all of the United States Eastern part and then the infestation in uninvaded areas continued[18]. The other amazing behavior of the insect is its annual migrations during the winter to the warmer parts of Central and South America, where it overwinters and disperses again. Recently, it was detected for the first time in the year 2016 in some parts of Africa and invaded the whole of Africa within two years. Similarly, the insect was spread to different parts of the Asian continent during 2018, like India[19], Thailand, and Yemen. Data shows that the pest was present in North America, Central America, and Caribbean Region, and South America. Interestingly, the pest was introduced into Europe (Germany, Netherlands, and Slovenia) and eradicated in 2012. Based on the reports from Africa and Asia, the insect has the potential to spread into new geographically similar areas in the world.

Current fall armyworm distribution in Africa and Asia: The FAW in 2016 was reported from Africa for the first time. As the report confirmed, the insect pest is spreading season to season to new areas in Africa and Asia (Table 1). During mid of 2017, CABI reported that the insect spread into 28 countries in Africa[20]. After a year, by the end of 2018, the current distribution map of FAW in Africa confirmed that it covered the entire Sub-Saharan Africa (Fig. 2). Based on the map, only 8 countries from Africa are suspected to be free of the insect. In the Asian continent, during 2018, India (five states)[21]. Thailand and Yemen were found to have the presence of FAW.

Factors aggravate FAW distribution in Africa: The most important factor that speeds up the distribution of FAW is climate. Even though, distribution of FAW follows tropical climate, in Africa, the distribution and migration pattern may not be two-way due to various reasons. The African continent spans both equatorial and subtropical latitudes in the Northern and Southern hemispheres, leading to a wide range of climate types[22]. The Central Regions of Africa, particularly in the tropics, are characterized by dense, humid, and warm conditions, which are favorable for insect development[23]. In contrast, the Northern regions experience arid conditions with high temperatures. The Mediterranean climate is limited to the Northernmost and Southernmost fringes of the continent. Africa's diverse climates, including equatorial, tropical wet and dry, tropical monsoon, semi-arid, desert, subtropical highland, and temperate climates (at the Southern and Northern extremes), contribute to the complex life history of the FAW. This diversity may complicate its migration patterns, posing a significant challenge for future pest management interventions in Africa[24].

In America, the coldest annual temperature and amount of rain in the wet season determine the migration of FAW, but in Africa, these may not be the factors, as temperature and rainfall are highly variable from region to region, providing good opportunities for FAW to regulate its population throughout the year. Thus, in Africa, it needs special behavioral studies in various regions to develop a migration model for each sub-region.

The other factor responsible for the establishment of FAW is the presence of the host plant. Species distribution and ecological interaction depend on regional resources such as the distribution of forest, grass, crop vegetation, etc., that need specific intervention. About this, Sub-Saharan Africa (SSA) has a wider range of hosts and a suitable climate that probably supports FAW seasonal migrations, though Nile to Northeast Africa (Appendix 3). For instance, the report made on species distribution modeling indicates that the ecosystems most suitable for FAW were recorded from the Saharan belt to South Africa, whereas Congo, Democratic Republic of Congo, Gabon, and Cameroon were recorded with low suitability, probably due to forest and crop vegetation coverage. Several literature documents that in Africa, there is an information gap on FAW persistence, dispersal, and migration because there are various rainfall patterns, such as bimodal, that determine population build-up and distribution. Therefore, a detailed investigation is important in this area. On the other hand, the same study characterized Northwest and Northeast Africa as less suitable for FAW due to low vegetation in these areas. However, countries such as Sudan, Egypt's Nile Valley, and Ethiopia[25] have potential habitats that support populations of FAW throughout the year[26] (Fig. 2).

The other challenge in FAW distribution is that genetically it does not develop a diapause state, but it responds to seasonal climatic changes and moves to other regions where climate and food are major limiting factors[27]. For instance, FAW can make three successive generations, travel about 1700 km North from Texas and Florida to invade crops[28]. Such genetically determined physiological changes are not investigated in African climatic conditions.

