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Review paper

Current and future potential distribution, risk and management of *Spodoptera frugiperda*

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The fall armyworm, *Spodoptera frugiperda* is notorious pest that challenge worldwide particularly tropical and sub-tropics. Currently, beyond its native continent, it invaded most African and Asian countries. Based on several researchers' pest risk prediction, this pest has potential to colonize remaining world. The biological traits accompanied with geo-ecological diversity of continents have been complicated global distribution that currently impedes human intervention. Currently, fall armyworm management approaches are varying among countries. In America, various management options including advanced technology have been developed to minimize fall armyworm risk. In Africa, even though various attempts have been made, still now, no concrete management options have been developed due to lack of adequate information on bioecology of this pest. Therefore, future researches need to focus on base line information on pest bio- ecological interaction, simulating distribution pathway, introducing and adapting available technology from native countries is very important. In addition, scattered effort and research output made in African and Asia countries need to be pooled together to help resource poor farmers.

Key words: *fall armyworm, potential distribution, management risk, Spodoptera frugiperda*

INTRODUCTION

The fall armyworm *Spodoptera frugiperda* (J.E. Smith), (Lepidoptera: Noctuidae) is a polyphagous pest native to the tropical and subtropical parts of the western hemisphere and the first outbreak in Africa (Central and Western) was reported during 2016 (Goergen et al., 2016). Early in the year of 2018, it has been reported that the insect has distributed in to almost all of sub Saharan African countries causing extensive damage, especially to maize fields (FAO, 2018b). Know day, its establishment have been reported from 45 African countries (Kasoma et al., 2021; Rwomushana et al., 2018). Surprisingly, transcontinental distribution has been reported from Karnataka state of India, in May 2018 (IITA, 2018). Recently, FAW reported from almost all potential maize producing agroecology of Asian continent (Lamsal et al., 2020). Based on the Africa and India distribution evidence, if appropriate global and local measures will not be taken, the migration of the pest in to the other world countries and causing considerable loss is easily predictable. The global change, crop farming diversity, seed export and import system, may fasten the speed of the spread of fall armyworm. From the view of its host range, it is polyphagous insect though family Poaceae (maize, rice and sorghum) are the most at risk crops (CABI, 2018). This can be one of the most factors that enable the insect pest to survive all over the seasons and multiply easily. This factor could make complex the development of management options. In the newly introduced areas, apart from detection, reporting the occurrence and distribution of the pest, the work has been done on the management part is limited. The first measure taken in all areas was synthetic insecticides application, although other management options were also tested. Therefore, this review paper focused on the analyzing the potential distribution and related risks and future management direction to mitigate the distribution of fall armyworm in Africa. We believe that the contribution of this review is great in the decision making and integrated pest management development. Thus, in this review, we covered distribution history, potential distribution and expected risk, current status of the management and future direction on the management of fall armyworm.

Biology and ecology of fall armyworm

Understanding of the biology and ecology of insect pest in general, fall armyworm in particular, plays paramount role in the study of distribution and population dynamics of the pest. Recently, (Niassy et al., 2021) reported the impact of rainfall and agronomic practice on fall armyworm abundance and distribution in East Africa suggesting that understanding fall armyworm activities in specific agroecology is vital to plan appropriate management options. However, the detail biology, ecology and population dynamics of fall armyworm in African continent is yet to be investigated. In general, the insect is holometabolous in which it passes through four life stages (eggs, larvae, pupae and adult stage) (Hardke et al., 2015). Eggs are generally laid in batch on the underside of the leaves close to the junction of the leaf and the stem. Larval instars feed on different part of the host plant. For instance, in maize, early instars feed superficially, usually on the undersides of leaves consequence in the symptom of semitransparent patches on the leaves. The young larvae (6-14 days old) reach the reproductive part (tassel, silk and cob) and causes serious damage on the plant (FAO, 2018b). The number of generations occurring in an area varies with geographical range and temperature. For example, In Minnesota and New York, one generation in a year in August, 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 (Capinera, 2000). In Africa, where it is invasive insect pest, area-based insect biology and population dynamics study is highly needed.

