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Review

Impact of climate change on armyworm infestation on maize in Nigeria: A review

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Maize (*Zea mays*) is an important food crop in Nigeria, and it is fast becoming the most widely cultivated crop. Several efforts have been made by the Nigeria Government to make the country self-sufficiency in maize production, but some biotic and abiotic factors are impeding this achievement. Among the biotic constraints militating against maize production in Nigeria, armyworm (*Spodoptera frugiperda*) is most devastating in recent times. The larvae of this insect pest are the culprits that caused damage to maize plants. They leave several feeding holes on the leaf lamina of the crop, giving maize tattered appearance. The infestation level by armyworm on the field experienced by maize growers in recent times calls for great concern in Nigeria. This outbreak is not out of mere coincidence, but a result of numerous factors which is chiefly driven by climate change. Climatic change over the years has altered temperature, moisture, relative humidity and CO_2 concentration in our ecosystem. These changes seem to favour the proliferation of pests, even making secondary pests like armyworm to become a major pest of maize in Nigeria and Africa at large. In this paper, we reviewed the biology of armyworm, the influence of climate change on pest prevalence and some control measures for coping with armyworm infestation. Integrated pest management was advocated as the most sustainable management approach.

Key words: Armyworm, temperature, rainfall, maize, integrated pest management.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most superior cereal crops in the world due to its wide adaptation and varieties of utilization (Sesay et al., 2017; Fayeun and Sesay, 2019). It is a widely grown crop in most parts of the world, due to its adaptability, versatility, varieties and productivity. It is an annual and monoecious C_4 plant. Maize is usually 1.5 to 3.0 m tall, has 12 to 18 leaves with a fibrous root system and edible grains which serves as food for man and animals. In the human diet, maize is a good source of vitamin B1, vitamin B5, folate, dietary fibre, vitamin C, phosphorus and manganese (Australian Government, 2008). This makes it an important food security crops in developing countries (Adunola et al., 2019).

In Nigeria, annual maize cultivation and utilization has become a norm and tradition of the people. It is widely consumed by the populace as a staple food, in different forms of their diets. Maize is well adapted to different

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agro-ecological zones in the country ranging from the southern mangrove forest to the northern Sudan savanna (Olaniyan and Lucas, 2004). The crop is commonly cultivated with other crops (mixed cropping system) by small scale farmers and sometimes as a sole crop when planted on a large scale (Thayamini and Brintha, 2010). According to Olajoko and Olaoye (2007), maize grain yields in Nigeria between 0.8 and 8.0 tons/ha depending on the variety used, ecology, farming system adopted, and management practice involved. Despite cultivating about 6.3 million hectares of maize in 2019 (USDA, 2019), maize yield is low in Nigeria (about 1.7 tons/ha) compared to South Africa (5.86 tons/ha) (USDA, 2018) and United States (10.7 tons/ha) (Purdy and Langemeier, 2018). This is because of some limiting factors of maize production, which include low soil fertility, low yielding maize varieties, unproductive cropping system, climate change, low input supply, prevalence pest and disease just to mention a few (Ojo, 2003; Fayeun et al., 2017).

In recent times, the influence of pest infestation on maize took a new turn in Nigeria. This was observed as armyworm (*S. frugiperda*) (J. E. Smith) (Lepidoptera: Noctuidae) ravaged maize fields across the different agro-ecological zones (Goergen et al., 2016; Abrahams et al., 2017). The larvae of the armyworm caused tremendous damage to maize by feeding on the leaves, thereby, giving it a tattered appearance. Infestation by armyworm commences about one week after planting under favorable climatic conditions. The feeding by this pest stunts the vegetative growth as well as cause significant economic yield loss (90%) of maize when uncontrolled (Infonet-Biovision, 2017; FAO, 2019). The problem of climate change is the most important environmental challenge facing the world today. Climate change affects every life on the earth be it plant, animal, micro-organisms living in the air, water, on the ground and under the ground. The influence of climate change on life forms on earth is most severe in terms of heat and drought. The change experienced in our climate in recent times can be attributed to the activities of man. Agro-ecological environments around the world are also adversely affected by the change (Selvaraj et al., 2013). These changes in climatic conditions over time caused variation in the onset and cessation of rainfall, flooding, extreme heat, drought and outbreak of pests and diseases. An increase in temperature and change in rainfall patterns has made previous non pest or secondary pests become major pests. These factors favour the physiological development, migration and dispersal of armyworm (Risch, 1987). Therefore, this paper seeks to review and critically consider the impact of climate change on the outbreak of armyworm s in Nigeria.