The FAW was introduced in Ethiopia in early 2017 where it was first detected in Southern part of countries in limited area, however now a days, it has invaded almost all maize-grown areas (Fig. 3). This is probably due to various reasons such as favorable climatic conditions, presence of maize (favorite diet), existence of multiple host crops in the country and multiple maize growing seasons per year (meher, residual moisture, belg and irrigation). However, to document this reasonable assumption, information on this aspect needs to be collected through research in the future.

Potential distribution and expected risk: The current distribution history of FAW in Africa and Asia justifies that the insect has the potential to distribute across continents. More evidently, the recent study on forecasting the global extent of invasion of the insect using climatic SDMs revealed that it could invade areas that have a similar climate to the native distribution. Accordingly, Sub-Saharan Africa can host

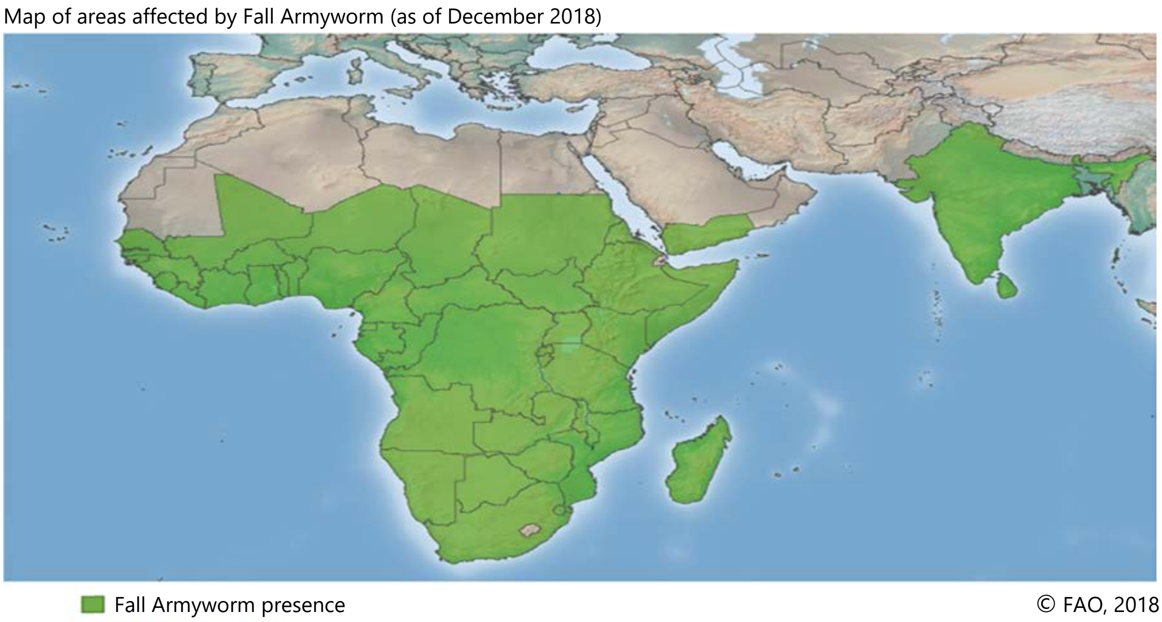


Fig. 2: Current distribution map of FAW in Africa and Asia

Appendix 3: Major agro-ecological zones of Sub-Saharan Africa

Sub-region	Rain fall	Altitudes (m.a.s.l.)
Sahel (A2)	Characterized by erratic rainfall of 250 to 500 mm per annum, more than 8 months of dry season	Less than 900
Sudan Savannah (A3)	Rainfall 500 to 900 mm, dry season 8 months	Less than 900
Guinea Savannah (A4)	Rainfall 900 to 1500 mm (mostly unimodal), dry season of 5 to 7 months	Less than 900
Forest-Savannah transition (A4/5)	Rainfall 1300 to 1800 mm (unimodal or bimodal), dry season of 4 months	More than 900
Forest (A5)	Rainfall 1500 to 4000 mm, virtually no dry season	Less than 900
East coast (A6)	Rainfall 750 to 1500 mm (bimodal in some countries)	Less than 900
Semi-Arid East and South (A7)	Rainfall 250 to 750 mm, more than 8 months of dry season	Less than 1500
Plateau (B7)	Rainfall 750 to 1500 mm (mostly unimodal), dry season 5 to 8 months	900 to 1500
Uganda and Lake Victoria shore (L1)	Rainfall 1000 to 1500 mm (bimodal)	1135 to 1300
Mountain (B2)	Rainfall 750 to 1800 mm (unimodal or bimodal)	More than 1500

Source: EFSAPPH *et al.*[22]

year-round FAW populations, which could be the source of seasonal migration into Northern African countries, while South and Southeast Asia and Australia have a similar climate that would permit FAW to invade. From this pattern of distribution in a similar native climate, it could be concluded that the insect did not undergo a niche shift.