Taxonomy and genetic difference of fall armyworm

The fall armyworm has a very wide host range, with over 350 plants recorded, but clearly prefers grasses (Jiang et al., 2019). Based on the host preferences, two strains of fall armyworm have been confirmed in native area (Dumas et al., 2015; Meagher and Nagoshi, 2004; Nagoshi & Meagher, 2004). These strains are maize strain which predominantly feeds on maize, cotton and sorghum and second strain is rice strains which prefers rice and grasses. In Africa, both strains have been reported based 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 (Cock et al., 2017; Nagoshi et al., 2017). They confirmed from the DNA barcoding that the specimens are of the subgroup that predominantly exist in the Western Hemisphere. The mitochondrial haplotype configuration showed these populations are similar with the Caribbean region and the eastern coast of the United States and speculated as the likely originating source of the Togo infestations is from 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) on the basis of differences in the frequency of mitochondrial haplotypes (Nagoshi et al., 2015). Recently, the partial cytochrome oxidase I (coxI) gene sequence confirmed that fall armyworm population from Tanzania feeding on maize is rice strain (NONZOM and SUMBALI, 2018). In India, one of the country where the insect newly reported in 2018, the mtCOI (5') based sequence analyses revealed that the fall armyworm populations feeding on maize aligned with rice strain (Swamy et al., 2018). The study in these two different continent countries showed same result in which rice strain is the suspected strain in both countries. The most surprising point is that in both countries, the insect population is confined with maize showing no incidence on rice. The question why rice strains are confined in maize habitat is the future research direction. 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 (Nagoshi, 2010). In addition, most recently, the sequence comparisons between the South Africa and India collections were conducted and the result suggested that the genetic homogeneity between the South African and Indian fall armyworm populations (Nagoshi et al., 2019). The result of this study may give some clue that the new invasive fall armyworm in Africa and India are the hybrid strain, though it needs detail investigation. Supporting this view, very recently, Nagoshi reported the absence of R-strain in Africa based on the study of strain-biased mating behaviors (Nagoshi, 2018). He also suggested that African fall armyworm populations are dominated by two groups, the C-strain and the descendants of inter-strain hybrids. Overall, there are contradictory reports on the invasive fall armyworm strain in Africa. Therefore, to develop the appropriate management strategies, the exact strains and their abundance needs further study in Africa.

Bionomics, overwintering and dispersal mechanisms

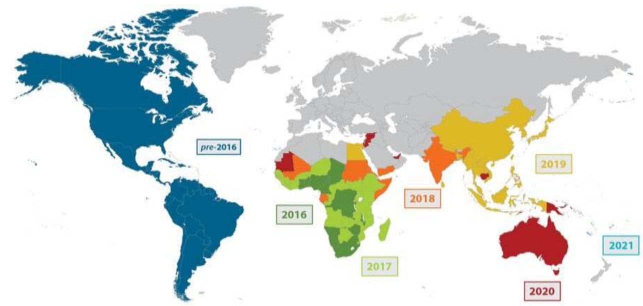
The study on insect ecology plays great role in the understanding of the insect niche, overwintering mechanism and its dispersal ability, thereby develop management strategy to mitigate its impact on agricultural crops. In relation to this, the understanding of biotic and abiotic factors affecting the insect life cycle is crucial in forecasting the potential distribution (Niassy et al., 2021). Accordingly, high temperature (over 32^{o}C) has been reported affecting larval and pupal survival and development rates (Busato et al., 2005; Valdez-Torres et al., 2012) as well they cannot not survive prolonged freezing (Nagoshi et al., 2012). In particular, the effect of temperature on the development of FAW was studied and the result suggested that larval and pupal developmental rate decreases between 33 and 35.5^{o}C (Ali et al., 1990). The study in its native area suggested that fall armyworm migrates during winter season to worm and moist areas where host plants are available to overwinter (Nagoshi et al., 2012). The other interesting behavior of fall armyworm is its long distance seasonal migration potential over sea (Westbrook et al., 2016). Thus the infestation in Africa most probably could be suspected migration in this route. The presence of year round host plant availability, long distance migration potential of the pest, and suitability of the ecology may create conducive environment for the survivability and wide range dispersal of fall armyworm in Africa. However, regional based ecology and overwintering mechanism of the insect needs further investigations.