MAIZE PRODUCTION IN NIGERIA

Out of the 1,108.62 million metric tons of maize produced in 2019 (USDA, 2020), Nigeria, the second largest producer in Africa produced 11 million tons representing 0.99% of the world's production. Maize production in Nigeria has greatly increased in the new millennium (from 4000 million tons in 2000 to over 11,000 million tons in 2019). The average maize grain yield increased from less than 1 ton/ha in the last two decades to more than 1.7 tons/ha in 2006 (Offiah, 2015). However, there has been relatively small increase in productivity since 2015. An average growth rate of 2.03% has been recorded over the past 5 years. This small growth in productivity can be attributed to the recurrent problems of agriculture in Nigeria and compounded by the recent armyworm infestation. Armyworm ravaged farmers' fields and caused significant yield losses as well as the high cost of production due to the additional cost of synthetic insecticide (FAO, 2018a). In addition to this, the Federal Government of Nigeria has expended about ₦5.8 billion ($15.2 million) on maize importation in 2017 to cushion shortfall as a result of the devastating effect of armyworm infestation (The Guardian, 2017). The attendant consequences of this have placed untold hardship on the populace; it affected agro-allied industries that depend on maize as their raw materials, increased prices of food and poultry products and in some cases loss of jobs (FAO, 2018a).

ECONOMIC IMPORTANCE OF ARMYWORM AS A PEST OF MAIZE

Armyworm is a cosmopolitan pest of maize. Though armyworm is the most important of the polyphagous insects feeding on cereals, yet it is an occasional pest (Olufade, 1974). An outbreak does not last for more than one generation on the same site (Brown, 1962). However, its outbreak has been reported over the years in developed countries like USA (Bessin, 2003; Cook et al., 2004; Peter and Fishers, 2006; Calvin and Tooker, 2009; DiFonzo, 2010). Most recently, several infestations by the larvae of armyworm on maize have been observed and reported in different countries in Africa (South Africa, Togo, Benin Liberia, Zimbabwe, Uganda, Niger, Lesotho and Nigeria) (Rose et al., 2000; IITA, 2016). According to Maiga (2017), armyworm infestation has been confirmed in Ghana, Zimbabwe and some cases have been recorded in Malawi, in Mozambique, in Namibia, and Zambia. In the past, armyworm occurred as a secondary pest of maize in Nigeria. They were not considered as a major pest by farmers because their populations were under the control of environmental forces. The 2016 cropping season for maize witnessed an unexpected armyworm infestation. Their infestation begins with very little obvious damage few days after the crop emerges on the field and causes irreparable damage within the first two weeks of planting. As rightly reported by IITA (2016), army worm attacks attributed to larvae of the genus

Spodoptera were made on maize plants in the rain forest of southwest Nigeria in late January and in IITA maize fields in Ibadan and a farm in Ikenne. The pest ravaged farmers' fields such that significant yield losses were recorded (IITA, 2016) as well as high cost of production due to the additional cost of synthetic insecticide. The report by USDA (2019) iterates farmers' concern about potential armyworm resurgence and their reluctant to cultivate maize having previously lost their crops despite collaboration with research institutes and agricultural stakeholders in the country.