Based on the distribution model constructed in native regions, it is possible to predict the global distribution of FAW. The FAW has developed a year-round movement based on temperature and precipitation in native continents. By this, it has been predicted that FAW can fly to North Africa, crossing the Saharan Desert then it may establish itself in these regions as cool climate seasons prevail in North Africa. This migration may create another opportunity in which FAW establishes movement between North Africa to Europe, as it has been able to migrate between South and North America. The study on pest risk assessment of FAW in the European Union also predicted that continuous flight of nocturnal moths has established itself in vegetated Saharan regions to raise the next generation that continues up to the final destination. There is no consensus on the pathway of FAW from the Saharan Desert to North Africa, and it needs further detailed investigation and modeling. However, the capacity of FAW to fly long distances keeps distant places like Northern Africa and Europe under continuous threat.

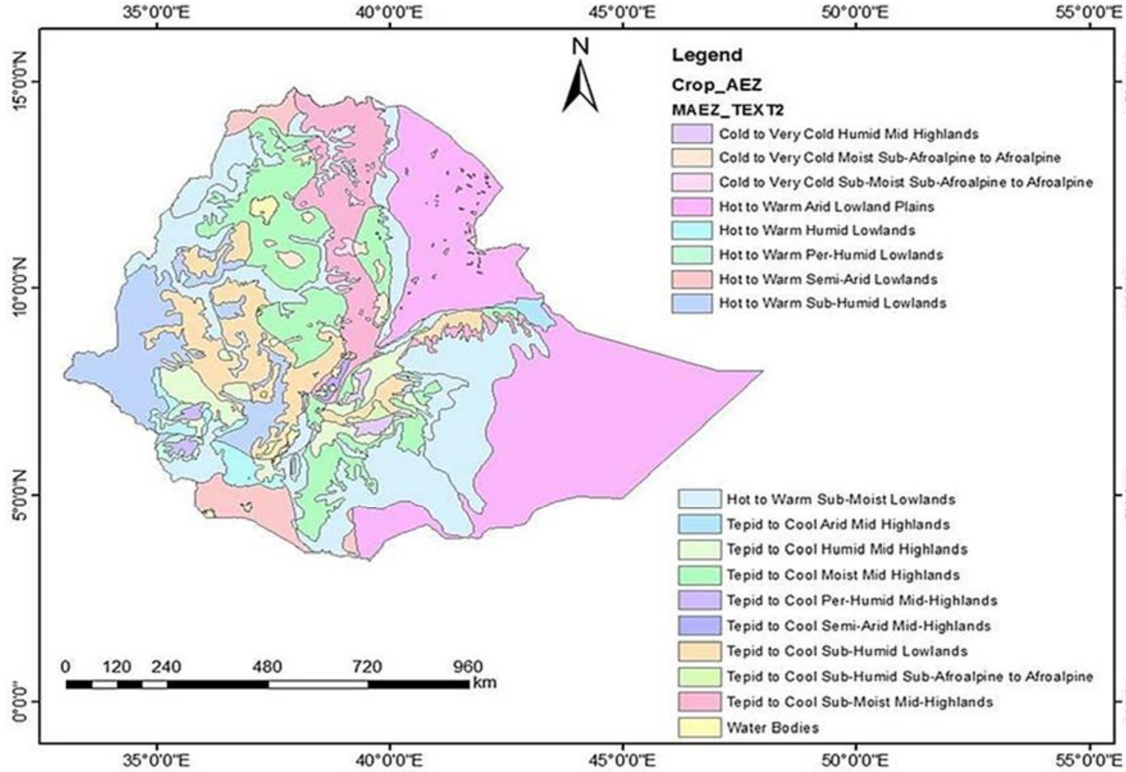


Fig. 3: Agro ecological map of Ethiopia

Additionally, based on the trade and transportation paths, Australia, China, India, Indonesia, Malaysia, Philippines, and Thailand are also considered high-risk areas[29]. The outbreak in the Indian subcontinent disclosed unrestricted access to a whole new region of the globe and could be a source of migration to neighboring countries like Bangladesh, Nepal, and Pakistan, which will seriously risk the maize production of the Asian Continent.

