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PREFACE: The 2nd International Conference on Sustainable Cereals and Crops Production Systems in the Tropics (ICFST)

The 2nd International Conference on Sustainable Cereals and Crops Production Systems in the Tropics (ICFST) was held on 23-24 September 2021 in Harper Hotel Makassar, Indonesia. The Conference was organized by Indonesian Agency for Agricultural Research and Development (IAARD)-Ministry of Agriculture of Indonesia, collaborated with International Maize and Wheat Improvement Center (CIMMYT) and Ministry of Research, Technology and Higher Education of Indonesia.

The theme of the conference is “Strengthening Agricultural Resources Management to Support Food Security and Industry 4.0” with the sub themes of Breeding and Biotechnology, Crop Production Systems, Pest and Disease Management, Post Harvest, Socio-Economy and Community Development. The conference was conducted in two days offline/on site and virtual scientific sessions. Due to the pandemic reason, offline/on site meeting was limited to a maximum of 100 participants and the remaining 900 participants joined via virtual zoom meeting. The conference facilitate the research community focusing in food crops and provide platform for scientists to meet and interact with each other to share their knowledge and their research results along with the obstacles and challenges they faced in their development, achievement as well as experiences through the presentation of papers and discussion. This international conference is also an event to establish cooperation in the development of food crops research in the future as well as enhancing the knowledge of environmental protection with the current agricultural technologies.

We would like to convey our deepest gratitude to the Minister of Agriculture of Indonesia, Keynote Speakers: Dr Kevin Pixley (Director of Genetic Resources Program CIMMYT & the CGIAR Research Program), Prof. Keerti S. Rathore (Texas A&M University, USA), Dr. Juan Landivar Bowles (Texas Agrilive-USA), Prof Bunyamin Tar’an (University of Saskatchewan Canada), Dr. Yu Shin Nai (Chung Sing University-Taiwan), Dr. Naori Miyazawa (Nagoya University), sponsors, organizing committee and also to all participants.

We also would like to express our deepest gratitude to the Indonesian Agency for Agricultural Research and Development (IAARD) conducted such conference. We are looking forward to the 3rd ICFST that will be held on September 2023 in *Bali Island*. We expect that these future ICFST conference will be as stimulating as this most recent one was, as indicated by the contributions presented in this proceedings volume.

Makassar, 23-24 September 2021

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Different controlling methods of fall armyworm (*Spodoptera frugiperda*) in maize farms of small-scale producers in Cameroon

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Abstract. Fall armyworm (FAW) is a polyphagous and voracious pest, destroying maize plants in farms in Cameroon. An annual yield loss is estimated to range from 15 to 78%, valued at US\$ 2,481 to US\$ 6,187 million. With most damage experienced in the mono-cropping system. Maize is the most widely grown cereal crop globally due to its several uses, namely human consumption, animal feed and biofuel. In Cameroon, maize is a staple food grown by small-scale producers in all ten regions. The control of FAW is unsuccessful with only the use of pesticide method, the application is knowledge-intensive, and misuse often leads to pesticide resistance, resurgence and increased production cost. The purpose of this review was to explore the different controlling methods adopted to suppress FAW from causing economic damage in maize farms of small-scale producers in Cameroon. Integrated pest management (IPM) approach was used to control FAW, including cultural control, chemical control, botanicals, push-pull farming system, biological control and indigenous knowledge. Results showed that push-pull farming system provides protection and improves maize nutrition, botanicals have similar efficacy like synthetic insecticide, and wood ash is a bio-pesticide. The combined application of pesticides and handpicking FAW was effective though feasible in small surface areas. Based on the general assessment, the push-pull farming system deserves to be promoted due to its numerous benefits: eco-friendly, enhancement of natural enemies, increased soil fertility and economic returns. Natural enemies and bio-pesticides application are essential to control FAW since farmers are resource-poor, causes no health problem and are environmentally friendly.



1. Introduction

Maize (*Zea mays L.*) is one of the most widely used cereal crops in the world, third after wheat and rice due to its many uses, including human diet, animal feed, biofuel and construction [1]. Therefore, maize is known to sustain the capacity to reduce food insecurity and improve the living standards. Currently, it is used as a biofuel, renewable energy which helps to mitigate climate change effect, thereby increasing crop productions. The global production of maize in 2016 was estimated at 1.291 million tons [2], and in Cameroon the production was 2.100 tons in 2019 [3]. Maize is a staple food to millions of people in the world particular in Sub-Saharan Africa (SSA), where the surface area of cultivation stands at 36 million hectares [4].