Biology of armyworm

Armyworm is a highly polyphagous insect with wide host range of over 80 plant species (IITA, 2016). It prefers to feed on grasses, in particular, on economically important crops such as maize, millet, sorghum, rice, wheat, and sugar cane (Goergen et al., 2016). Armyworm developmental stages is divided four namely: egg, larva, pupa and adult. The adult is a stout moth approximately 2.5 cm long, with tan to grayish-brown wings that measure about 3.5 to 4.0 cm (Calvin and Tooker, 2009). The development of insects, like armyworm, is highly affected by deviation from optimum temperature, therefore, the rate of development, life-cycle duration and survival. There is increase in the body metabolism and activities of insect ambient temperature increase towards thermal optimum temperature.

The adult female lay about 10 to 300 eggs on the leaves of maize or surrounding plants, grasses in particular. The eggs are in clusters and are white. The eggs hatch into larva after 2 to 5 days depending on the prevailing temperature (Maiga, 2017). Ali et al. (1990) found that temperature between 17 to 38°C favours egg development while Du Plessis et al. (2020) found optimal egg development between 30 and 32°C. However, there is decline in egg development rate at 35.5 and 38°C. Du Plessis et al. (2020) also reported slow and very low percentage hatched eggs at constant temperature of 18°C. It has been reported that the optimum temperature for larval development is 28 °C but is lower for egg-laying and pupation (Maiga, 2017). Newly hatched larva is about 1 mm long, light green and moves in a looping motion. Young larvae feed on the underside of leaves mostly at night or during cloudy days, causing characteristic windowing of the leaves. Fully-grown larva is about 30 mm long, light green and pupates after completing sixth in-stars (averagely 15 days) (Calvin and Tooker, 2009). The rate of larvae development increases linearly with increase in temperature ranging between 21 and 33°C (Ali et al., 1990). The pupa falls into the soil before they emerge as adult at about 2 weeks later (Cook et al., 2004). Armyworm larvae pupate below the soil surface under field conditions at 2 to 8 cm depth (Sparks, 1979; Capinera, 2001). This growth phase exposes them to daily changes in soil temperatures (Simmons, 1993). Soil temperature in most sub-Saharan countries is above 30°C during dry season. The ability of armyworm pupae to survive and develop at high temperatures in the soil, therefore, provides an advantage for this pest in terms of its development and survival (Du Plessis et al., 2020). According to Busato et al. (2005) and Du Plessis et al. (2020), larval development takes 34.39 to 41.9 days at 18°C and 10.45 to 11.1 days at 32°C. Adults emerge at night and usually use their natural pre-oviposition period to fly several kilometers before settling for egg-laying, sometimes migrating over long distances. Generally, temperature plays important role in the overall development of armyworm. Busato et al. (2005) and Du Plessis et al. (2020) reported decrease in development period from 71.44 to 77.3 days at 18°C to 20.27 to 21.0 days at 32°C. Armyworms do not diapause which allows them to migrate to areas with more favorable environmental conditions (Luginbill, 1928). On average, adults live 12 to 14 days (Maiga, 2017).

Armyworms are nocturnal insects that actively feed on maize at night. They prefer eating the succulent portion of the leaves (meristematic region) making their infestation start from the whorl of the plant. Hence, they continue feeding on the leaf lamina until the plant is completely defoliated remaining the mid-rib. Infestation by armyworm on maize is most severe when the growing portion of the plant is fed on. This will stunt the growth of the plant and can result in significant yield loss. Feeding activities by this pest can significantly reduce the photosynthetic structures of the plant. Armyworm sometimes feed on the stem of the plant thereby causing the plant to break when blown by the wind.

Environmental temperature does not affect only the development of insects; it also impacts their competitivity, predatory and herbivory ability. Rise in environmental temperature increases the metabolic activities of insect which result is increase in food intake to compensate for energy lost (O'Connor et al., 2009; Vucic-Pestic et al., 2011; Lemoine et al., 2013). This could explain rise in voracious feeding by armyworm in recent times. Previous study by Stamp and Yang (1996) has found relationship temperature and quality of the growth of *Spodoptera* species. Singhal (1979) found increase in consumption, digestion and utilization with increase in temperature in *Poecilocerus pictus*.