Origin and distribution history of fall armyworm

Fall armyworm has over 200 years' history in United States. The first record of outbreak on fall armyworm was on grains and grasses in Georgia during 1797 (Smith and Abbot, 1797). Since its first identification, its outbreaks were recorded as sporadic in limited areas of United States for about 100 years (Luginbill, 1928). The most serious outbreaks were observed in 1899 and 1912 in all of the United States eastern part and then the infestation in new uninvaded areas (Johnson, 1987). 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 overwinter and distribute again (Nagoshi et al., 2017). Very currently, in 2016, for the first time, it detected in some parts of Africa and within two years (2018) it distributed to almost whole of Africa (EPPO, 2018). Similarly the insect was spread to different parts of Asian continent during 2018; India (Ganiger et al., 2018; Sharanabasappa et al., 2018; Swamy et al., 2018), Thailand (IPPC, 2018) and Yemen (FAO, 2018c). Recently, almost all maize producing countries in Asia found under fall armyworm risk (Lamsal et al., 2020). The current global distribution of fall armyworm has been reported by (Early et al., 2018b; EPPO, 2018). The data shows that the pest was present in north America, central America and Caribbean, and South America. Interestingly, the pest was introduced in to Europe (Germany, Netherlands and Slovenia) and eradicated from 2012. Based on the reports from Africa and Asia, the insect has a potential to distribute in to new geographically similar areas in the world.

Current fall armyworm distribution in Africa and Asia

FAW was reported from Africa for the first time during 2016 (Goergen et al., 2016). As the report confirmed, the insect pest is speedy spreading season to season to new areas in Africa and Asia (Table 1). During mid of 2017, CABI reported that the insect spread in to 28 countries of Africa (Day et al., 2017). By 2019, the current distribution map of fall armyworm in Africa and Asia confirmed that it covered entire sub-Saharan Africa and some parts of Asian countries (Fig 1) (FAO, 2019a; Rwomushana, 2018). Based on the map, only 8 countries from Africa are suspected to be free of the insect. In Asia, during 2018, from India five states (Ganiger et al., 2018; Sharanabasappa et al., 2018; Swamy et al., 2018), Thailand (IPPC, 2018) and Yemen (FAO, 2018c) have been reported as presence of fall armyworm. The China's Ministry of Agriculture and Rural Affairs reported the first detection of FAW in Yunnan province during January 2019 (Babcock, 2019a). By June 2019, it has been spread across 15 Chinese provinces (Babcock, 2019b). The pest was confirmed in Australia, Mauritania, Timor Leste and the United Arab Emirates during mid-2020. In late 2020, it was detected in Jordan, Syria and Papua New Guinea. In January 2021, New Caledonia confirmed FAW and by April it had invaded the Canary Islands of Spain in Europe. Over all, currently, FAW spread to all potential maize producing countries in Africa and Asia (FAO, 2021)(Fig 1)



FAO (2021) http://www.fao.org/fall-armyworm/monitoring-tools/faw-map/en/

Figure 1. World map of areas affected by fall armyworm.