Cameroon is a SSA country located in the tropical belt of the globe [5]. The production of maize was introduced in Cameroon in the 16th century by the Portuguese, and serves as employment to many communities, providing income to about 3 million small-scale producers [6]. In Cameroon, maize cultivation is performed in the five agro-ecological zones in the ten regions with highest production in the West and Northwest [7]. It contributes to an estimated amount of CFAF 5.6 billion to the gross domestic product (GDP) to the economy of Cameroon. Maize is largely produced by small-scale producers in rural communities and supplied to urban communities. Further, it is a source of livelihood to farmers, providing incomes to approximately 3 million small-scale producers [8]. Nonetheless, much is still being imported to meet the deficit faced by the different sectors in the country such as the animal production sector, industrial (e.g brewery), etc. Generally, maize differ according to their characteristics such as colour, shape and size, taste and nutrient content. In Cameroon, the varieties frequently produced differ in size and the kernel pigments are either yellow, red, and white. The most consumed variety in Cameroon are yellow and white. The choice of the selection for what type to consumed depends on the method of preparation and the eating habit of the community. While for industries, it depends on the manufacturing of the product and the market preference [9].

The maize supplies half of the intake of calories in the rural and urban communities in Cameroon. Maize is consumed in different forms namely; roasted, boiled, porridge ‘corn chaff’, pudding, processed to local corn beer, and also as flour for making doughnuts. Besides its high carbohydrate content (72%) for energy, is comprised of vitamins A, B1, B2, B3, B4, B5, B6, C and E, 9% protein, 5% fat, 2% dietary fat, 2% ash, and essential minerals [10]. Unfortunately, the amount of maize produced by smallholder farmers in Cameroon has been dwindling from 2009 to 2019 but worsen from 2015 to 2019 [11], producing a difference of only 1.75 ton/ha (Table 1). This declined is attributed to serious damages caused by fall armyworm (FAW), which combined with other pests such as maize stem borer and weaver birds [12] to skeletonise maize. Maize production in Cameroon like other countries in the SSA is faced with plethora of constraints categorised into biotic and abiotic factors namely; poor soils fertility, droughts, crop pests and diseases, weeds, unfavorable climate change [13-15].

Fall armyworm, *Spodoptera frugiperda* (J. E Smith) belongs to the Order (Lepidoptera) and Family (Noctuidae), same with *Busseola fusca*. Currently, FAW is the major problem faced by small-scale producers of maize in Africa and other regions of the world. Its originated from the Americas [16]; [17] and migrated over long distances with an average flight of about 100 km in a single night [18]; [19]; [17]. Its migratory capacity has sustainably enhanced it spreads in all continents of the world in a very short period. Researchers in different regions of the globe have proven this pest to be destructive to crops in tropics and subtropics. FAW is polyphagous and voracious pest damaging several crops about 76 plants with over 106 plant species in the Family Poaceae, 31 Fabaceae and 31 Asteraceae [20]. It infests food crops such as maize (*Zea mays L.*), sorghum (*Sorghum bicolor (L.) Moench*), cotton (*Gossypium sp. L.*), millet (*Panicum miliaceum*), peanut (*Arachis hypogaea L.*), rice (*Oryza sativa*), and others [21]; [22]. Besides, FAW is the major pest to maize [23], reducing its yield to 40% in a mono-cropped system [24]. Some of the damages include loss of photosynthetic area by consuming the leaves, lodging, retard growth, impaired reproduction, damaged fresh kernel, destroys leaf whorl, tassel and ears [25]. There are basically two main strains of FAW namely the rice and maize strains [26] with the maize strain being the most dominant [27]. In 2017, both strains were identified in Cameroon [28]. The

devastating damage of FAW increase food insecurity in countries affected especially in developing nations.