During the maize reproductive growth stage, this pest eats up the ears and tassels, and can also bore into the cob and feed on the succulent maize grains. Armyworm outbreak is common in fields or surrounding fields that are predominantly colonized by grasses. Also, armyworm damage is common in no-till and grassy fields treated with post-emergent herbicide (Maiga, 2017). Damage by armyworms arises when the surrounding field is infested, and the pest migrates to continue feeding activities on maize. The first obvious symptom of armyworm infestation is small tattered holes scattered on the leaves rising or close to the whorl of the plant. Along with the foregoing, on top of the leaves are wet, round, green-brown pellet (feces) in the area (IITA, 2016). The pest is usually found hibernating in the whorl of the plant during the day. Infestations during the mid-to-late maize stage can result in yield losses of 15 to 73% when 55 to 100% of the plants are infested with armyworm (Maiga, 2017). Maize can recover from feeding activities by armyworm if feeding is moderate, growing portions of the plant have not been damaged and control measures are timely introduced.

CLIMATE CHANGE IN NIGERIA

The climate condition in Nigeria has changed in terms of rainfall and temperature since the 1990s. Between 1960 and 2006, the annual average rainfall has decreased by 3.5 mm per month per decade (WBG, 2020). There has also been shift in peak in maximum rainfall from July to September in Southern Nigeria and August to July in Northern Nigeria. In addition, significant rise in sea level was forecasted to be 0.3 m from the 1990 levels to 2020 and 1 m by 2050 (DFID, 2009; FME, 2014). The average temperature has significantly increased from 27°C in 1990s to 31 to 33°C in 2014 (WBG, 2020). Southern Nigeria has experienced more rise in mean temperature compared to the north with continuous change in vegetation type from rain forest to derived savanna. According to DFID (2009) and FME (2014), there could be 3.2°C rise in temperature by 2050 under a high climate change scenario.

EFFECT OF CLIMATE CHANGE ON PEST OUTBREAK

In recent decades, climate change resultant global warming has become an issue of serious concern worldwide for the existence of life on the Earth (IPCC, 2007). Average global surface temperatures have increased by about 0.7°C over the last 100 years. Also, CO_2 concentration in the atmosphere has increased drastically, 280 ppm in 1750 to 370 ppm in 2006 and is likely to be doubled by 2100 (IPCC, 2007). Global warming has been associated with the melting of polar ice and the increase of ocean water levels (Siegert, 2001). It has produced shorter and warmer rainy season, with earlier arrival of very hot dry season conditions (Salinger et al., 2005; Collins et al., 2007).

Climate change impact in Nigeria is felt through sea-level rise along the coastline, intensified desert encroachment, change in ecological pattern, erosion, flooding and degradation of arable lands. Climate change has been forecasted to have a devastating negative impact on agriculture by lowering crop productivity, especially maize over the entire country with a predicted loss of 30 to 50% by 2020 (BNRCC, 2011). Bello et al. (2012) observed that the changing rainfall pattern will increase the incidence of pests, diseases, drought and flooding which will result in food shortage and an increase in the cost of production, thus reducing profit farmers would have realized without climate change. Pest outbreaks are more likely to occur with stressed plants as a result of the weakening of plants' defensive system, and thus, increasing the level of susceptibility to insect pests (Sharma, 2016). Pest outbreak due to climate change have been reported in some crops, including sugarcane (Joshi and Viraktamath, 2004; Srikanth, 2007), rice (IARI, 2008), cotton (Dhaliwal et al., 2007), grapevine (Boudon-Padieu and Maixner, 2007), maize (Diffenbaugh et al., 2008) and pawpaw (Tanwar et al., 2010).

CHANGING CLIMATIC FACTORS AS DRIVERS OF INCREASED PEST POPULATION

Environmental factors such as temperature, moisture and CO_2 are the most important climatic conditions influencing the abundance, proliferation, migration and feeding habits of insects.