Factors aggravate FAW distribution in Africa

The factor speeds the distribution of FAW is climate. Even though, distribution of FAW follows tropics climate, in Africa distribution and migration pattern may not be two directions due to various reasons. Obviously, African continental position characterized by Equatorial and subtropical latitudes in both the northern and southern hemisphere, several different climate types can be found within it (Jeger et al., 2018) . Most African tropics that run through middle Africa characterized by dense humid, warm, hot climate that suit for the insect development (Stein et al., 2015). Whereas, the northern climate mainly characterized by arid and high temperatures. In African continent only northernmost and the southernmost fringes of the continent have a Mediterranean climate (Stein et al., 2015). Various climates such as equatorial climate, the tropical wet and dry climate, the tropical monsoon climate, semi-arid, the desert climate, the subtropical highland climate and temperate (at south and north apex) can cause complex life history of FAW that may complicate migration patter that may be the great challenge in future intervention in Africa (Early et al., 2018a). In America coldest annual temperature and amount of rain in wet season determine the migration of Fall armyworm, but in Africa this phenomenon may not expected as temperature and rain fall is highly variable in intercontinentally that create good opportunities for FAW to regulate is population though out a year. Thus, in Africa it needs special behavioral study in various regions to develop migration model for each sub regions. (Niassy et al., 2021) also suggested specific agroecology determined population structure of fall armyworm, which need special plan during management decision. The other factor responsible for the establishment of FAW is presence of host plant. Species distribution and ecological interaction is depending on regional resource commotion such as distribution of forest and grass, crop vegetation that need specific intervention (Niassy et al., 2021). In relation to this, Sab-Saharan Africa have wider ranges of host that probably support FAW seasonal migrations though Nile to Northeast Africa (Niassy et al., 2021). For instance, report made on species distribution modeling indicate that FAW highly suitable ecology were recorded from the Saharan belt to South Africa wearers Congo, Democratic republic of Congo, Gabon, and Cameroon were recorded with low suitability probably due to forest and crop vegetation coverage (Early et al., 2018a). Various literature documented in Africa there are information gap on FAW persistence, dispersal and migration because there is various rainfall pattern such as bimodal that determine population build up and distribution (Hailu et al., 2021; Niassy et al., 2021). Therefore, detail investigation is important in this area. In other way, the same study characterized that Northwest and Northeast Africa as low vegetation dispersal reported with low suitability due to no host year-round populations that support FAW; However, countries such as Sudan, Egypt's Nile Valley, and Ethiopia (Fig 2) have potential ecological habitats that support FAW year round population sustainability (Stefanescu et al., 2016). The other challenge in FAW distribution genetically it not develop diapause state, but it responds seasonal climatic change and move to others regions where climate and food are major limiting factor (Sparks, 1979). For instance, FAW can make three successive generations travel about 1700 Km north from Texas and Florida to invade crops (Westbrook et al., 2016). Such genetically determined physiological changes are not investigated in African climatic condition.

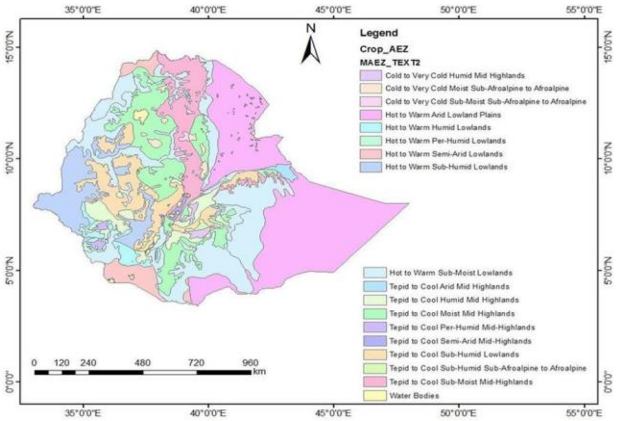


Figure 2. Crop agroecological and maize growing belt of Ethiopia

Potential distribution and expected risk

The current distribution history of fall armyworm in Africa and Asia justify that the insect has potential to distribute across continent. More evidentially, the recent study on forecasting the global extent invasion of the insect using climatic SDMs revealed that it could invade areas that have a

Table 1. Spreading of insect pests during season to season to new areas in Africa and Asia