Integrated pest management (IPM) is a holistic approach of managing the growth of insect pest's population through proper combination of methods, including cultural, biological and minimal use of synthetic chemicals to prevent economic damage. According to Stern et al., (1959)[29], IPM is defined as "applied pest control which combines and integrates biological and chemical control." The main objective of IPM is to prevent the population of the pest from rising above the economic injury level by resorting to the use of appropriate method and/or use of right dose of pesticides as a last measure to control the pest. IPM emphasizes is to cultivate a healthy crop within minimal disturb in the ecosystem and encouraging mechanism that promotes natural pest control method and reduce the negative externalities to human health and the environment [30]

The purpose of this review was to explore the different controlling methods adopted by small-scale farmers in Cameroon to suppress FAW from causing economic damage in their maize farms. This review is expected to benefit stakeholders in maize production and usage including farmers, students, agricultural experts, government, and donors both national and international. Primary and secondary literature were used to analyse the FAW status and propose mitigation techniques.

Table 1. The dwindling yield of maize production in Cameroon

Year	Value/tones	Change/%
2019	2,100	-10.45
2018	2,345	4.41
2017	2,246	3.79
2016	2,164	4.49
2015	2,071	5.72
2014	1,959	18.94
2013	1,647	-5.89
2012	1,750	11.32
2011	1,572	-5.87
2010	1,670	2.77
2009	1,625	16.07

Source: World data atlas, (2019)

2. Distribution of Fall Armyworm

FAW originated from the Americas and in 2016, it was reported in Central and Western African countries; Nigeria, Togo, Benin, and the island of Sao Tome [31] and in 2018, it has spread to over 44 African countries. FAW first report in Cameroon was in 2017 by researchers of the International Institute of Tropical Agriculture (IITA). And in 2021, a new variety of Southern armyworm (SAW), *Spodoptera eridania* was reported in Cameroon [7]. Besides its origin and in Africa, it was found in many Asian countries in 2019, including Yemen, India, Indonesia, Thailand, Myanmar, China and Sri Lanka, Laos, the Philippines, Malaysia, Viet Nam, Cambodia, the Republic of Korea and Japan. In 2020, FAW was reported in Australia, Mauritania, Timor Leste and the United Arab Emirate. And in 2021, it was found in New Caledonia and Europe at Canary Islands in Spain [32]; [33]; [34]; [35].

2.1 Agro-ecological zones and climate change of FAW in Cameroon

The FAW migrates very fast at the speed of 1600 km in 30 h, and within a single night, it can cover 100 km [19]. It was very easy for the pest to get into Cameroon due to its rapid migratory ability. Hence, moving from Nigeria to Cameroon is simple because both countries shared a common border. However, before the first report in Cameroon, smallholder farmers had suffered devastating damages from FAW in March and July, 2015 cropping season. On 18 December 2015 in Foubot, Western region of Cameroon a team of IITA researchers undertaking field training of smallholder farmers on Integrated Management of Maize Pests observed devastating damages [36]. They collected the pest for incubation and identification at the Insect laboratory, University of Douala. It was identified from the literature

published in March 2016 by Goergen and colleagues on FAW in Africa. Most probably the pest was available in Cameroon before it was first reported in Africa [37]. Officially, the FAW was reported in Cameroon in 2017 [36]. Environmental factors such as temperature, relative humidity and rainfall directly influence insect pests' reproduction, development, distribution, and survival [38]. Early et al (2018) reported that FAW inhabits regions with similar climate like its native origin with an average minimum temperature ranging from 18-26°C and rainfall of 500-700 mm. Similar temperature range is found in Cameroon. In addition, Cameroon has two climatic zones namely, tropical and equatorial zones [5]. Thus, Cameroon is commonly referred to as "Africa in miniature", due to her variation in climates, cropping systems and crop diversities and possess similar features with many other Africa countries in the SSA region. Furthermore, the ten regions of Cameroon are partition into five agro-ecological zones (AEZ) (Table 2) and in 2019, FAW was reported to be residing in all zones. In 2020, [7] investigated the presence of the natural enemies of FAW in the five agro-ecological zones in Cameroon. According to Fotso et al., (2019) [28] survey of FAW, they found no FAW in ARZ I during their investigative studies of the pest in the off-cropping seasons in February and March. ARZ 1 is an arid and semi-arid region characterized with drought so at off-cropping season there is no rainfall. Therefore, no swampy areas for cultivation of crops. The most likely reason while no FAW was observed. The climate in Cameroon is believed to be favourable for the growth and spread of the pest because of its presence in all regions [28].