Effect of increased temperature on the armyworm population

Insects are poikilothermic organisms, that is, the body temperature of insect changes with change in environmental temperature (Bale et al., 2002; Menéndez, 2007) due to their lack of regulatory mechanisms that control temperature. Hence, temperature strongly influences the development, geographic distribution, and population density of insects (Andrea et al., 2014), including agricultural insects with unknown consequences in agricultural systems (Gutierrez et al., 2010). The prevailing change in climate which causes a rise in temperature can directly influence insects' physiology and behavior or indirect, as mediated by host plants, competitors or natural enemies (Thomson et al., 2010). Armyworms have been identified to develop quickly when temperatures average at about 29°C and develop much slower under cold conditions (Palumbo, 2011). Pogue (2002) reported that a minimum average temperature greater than 10°C enhances the voracious feeding of plant leaves and stem by armyworm. As stated by Yamamura and Kiritani (1998), insects might experience one to five additional life cycles per season with an increase of 2°C temperature. An increase in the surface temperature may have a profound effect on the initiation and termination of diapauses with a subsequent change in the voltinism (Sable and Rana, 2016). Some insect species may be affected by climate change if diapauses requirements have a lower chance of being met thereby disrupting developmental cycles (Ayres and Lombardero, 2000). For all the insect species, higher temperatures, below the species' upper threshold limit, will result in faster development, resulting in the rapid increase of pest populations as the time to reproductive maturity is reduced (Sharma, 2016).

Effect of increased moisture on the armyworm population

Moisture is an important weather factor that influences the growth, reproduction and survival of armyworm. Insects do not necessarily drink water; they obtain water through the type of food they feed on. Severe outbreaks usually coincide with the onset of the wet season, especially when the new cropping season follows a long period of drought (Goergen et al., 2016), which concentrate egg-laying moths and provide flushes of new grass as food for newly hatched caterpillars, and dry and sunny periods during the caterpillar development, which promote survival and rapid development. Silvain and Ti-A-Hing (1985) found that the highest populations of armyworm moths and larvae were observed during the rainy seasons and lowest during the dry seasons. Murua et al. (2006) also reported a positive associated response between rainfall and armyworm infestation which indicates that a rise in rainfall may also encourage the infestation of maize by armyworms.

Temperature and humidity change can influence insects indirectly by changes in host plant metabolism and physiology (Moore and Allard, 2008; Netherer and Schopf, 2010). Relative humidity or lack thereof can influence insect growth and behavior by affecting the insect's ability to regulate water loss (Palumbo, 2011). A study by Shahzad et al. (2014) showed that relative humidity was positively correlated with armyworm abundance. Warm humid weather condition prevailing in Nigeria is close to ideal for armyworm proliferation, growth and infestation. Also, the recent delay in the onset of rainfall observed across most agro-ecological zones in Nigeria might have been a contributing factor to this plague.

Effect of increased CO_2 concentration on armyworm population

Plants are important carbon sinks in the environment. Consequently, as a result of climate change, an increase in the atmospheric CO_2 will cause an increase in the ration between Carbon and Nitrogen (C:N) in plant tissue. Hence, compensatory feeding by insect herbivores like armyworm is expected to make up the reduced nitrogen content in the plants. Caterpillars may eat larger portions of plants grown in enriched CO_2 environments due to nutrient dilution in the plant tissues (Sable and Rana, 2016). Hamilton et al. (2005) noted that soybeans grown in elevated CO_2 atmosphere had 57% more damage from insects. Hamilton et al. (2005) further reported in their study that increases in the levels of simple sugars in the soybean leaves may have stimulated the additional insect feeding. Therefore, it can be said that increased CO_2 concentration in the atmosphere as a result of climate change results in increased sugar accumulation in plant tissue which might enhance voracious feeding by armyworm. Young maize plants are more severely damaged during attack by armyworms because they have succulent tissues and considerably lower C:N ratio compared to matured tissues of older plants. Coviella and Trumble (1999) noted that the increased C:N ratios in plant tissue resulting from increased CO_2 levels may slow insect development and increase the length of life stages vulnerable to attack by parasitoids.