Related to the risk analysis, many authors reported that FAW can feed over 100 plant species depending on temperature and food availability of the regions[30,31]. In another study, there is no clear FAW host list at the global level. For instance, it has been reported that 186 host plants belonging to 42 different families have been listed in the Americas, whereas another author has reported 353 host plant species from 76 plant families in Brazil[32].

Since FAW is recently been introduced in Africa, host diversity and interaction need further investigation. According to the EFSA report, several agro-ecological conditions present in the world have the potential to support FAW distribution throughout the World that might need specific design to combat this pest at the global level.

Appertaining to the view of the above analysis, the pest is going at a very high speed into new areas which have a similar climate. Therefore, if appropriate measures are not taken globally, all similar areas and maize-producing countries are at high risk. In general, the potential risks of the insect could be seen mainly in terms of yield loss, which would challenge food security, especially in the major maize-producing areas, and greatly increase the costs of management. The other risk will be a global economic loss due to trade discontinuity between the countries.

Forecasting model of FAW: The FAW population outbreak, survival, abundance, and generation per year are associated with other factors such as host, and natural enemies within each agroecosystem are complicated. Population outbreak of FAW studied using two circulation models (GCMs), CSIRO Mk3.0 and

MIROC-H, to predict the risk for a long time[33]. There are two FAW strains reported in Africa, both strains probably distribute following their host distribution. A detailed investigation using model simulation in the African agroecosystem and climate conditions is needed. Having data based on population dynamics in each agroecosystem probably helps to simulate the long-term impact of FAW, which helps policymakers and researchers to design appropriate management options.

Studying insect population within their ecosystem, determined by global climate change, that causes insect movement to new habitat[34,35] and changes insect abundance, diversity, and time and magnitude of outbreak[36] and changes genetic trait of an organism[37] have been reported to help understand the management strategy. However, such important information has not been well documented and modeled in Africa. Pest management would be more facilitated if ecological modeling is established based on insect behavioral patterns and trophic interaction[38,39]. It also plays an important role in describing the processes associated with insect population dynamics, such as prey-predator or host-parasitoid relationships[40].

Before practicing pest management plans, pest monitoring is the best strategy to organize efforts accordingly[41]. In many parts of Africa, growers are not supported with a pest monitoring strategy that would enhance the capacity of the farmer to take action on time to save their crop. For example, in Ethiopia, since the introduction of FAW, farmers are challenged with understanding migration patterns and seasonal occurrences. Thus, developing a monitoring system model with an intervention method at the regional level is very important.

CONCLUSION

The FAW presents a significant challenge to crop production, especially in Sub-Saharan Africa, where its complex biology, wide host range, and year-round populations complicate management. Factors such as inconsistent farming practices, poor pesticide regulation, and inadequate infrastructure exacerbate the issue. Limited research on its overwintering sites, population dynamics, and yield losses makes predicting outbreaks difficult. To address this, comprehensive strategies are needed, including understanding FAW migration, regional climate patterns, and host interactions, alongside improving monitoring and communication networks for better pest management at local and regional levels.

SIGNIFICANCE STATEMENT

The fall armyworm (*Spodoptera frugiperda*) is a highly destructive agricultural pest with a remarkable ability to spread rapidly, causing significant economic losses in America, Africa, and India, and posing a significant threat to food security. By addressing the risks associated with its further spread, the study will help in effective pest management strategies, policy decisions, and international collaborations aimed at mitigating the impact of this pest on agriculture and food systems. Policymakers, farmers, and researchers can utilize this information to develop more targeted and sustainable approaches for controlling fall armyworm infestations, thereby minimizing crop damage and economic hardship. The findings will contribute to the development of Integrated Pest Management (IPM) strategies that minimize the use of pesticides and promote biological control methods, ensuring food security and sustainable farming practices in affected and at-risk regions.

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