Table 2. Agro-ecological zones (AEZ) in Cameroon and survey of Fall armyworm

AEZ	2017 survey			2019 survey			2020 survey	
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	Total
Zone I				13	51			64
Zone II	4	5	2					11
Zone III	31	35	41					107
Zone IV	19	20	26	17	7	12	7	108
Zone V	53	52	68	75	26	17	15	306
Total	107	125	188	105	84	29	22	596

Zone I: Soudano-sahelian zone (North and Far North regions), Zone II: High Guinea savannah (Adamawa region), Zone III: Western Highlands with savannah vegetation and mono-modal rainfall (West and Northwest regions), Zone IV: humid forest with Monomodal rainfall (Littoral and Southwest regions) and Zone V: humid forest with bimodal rainfall (Center, South and East regions) [7];[28].

2.2 Status of Fall armyworm in Cameroon

Fotso et al., (2019) [28] reported the presence of two species of FAW which constitutes the rice and maize strains in Cameroon. Maize strain is found in South Africa, Indonesia and US whereas rice strain has been reported to be found in Nigeria, Tanzania, Brazil, Costa-Rica, and Sao Tome as well as the maize strain [39];[40];[34]. FAW was observed in a field experiment on maize for both first and second cropping season at the West and Southwest region (SWR) of Cameroon [41]; [42]. The presence of the pest in all regions elucidated the high migratory capacity and adaptability to varying environmental conditions. As mentioned above, environmental conditions, particularly temperature, are responsible for its distribution, rate of infestation, severity, biology of insect, distribution and activity of natural enemies in the ecosystem. Temperature is accountable for the rise and fall in pest population. In many districts in South Africa, smallholder farmers involved in vegetable farming, including maize for both dryland and irrigated systems reported increase pest incidence due to high temperature [40]. Those implementing irrigated system frequently observed increased pest attacks during the warm winter planting season. This corroborated with similar findings in the SWR of Cameroon, where farmers reported increased pest damage in maize farms by *B. fusca* in the second season of planting [43]. Based on this phenomenon, therefore, FAW are vulnerable to rainfall. Moreover, the peak of the rainy season in Cameroon usually occurs between May and July, which recorded the lowest FAW infestation on maize in all regions except

North which registered the highest compared to the next season. The exception is attributed to climate change or abnormal weather conditions in a cropping season due to delay rainfall. The South armyworm (SAW) was detected in the maize fields in Cameroon by IITA researchers.