Effect of climate change on natural enemies of armyworm

Majority of insects are benign to agro-ecosystems, and there is much evidence to suggest that it is due to population control through interspecific interactions among insect pests and their natural enemies (pathogens, parasites, and predators) (Sharma, 2016). Natural enemies play important roles in checking the population of armyworms on the field. Important natural enemies of armyworm include *Trichogramma wasp* (*Trichogramma* spp.), lacewing (*Chrysopa* spp.), ladybugs (*Coccinella* spp.), pirate bugs (*Orius insidiosus*), and nematodes (*Heterorhabditis bacteriophora*, *Heterorhabditis indica, Steinernema carpocapsae*) (Negrisoli et al., 2010). Climate change affects the potency of these natural enemies in pest control. The efficiency and population of natural enemies can be adversely affected by the change in temperature, CO_2 and moisture. Climate change could cause the acceleration in developmental stages of insect pests such that there is a shorter time of exposure to adverse environmental conditions such as low temperature, too high or insufficient humidity, attacks of predators and parasitoids, and entomopathogen's activity (Jaworski and Hilszczanski, 2013). The susceptibility of the plant-feeding insects like armyworm to predation and parasitism as influenced by climate change could decrease (Linda et al., 2010; Sikha et al., 2011):

(1) Through the production of additional plant foliage or altered timing of herbivore life cycles in response to plant phenological changes;
(2) If pest distributions shift into regions outside the distribution of their natural enemies;
(3) Through adaptive management strategies adopted by farmers to cope with climate change and;
(4) If the pest population grows quickly through their susceptible stage to predation or parasitism.

One or a combination of the foregoing will limit the potency of the natural enemies for effective biological control of armyworm.

MANAGEMENT STRATEGIES FOR COPING WITH CLIMATE CHANGE AND ARMYWORM INFESTATION

Prior to the 2016 cropping season in Nigeria, infestation of maize by armyworm has been a secondary problem which farmers often do not consider as a serious threat compared to stem borers (*Busseola fusca*) and grasshoppers (*Zonocerus variegatus*) (Ofor et al., 2009). This makes the devastation of maize fields by this pest sudden and unforeseen by both farmers and agricultural stakeholders. The change in the pest status of armyworm can be much attributed to the effect of climate change. Climate change variables experienced in terms of delay in the onset of rainfall and high temperature (DFID, 2009; FME, 2014) contributed greatly to the outbreak of this pest. According to Phiri (2017), armyworms outbreak is highly dependent on the seasonal patterns of wind and rainfall. He added that with continual change in weather pattern in Africa, these factors will drive the increase or decrease in armyworm outbreaks. Climate change factor like rise in temperature can alter the phenology of plant and pest with likely impact on synchronization between the two. This could indirectly influence the activity of natural enemies and the effectiveness of their natural control (Prasad and Bambawale, 2010). A study by Hulle et al. (2010) found that increase in temperature of merely 2°C could increase the number of generations of aphids per year from 18 to 23 and result in a larger population size. This could explain the low influence of natural enemies' in natural control, further compounded the problem as the pest population greatly outnumbered that of the natural enemies.

As a reactive measure, farmers resulted in the indiscriminate use of available synthetic chemicals for armyworm control. This seems to control the pest at first, but pest resurgence was observed as the pest continued their voracious feeding on the crop causing the plant to be greatly devastated (Fayeun, personal communication, 2016). Higher dose more than the recommended rate of this insecticide and repeated spraying was adopted by farmers to control the pest.

However, a significant level of recovery was observed when rainfall became steady alongside with the spraying of insecticides. This renders the sole use of synthetic insecticides not only ineffective, uneconomical and unsustainable but also poses health and environmental hazards to farmers, consumers and the ecosystem (Sisay et al., 2019). According to Petzoldt and Seaman (2007), the increased number of generations per year and frequent population outbreaks of potential insect pests necessitate continual applications of a high amount of insecticides and that will make the insects to develop resistance against these chemicals. Also, global warming will reduce the effectiveness of host plant resistance, transgenic plants, natural enemies, biopesticides, and synthetic chemicals for pest management (Sharma, 2010). Sustainable measures should be devised if success will be achieved in the battle between man and armyworm over maize. Integrated pest management (IPM) approach is one of the most sustainable measures of pest control because it is holistic. IPM is a dynamic process that makes use of an ecological systems approach and encourages the user or producer to consider and use the full range of best pest control options available given economic, environmental and social considerations (FAO, 2013). Heeb et al. (2019) also recommended Climate-smart pest management which includes the integration of local climate observation and forecasting, as well as pest risk assessment, into the pest management planning process. Given this, some components of IPM that can bring about sustainable control of armyworm and good maize productivity in the wake of climate change are discussed in the following.