Countries	Date of first report	Reference
Nigeria, Benin, Togo and São Tomé et Príncipe	January, 2016	(Goergen et al., 2016)
Ghana, South Africa, Malawi, Mozambique, Zambia, Zimbabwe, Democratic Republic of Congo	February, 2017	(CABI, 2017; IPPC, 2017)
Botswana, Burundi, Cameroon, Ethiopia, Kenya, Rwanda, Tanzania, Uganda, Burkina Faso, Equatorial Guinea, Niger, and Sierra Leone, Swaziland	May, 2017	(FAO, 2017a; IPPC, 2017)
Angola, Central African Republic, Chad, South Sudan, Republic of Congo, Guinea	December, 2017	(Day et al., 2017; FAO, 2017b)
Cape Verde, Côte d'Ivoire, Guinea Bissau, Madagascar, Mali, Senegal, Seychelles, Sierra Leone, Somalia, Liberia, Sudan	February, 2018	(FAO, 2018a)
Mayotte, Reunion	August, 2018	EPPO, 2018a)
India (Karnataka)	May, 2018	(CABI, 2018; IITA, 2018)
India (Andhra Pradesh, Maharashtra, Tamil Nadu, and Telangana, Karnataka)	August, 2018	(Acharya, 2018; CABI, 2018)
Bangladesh		(FAO, 2019b)
China (Chongqing, Fujian,Guangdong,Guangxi, Guizhou, Hainan, Henan, Hubei, Hunan, Jiangxi, Sichuan, Yunnan and Zhejiang	January 2019	(Babcock, 2019a) (Wu Qiulin, 2019) (FAO, 2019b); (FAO, 2019c),(FAO, 2019d);
Japan	2019	(IPPC, 2019a)
South korea	2019	(IPPC, 2019b)
Myanmar	2019	(FAO, 2019b); (IPPC, 2019c)
Sri Lanka, Nepal	2019	(FAO, 2019b)
Australia, Mauritania, Timor Leste and the United Arab Emirates, Jordan, Syria and Papua New Guinea	2020	(Tepa-Yotto et al., 2021)
Canary Islands of Spain in Europe	2021	(Tepa-Yotto et al., 2021)

similar climate to the native distribution (Fig 3) (Early et al., 2018a; Tepa-Yotto et al., 2021). Accordingly, sub-Saharan Africa can host year-round fall armyworm populations which could be the source of seasonal migration in to Northern African countries; while South and Southeast Asia and Australia have similar climate that would permit fall armyworm invasion to Europe. From this distribution in similar climate of native, it could be concluded that the insect did not undergo niche shift (Day et al., 2017). Premised on distribution model constructed in native regions, it is possible to predict global distribution of FAW. FAW have been developed year round movement based on temperature and precipitation in native continents (Early et al., 2018a; Jeger et al., 2018). In accordance with this, FAW has been predict that it can fly to North Africa crossing the Saharan desert then it may establish itself in these regions as cool climate seasons of North Africa. This migration may cause the other opportunity in which FAW establish movement between North Africa to Europe as it developed migration between south and North America (Fig 4) (Early et al., 2018a). The study on pest risk assessment of fall armyworm in European union also predicted that, nocturnal moth continuous flight establishing itself in vegetated Saharan regions to rise next generation that continues up to final destination (Jeger et al., 2018). There is no consensus on the pathway of FAW though Saharan desert to North Africa that need further detail investigation and modeling. However, the long distance flight capacity of fall armyworm (Westbrook et al., 2016), and Northern African under area of risk (Early et al., 2018a), Europe will be threating to be reinvaded. Additionally, based on the trade and transportation paths, Australia, China, India, Indonesia, Malaysia, Philippines, and Thailand kept as high risk areas (Chapman et al., 2017; Early et al., 2018a). The outbreak in the Indian subcontinent disclosed unrestricted access to a whole new region of the globe and could be source of migration to neighboring countries like Bangladesh, Nepal, Pakistan, which will seriously risk the maize production of the Asian continent (IITA, 2018). Related with the risk analysis, many authors reported that FAW can feed over 100 plant species depending on temperature and food availability of the regions (Capinera, 2000; Foster, 1989; Mitchell et al., 1991; Pair et al., 1991). In other study there is no clear FAW host list at global level. For instance, it has been reported that 186 host plants belonging to 42 different families in the Americas (Casmuz et al., 2010) whereas, the other author has reported 353 host plant species from 76 plant families in Brazil (Montezano et al., 2018). Since FAW is recently introduced in Africa host diversity and interaction need further investigation. According to EFSA report several agro-ecology of the world have potential host and environmental suitability to support FAW distribution throughout the World that need specific design to combat this pest at global level (Health et al., 2018). FAW population outbreak, survival, abundance and generation per year associated with other factors such as host, and natural enemies within each agro-ecology are complicated that need modeling system. For, example, Ramirez et al., reviewed FAW population outbreak using two circulation models (GCMs), CSIRO Mk3.0 and MIROC-H to predict the risk for long time (Ramirez-Cabral et al., 2017). In other study, insect population within their ecology determined by global climate change that cause insect movement to new habitat (Porter et al., 1991; Ward and Masters, 2007) change insect abundance, diversity, time, magnitude of outbreak (Olfert and Weiss, 2006) and change genetic trait of an organism (Parmesan, 2007) have been reported. However, such important information has been not well documented and modeled in Africa. Pest management intervention more facilitated, if ecological modeling is established based on insect behavioral pattern and trophic interaction. It also play important role in describing process associated with insect population dynamics such as prey-predator or host-parasitoid relationships (Lima et al., 2009). Before pest management action, pest monitoring is the best strategy to organize effort accordingly (Gilson et al., 2018). In many parts of Africa, growers are not supported with pest monitoring strategy that enhanced capacity of the farmer to take action on time to save his crop loss (Capinera, 2000). For example, in Ethiopia, since introduction of FAW, farmers challenged with recognition of migration pattern and seasonal occurrence. Thus, developing monitoring system model with intervention method agro-ecology and regional level is very important as early warning infestation. Appertaining to the view of the above analysis, the pest is going at very high speed in to new areas which have similar climate. Therefore, if the appropriate measures will not be taken globally, the whole similar areas and maize producing countries are at high risk. In general, the potential risks of the insect could be seen majorly in terms of yield loss, which consequences reduction of food security especially in the major maize producing area and costs of management. The other risk will be the associated with the potential income loss because of the trade discontinuity between the countries.