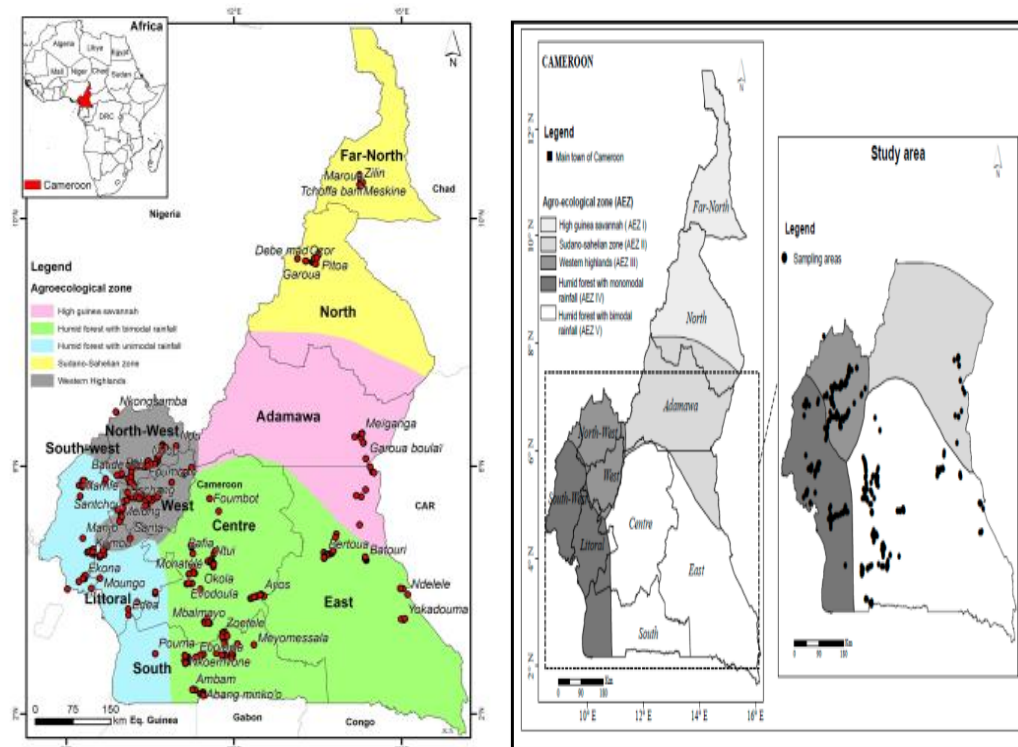


Figure 1. Map of Cameroon on the left (red dotted spots) shows field survey studies of fall armyworm in all ten regions and the right (dark dotted spots) shows survey studies of natural enemies of fall armyworm [7];[28].

2.3 Season fluctuation in Cameroon

FAW cause huge damage because of its high migratory ability and can attack many host plants. Hence, the pest has many food sources for rapid reproduction. FAW survive in extremely hot areas with an optimal temperature of 28 °C. Although the rate of reproduction is substantially quite low due to the harsh environmental temperature. This fact buttresses the result obtained in the three surveys conducted in Cameroon, where the lowest number of FAW was recorded in the Zone 1 (Table 2). The Zone I (North and Far North) is the hottest region in Cameroon both in the major cropping season (rainy season) and off-cropping season (dry spell). In Cameroon, the pest population increase during the major cropping period from March to July, when most farmers cultivate. To mitigate this damage the biology of FAW and different controlling methods have to be deployed.

3. Biology of Fall armyworm

The proper knowledge of the biology of a pest (life cycle) is a prerequisite to successfully control it. The life cycle provides understanding of its activities and various aspects of the bio-ecology system.

3.1 Generations of FAW

The duration of FAW generation is substantially influenced by the environmental condition combined with adequate food availability. The reproduction is efficient in the tropical regions, which attained several generations within a cropping cycle because of warm temperature. Whereas in the temperate regions barely few generations are attained. For instance, in some tropical and subtropical regions specifically in regions without frost, FAW can produce 10 generations within a year [44]. The

migration of FAW is influenced by environmental conditions. The FAW thrives above temperature 10°C usually when the weather is warm, and also during humid growing seasons with heavy rainfall which enable survival and population increase. When environmental conditions are suitable, several generations of FAW overlapped for a single cycle of crop production. Hence, it does not diapause. Its generations have been observed throughout the year in the presence of host plant including during off-season and irrigated crops [45]. In areas where the host plant was previously cultivated, it is most likely that there will be an early infestation in the main season which may lead to outbreak. Reason for proper sanitation of field previously cultivated with maize. Stalk should be removed from field either offer to animals as feed or compost as organic manure. Additionally, it could be heap on wood stump in the field or rock and burn. All these measures geared to avoid the presence of eggs, larvae and pupae in the field. Whereas, in the Americas, the cooler temperature causes the population to die out. The FAW is a persistence pest which is present year-round in bimodal rainfall pattern because of the migratory ability. In areas where the population cannot be increased year-round, it could be vulnerable to migratory FAW from areas with permanent population. The damage could be severe when both fields are closer to each other. However, research is needed to observe the population persistence, dispersal and migration in Africa including monitoring the conditions favouring survival in several areas in Africa using radar and Internet of Things. Additionally, night study could be performed to determine the pest behaviour since its nocturnal insect.

3.2 Morphological identification

The morphology of FAW is similar to other members of the Order and Family such as Spotted stem borer (*Chilo partellus*), African maize stalk borer (*Busseola fusca*), African cotton leafworm (*Spodoptera littoralis*), beet armyworm (*Spodoptera exigua*) and African armyworm (*Spodoptera exempta*). FAW has distinctive features at adult caterpillar phase to separate it from other species. The FAW has four pimples-like dark spots with hair on it, making it look rough to the sight. However, it has a smooth to tough body. The body is segmented with each segment comprises of four dark spots that could either be squared or unsquared form from the first to the last. While the head region is marked with white and dark Y-shaped with a chewing mouth part as shown in Figure 2. [46]. The female and male FAW can be distinguished at the pupa stage using the genital opening and the anal slot. The distance between the female genitalia and the anal slot is larger compared to the male [35]. The forewing of females are uniform with greyish brown to a fine mottling of grey and brown. In contrast, the forewings of females are coated with grey and brown, triangular white patch at the apical region and circular spot at the centre of the wing. Sharanabasappa et al., (2018) [35] found that the average wing length ranges from 3.00 to 3.4, and 3.00 to 3.50 for female and male, respectively. Both the hindwing of female and male FAW is silver-white with a narrow dark border [47]; [35]. Detailed morphological characteristics have been reported by [34].