(1) Monitoring and early warning: The primary control of armyworm in the context of changing climatic condition is by establishing strong in-country and community monitoring of pest incidence (pest risk) and natural enemies under prevailing and forecasted weather conditions. This involves field scouting, use of pheromone traps for sampling, quality data collection and creation of a strong database that will help in developing models, data visualization and prediction of possible future outbreaks. This information will help to provide early warming to farmers and prepare for immediate counter measures that will prevent economic damage attributed to such outbreak. According to FAO (2017), early warning should be made up of a centralized cloud-based platform comprising global database connected to a geographic information system (GIS). The Nigeria Federal Ministry of Agriculture should mimic the system adopted during agro-input distribution to farmers through text messages in sending early warning and assisting farmers with armyworm control advice. Government also should raise more awareness, enact relevant policies and regulations that will speedup evaluation, registration and quality management of armyworm management options.

(2) Use of synthetic insecticide: As earlier stated, the use of insecticide seems to be the immediate answer to the armyworm problem. However, its overuse could lead to the emergence of regional populations resistant to several classes of pesticides (Adamczyk et al., 1999; Togola et al., 2018). Monitoring activities together with the alternated application of insecticides such as pyrethroids, carbamates and organophosphates are recommended as an immediate measure during the early detection of young larval stages (Goergen et al., 2016). A recent study by Sisay et al. (2019) also recommended the application of Karate 5 Emulsifiable concentrate (EC),

Coragen 200 Concentrate Suspension (SC), Radiant 120 SC, Dimethoate 40%, Tracer 480 SC, and Ampligo 150 SC due to its effectiveness in increasing larval mortality of armyworm, reducing leaf damage, and increasing biomass in maize. The recommended rate of synthetic insecticides which poses less harm to natural enemies should be adopted. Farmers should be sensitized about the danger of over-application of synthetic insecticides. Application of the insecticide should be done early in the morning or late in the evening or on cloudy days when the pest is most active. The whorl of the maize plant should be targeted during application. As stated by Goergen et al. (2016), the use of chemicals should be based on pest incidence thresholds, primarily meant to better protect young plants and reproductive stages of maize.

(3) Weeding: Timely weeding of the field will reduce the chances of egg-laying by armyworm moth as well as migration from weed to maize plant. All plants that may serve as secondary hosts, should be removed from the field and the field surroundings, especially grasses and amaranthus (Maiga, 2017).

(4) Suitable cropping system: Cropping system describes how land is used for crop production, over a period, depending on available farm resources. FAO (2018b) reported that armyworm prefers laying in monoculture maize fields while maize in mixed cropping system often record reduced oviposition. The interaction between maize cultivation and other types of crops as well as management systems can help to boost the activity and abundance of natural enemies. It may also minimize the suitable habitat for the pest to hibernate during the off-season. The identification and introduction of plants that houses and enhances the proliferation of natural enemies will also be an easy and cost-effective alternative. Inter-cropping maize with non-host plants will limit the oviposition, feeding and migration of the pest. Rotation of crop on the field will reduce food source and oviposition which may significantly reduce recurrent pest infestation every growing season. Low-value trap crops like finger millet can be planted at different points on the field to tarp the pest and then destroy once infested.

(4) Use of tolerant or resistant varieties: Now that the problem of armyworm is considered important, tolerant or resistant maize varieties that can withstand feeding damage by armyworm without significant yield loss should be identified, recommended and adopted by farmers. Also, maize varieties that can quickly grow pass its susceptible stage to the pest should be used for subsequent cultivation. The use of maize varieties with thick epidermis is recommended. Also, transgenic Bt-maize should be considered as recommended by Goergen et al. (2016).