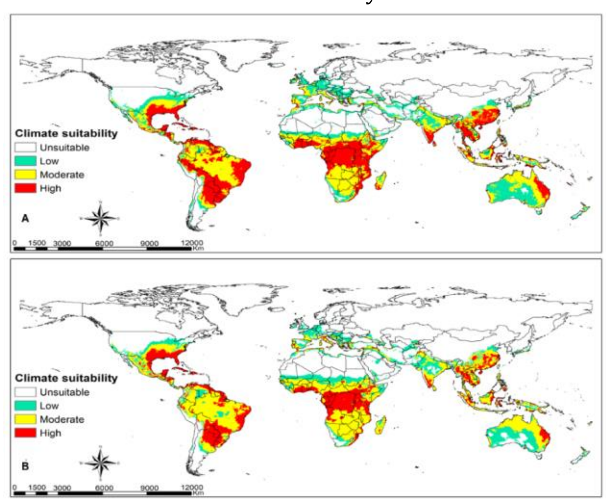


Figure 3. Potential bioclimatic suitability of *Spodoptera frugiperda* at a global extent using native and invaded population at (A) current climatic conditions and at (B) representative concentration pathway based on climatic scenario (Tepa-Yotto et al., 2021).

Due to the high fertility, short life cycle, wider host range, voracious feeding habit and strong power of flight to colonize new habitat its management is not so easy. Additionally, few or no natural enemies associated with it, poor understanding on biology, ecology and migratory behaviors of such FAW in in newly arriving areas like Africa, made the situation worst (Nagoshi et al., 2012; Niassy et al., 2021). In nature FAW is aggressive pest to control using conventional method practiced by African farmer. For instance, report show that FAW have been developed resistance to many pesticides due to indiscriminate or frequent use of insecticide (Yu, 1991; Yu et al., 2003). On the hand, FAW scape conventional insecticide sprayed after three instar and hide in maize whorl which reduce their vulnerability to unfavorable environment, natural enemy and contact insecticide (Foster, 1989; Pitre and Hogg, 1983). Additionally, mixing farming system that mostly practiced by African Farmer need specific approach to combat such serious pest.