Figure 2. Identification of FAW (Benson, 2017)

3.3 Life cycle of Fall armyworm

The FAW has a complete metamorphosis made of egg, larva, pupa and adult (Figure 3a). In summer, the life cycle is completed in 30 days, 60 days in the spring and autumn, and in winter it ranges between 80-90 days [48]; [49];[35].

Egg

The pre-oviposition, oviposition and post oviposition periods of FAW range from 3-4, 2-3, and 4-5 days, respectively. Female lays from 835 to 2000 eggs on the upper and lower surface of the leaf, near the base of the stem and leaves, and in the whorl [48];[22];[35]. Eggs are laid in clusters and are covered with a greyish scale which gives it a mouldy appearance. Sometimes, colour change may occur from pale yellow to creamy white and light brown [50], however, it turns black before hatching [35]. The egg is domed shaped with a broadly flattened end while the other end round pointed apex curved upward. Additionally, it is dorso-ventrally flattened. The egg height is approximately 0.3mm and 0.4 mm for the broad end. The temperature of 20-30 °C provides appropriate incubation conditions for between 2-3 days.

Larva

The larvae phase ranges between 14-30 days in summer [51] and completes six instars with different colour types and width sizes [35];[48]. The first instar is greenish with blackhead that changes to orange colour. The first instar has the shortest length of 1 mm compared to the sixth instar with the longest of 45 mm [45]. The head of the six instars is reddish brown with mottling of white lateral lines, and the body is covered starting from the fourth instar to the sixth instar [52]. On the dorsal surface are black pimples-like spots with hairs [35]. The larvae have four pairs of fleshy abdominal prolegs in addition to the pair at the end of the body [53].

Pupa

The pupa stage usually occurs in the soil at a depth 2 to 8 cm from 20-30 days in summer. larva forms a loose cocoon 20 to 30 mm long and oval shape by silking soil and leaf debris. However, when the soil is hard other soft materials and decay like decay/softwood are used to construct cocoon. The pupa is reddish brown, and its length and width range from 14 to 18 mm and 4.5 mm, respectively. Duration of the pupal stage is about eight to nine days. The pupal phase cannot withstand prolong periods of cold weather. For instance, [54] studied winter survival of the pupal stage in Florida, and found 51 percent survival in southern Florida, but only 27.5 percent survival in central Florida, and 11.6 percent survival in northern Florida. The pest survives in soil mixed with sand such as clay-sand and sandy clay, where pupation occur till adult [55].

Adult

The adult male with FAW of 1.6 cm and 3.7 cm length and wingspan is smaller than the female with a body length of 1.7 cm and a wingspan of 3.8 cm. Male can be easily be distinguished with its forewing that is mottled and contains a discal cell having straw color on three quarters and dark brown on one quarter of the area with triangular white spots at the tip and near the center of the wing [55]; [56]. Females differ from male in that they cannot be distinguished with their forewings since they are less distinctly marked with the uniform greyish brown to a fine mottling of grey and brown. The hindwing is iridescent silver-white for both sexes and contains a narrow dark strip border [52]. The adult pest possesses a nocturnal behaviour, meaning they are active only at night in the habitat. Female moths have a pre-oviposition period of 3 to 4 days [57], after which laying of eggs occurs during the first 4 to 5 days of life up to 3 weeks in some cases. The duration of the adult life span ranges between 7 to 21 days with an average of 10 days [45].

Damage

FAW is a phytophagous and voracious feeder which cause devastating damage by defoliating the host plant. The larva stage is responsible for the damages observed by farmers. Larvae consume the leaves, funnel between stem and whorl, and base of the leaves of host and none host plant as the population increases in the field. The noticeable damage symptom of FAW is consuming the leaf tissue from one

side, leaving a transparent opposite epidermal layer which easily turn into holes when the wind blows [23]. The larvae eat up the leaf tissues to the skeleton, leaving only veins and midrib, particularly for order larvae (Figure 3b). The damage occurs in all stages of growth at the young tender plant, tasseling and ears [58];[43]. Sometimes, FAW acts as a cutworm which feeds on the young tender maize plant leading to topping.