(5) Soil management: Tropical soils are generally low in organic matter. In a bid to minimize feeding damage by armyworm, soils should be amended with fertilizer from both organic and inorganic sources. This will reduce the voracious feeding by the pest as it would not need any compensatory feeding due to the low C:N ratio of the maize plant. Soil amendment application will also help young maize plants to grow quickly pass their susceptible growth stage.

(6) Plant breeding: This is a wakeup call for research institutes, universities, private organizations, ministry of agriculture and other government establishments to join forces in combating this problem. Maize lines expressing armyworm resistance should be identified by scientist and the resistance gene should be transferred to elite maize varieties cultivated by farmers. Collaborative efforts should be encouraged among researchers to share information that will hasten the quick release of armyworm resistant varieties. Also, resistance genes from *Bacillus thuringiensis* (Bt) maize varieties can be introgressed into the elite maize germplasms widely cultivated in the country. Transgenic crops have been reported to be effective in controlling targeted pests while causing little or no harm to non-target organisms (Wu et al., 2008; Carpenter, 2010). In order to prevent unprecedented field-evolved resistance to Bt maize previously reported in Puerto Rico, South Africa, Brazil and United States (Huang et al., 2014; Ferreira da Silva, 2015; Farias et al., 2014), stacking multiple transgenes (for example, VIP3A and Cry1Ab) expressing two or more Bt proteins with high insecticidal activity against the same target pest (Ghimire et al., 2011; Carrière et al., 2015) have the potential for delaying development of resistance.

(7) Biological control: Armyworm populations are often kept below damaging numbers by natural biological control (Peters and Fisher, 2006). Many parasitic *hymenoptera*, acting as larval parasitoids, have been grown from armyworm, and many predators are reported; it appears that natural controls are of considerable importance (Maiga, 2017). *T. wasp*, Tachinid flies, lacewing, ladybugs, pirate bugs, larva predators, birds, and nematodes are some of the important natural enemies of armyworm. Their destructive effects on armyworm include direct feeding, deposition of egg on armyworm larva, injecting paralyzing venom, etc. In the Nigerian situation, where most farmers cultivate small scale farms, the recommendation of augmentation of the natural enemy population by artificial introduction might not be adopted. However, big farms can adopt the release of natural enemies of armyworm like *T. wasp*, Tachinid flies, lacewing, ladybugs and pirate bugs. These natural enemies do not only control armyworms, but other pests of maize such as earworms, cutworms, and aphids may also be effectively controlled alongside. Also, the use of endophytic entomopathogenic fungi is still in its infancy and needs increased attention for providing viable alternatives to conventional insecticides (Goergen, 2016).

(8) Use of bio-pesticides: Formulations from plant origin (Neem, acalypha, euginia, etc.) that are potent as biocontrol agents should be experimented for the control

of armyworm. Also, their potency and efficacy under field conditions in the wake of climate change should be well tested before recommendation for use.

CONCLUSION

The infestation level by armyworm on the field experienced by maize growers in recent times calls for great concern in Nigeria. This outbreak is not out of mere coincidence, but a result of numerous factors which is chiefly driven by climate change. The larva of armyworm is the destructive stage of the pest, feeding on the leaves, whorl, stem and reproductive structures (ear and tassel) of the plant, stunting the plant's growth and causing significant yield loss when uncontrolled. The change in climatic conditions over the years has altered temperature, moisture, relative humidity and CO_2 concentration in our ecosystem. These have in a way favoured the proliferation of pests, even making secondary pests like armyworm become major pests of maize in Nigeria and Africa in general. Sustainable measures as recommended in this review should be implemented by research institutes, federal and local authorities, farmers and major stakeholders in the agricultural sector of the country if success will be achieved in the battle between man and armyworm over maize. Here, we suggest the integrated pest management approach towards achieving lasting and sustainable maize protection against armyworm under changing climatic condition in Nigeria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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