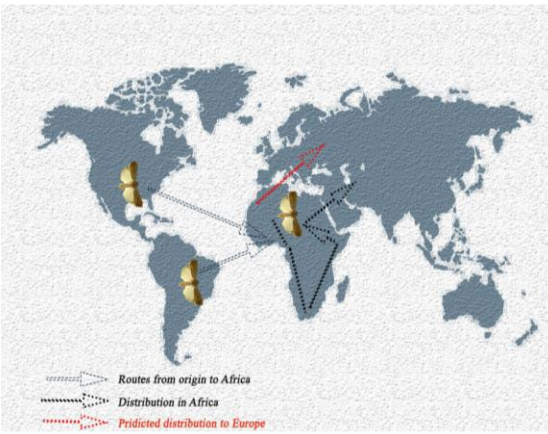


Figure 4. Current and future Fall armyworm flight route.

Factors limiting the management of fall armyworm and successful attempts

As result, FAW is more challenging to farmers compared to others regular insect pests. Despite the above limiting factors, various management options have been reported as a potential to control the FAW in which farmers awareness on the pest biology and ecology plays paramount role. For example, deep ploughing during off season has been reported reducing the FAW population through exposing the pupae to predators, adverse weather factors and solar heat (Nagoshi & Meagher, 2004). In addition, early planting help the plant to escape peak population of adult which results in early stage damaging (Pitre & Hogg, 1983). Push pull technology which was generated for stalk borer management has also reported for FAW. This could be done by planting Napier grass, Sudan grass, or Molasses grass on the border of the crop field as attract of FAW whereas planting Disodium inside the crop as oviposition repellent (Khan et al., 1997; Khan et al., 2008). Additionally, sun flower, safflower have reported as an attract of FAW's natural enemies (Pitre and Hogg, 1983). A single management option is not effective and need to be integrated in the way that considered the ecology and biology of the pest. For example, some of the recommended cultural practices are insufficient if used as single management option, labor intensive and dissenting the recommended agronomic practice (Mitchell et al., 1991). Therefore, integration of the recommended management options calls for due attention focusing on effectiveness and compatibility. Additionally, natural enemies such as egg parasitoid *Telenomus remus*, parasitoid such as braconid, tachinid and a *Cotesia* sp. have been reported as the most effective in controlling fall armyworm (Flanders, 2007; Rezende et al., 1994). Genetically modified maize varieties have been effectively used to control FAW in Brazil and North America countries (Siebert et al., 2008a; Siebert et al., 2008b; Waquil et al., 2010). Recently, several crystal protein genes (*cry*) gene families including *cry1A*, *cry1Ab*, and *cry1F* against FAW have been commercialized from *Bt* (Horikoshi et al., 2016).

CONCLUSION

Fall armyworm is a serious economic pest that spread in alarming rate following tropical and sub-tropical world. One's established in tropical and sub-tropics it is impossible to eradicate from a system due to environmental suitability. Several authors predicted that FAW can produce 10 to 12 overlapping generation in tropical condition which may influence production and productivity of the main host throughout a year. However, FAW interaction pattern with abiotic and biotic factors in tropical and subtropical still unclear. Due to such challenge farmers of these regions mainly depend on synthetic insecticide to tackle the damage inflicted by fall armyworm. Understanding overwintering sites and bioecology of FAW is vital to predict potential seasonal outbreak particularly in Sub-Sahara of Africa in specific agroecology, however only a few information have been documented. Base of quantitative data on yield losses and extent of damage specific to local agroecology are not well stated. FAW has wider host range list, but no detail data on extent damage and degree of affinity documented. Based on current evidence FAW is worldwide potential complex insect pest that can challenge crop producer, planner, policymaker, researcher in future crop production. During its life history, FAW evolved with life benefiting biological trait such as seasonal migration, non-diapausing life stage, short life cycle, high fertility and feeding of wider host range. Thus, understanding these biological traits interaction with specific agroecology can elevate practical knowledge to combat this pest. Similarly, understanding migration route based on wind pattern is essential for correct monitoring. Moreover, developing predictive model and monitoring network to generate farmer accessible management options.

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AUTHOR CONTRIBUTIONS

Tariku Tesfaye Edosa; conceptualization, information search, and wrote the manuscript. Teshale Daba Dinka: search the information and wrote the manuscript.

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