According to Kammo et al., (2019) [41], results showed that the incidence rate of death heart decreased with an increase in maize growth ranging from 60 % to 25 % for 34 days after planting (DAP) to 62 DAP, respectively. The severity of FAW in maize ranges from 16.25 % to 6.50 % in 34 DAP and 76 DAP, respectively. Marengo et al., (1992) [59] studied the effects of fall armyworm injury on the early vegetative growth of sweet corn in Florida. They reported that the early whorl stage was least sensitive to injury, the mid-whorl stage intermediate, and the late whorl stage was most susceptible to injury. Further, they noted that mean density range from 0.2 to 0.8 larvae per plant during the late whorl stage could reduce yield by 5 to 20 percent. This may occur in a week or two, depending on the population or rate of chewing [48]. The pest usually escapes pesticide effects because it hides in the holes created, for example, in maize stalk and also based on their nocturnal behaviour, where they damage in the night and hide in the afternoon when farmers usually spray. The period to intervene for pests is strategic and is vital for the sustainable production of maize. Tambo et al., (2020) [60] revealed the output obtained for various stages of management of FAW infestation on maize: early, mid and late vegetative growth stages to be 44%, 42% and 46%, respectively. In Cameroon, Tanyi et al., (2020) and Kammo et al., (2019) [42];[41], reported on yield loss caused by FAW at different cropping seasons. In 2017, Fotso et al., (2019) [28] revealed the presence of FAW in all ten regions devastating farmers farms.

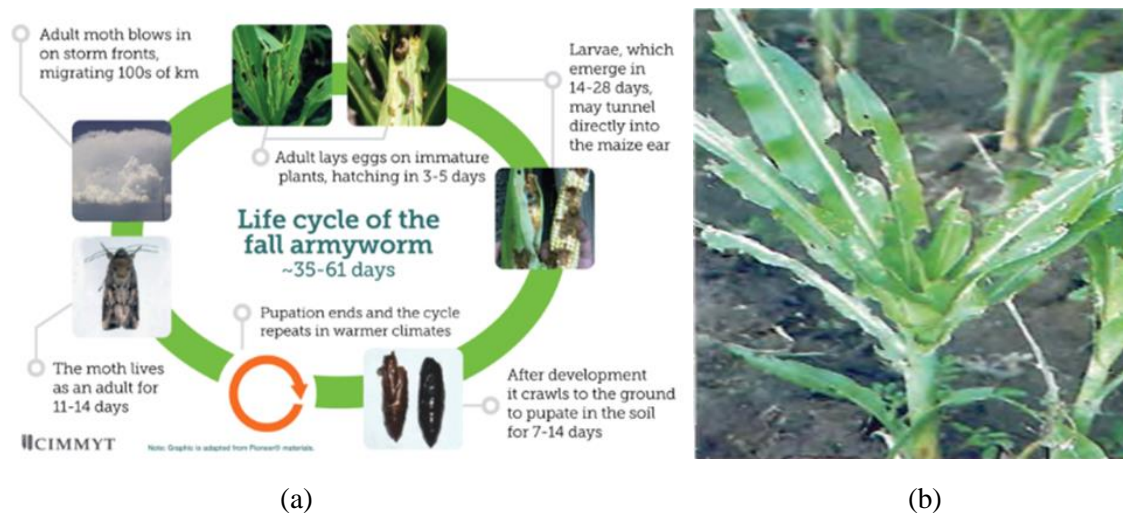


Figure 3. The life cycle of FAW (a) adapted from and damage; (b) (Serdar, 2019; Sharanabasappa et al., 2018)

4. Integrated pest management

The use of a single measure to control the population of FAW has proven unsuccessful. That prompted the small-scale farmers and researchers to adopt strategic management measures that are holistic and multidisciplinary, called integrated pest management. Day et al., (2017) [61] reported that IPM is the appropriate and best technique to manage FAW, especially in Africa. IPM application ensures the method is cost-effective to farmers, sustainable and minimize negative effects on human health and the environment [62]. The IPM technique uses practical measures to control pests, including cultural methods, biological and chemical as the last defence option. In Cameroon, IPM methods are implemented as handpicking, crop rotation, intercropping, planting time, weeding, biological: improve maize variety, bio-pesticides and synthetic chemicals in control the FAW.

4.1 Cultural control of Fall armyworm

Cultural methods are non-chemical measures that involve the manipulation of the agro-ecosystem so as to suppress pest build up beyond the threshold level that may cause economic losses. These measures include; sanitation, scouting and monitoring, weeding, fertilization, intercropping, crop rotation, mulching, tillage and push-pull technology.

Sanitation

The agricultural system in Cameroon is rainfed because farmers depend on rainfall during the cropping season. Farmlands are usually prepared in the off season (period of no rainfall) by clearing of grass and allowed to dry off. The field is exposed to scorching heat from sunlight which substantially treat the surface soil against eggs, larvae and pupae. Some farmers proceed with burning which is a practice discourage because of the damage of soil beneficial microorganisms and insects which serve as natural enemies. The field sanitation can be improved by converting maize stalk to animal feed which will largely remove the FAW population in the field. Further, manual tillage and mechanical plough of the field sterilized the field by bring eggs, larvae or pupae to the surface and are killed by the scorching heat from the sunlight. Larvae cannot resist extreme temperature either hot climatic or cool environmental conditions [55].

Pest scouting and monitoring

The success of the application of IPM starts with effective scouting and monitoring of the farmland. These processes enable proper diagnoses of the agro-ecosystem regarding the number and distribution of the pest, damage caused and the degree of damage generated. Commonly, smallholder farmers in Cameroon visit their farms between the fourth and fifth day after planting date to observe the germination rate and evaluate insect pests' damage. They continue to monitor the growth rate of the maize and the number of pest populations. Farmers recognize pest damage on the farm as holes in leaves and frass on the stem. Pitfall traps, sticky traps, light traps and pheromones are methods used to monitor and determine the presence of the pest and density in a farm. Prasanna et al., (2018) [45], used pheromones specifically sex pheromones produced from the female FAW to attract the male FAW in order to monitor the increase in population in the farm site. FAW can be trapped easily in the night with the use of light trap because it is a nocturnal insect. The moth can be monitored with black light trap due to the nocturnal behaviour of the moth [27].

Farmers with smaller farm sizes practiced handpicking during scouting and monitoring on the field, but this is unfeasible for a larger surface area. Handpicking was also reported in Ghana and Zambia [60]. Because of the cost involved such as labour which often is from family members or friends and hired workers. Besides, it is most likely to be ineffective as many could be hiding in the stalk or in the whorl of maize.

Planting time

Early planting is a cultural method applied for controlling FAW. Planting maize early when the rainfall is stable can reduce the damaging effect of FAW. This is because during the off season when just few green plants are available, the pest population is low before the pest builds up the maize could have attained a physiological adaptation to stress like infection from the pest. Therefore, by the time the pest population increase beyond threshold, the maize plants have grown such that the effect is minimal. Additionally, FAW damage is less when farmers in a particular region plants at the same time. This will substantially lead to equal distribution of the pest in the region, reducing the pest pressure on a single field. On the other hand, planting late will cause larvae to migrate from field with mature plants to field with younger plants. Damage on young plants is usually higher than adult plants because of ease to chewing the tender leaves and stems. Oben et al., (2015) [43], reported that in order for farmers to avoid the devastating loss of their crops, in Southwest region of Cameroon, planting was done during the early rainfall and pesticides application began two weeks after planting (WAP). The spray was aimed to destroy early eggs laid by pest of maize such as FAW and stem borers, hence, prevent development of larvae.

Intercropping

Intercropping legumes such as beans (*Phaseolus vulgaris*), groundnuts (*Arachis hypogaea*), cowpeas (*Vigna unguiculata*) and soybean (*Glycine max*) within maize to serve as trap crops for FAW. Beans are planted earlier such as planted 10 days before the maize in order to lure the pest to beans and allow the maize to germinate and grow with less pest pressure. Also, legumes help to improve on the soil fertility by converting nitrogen to the absorbable soil nitrate, hence, enable growth and yield. Further, legume serves as hide out for natural enemies against pesticide spray and site for overwintering and food resource. This diverse habitat beneficially manipulates the ecosystem to increase fecundity and longevity of parasitoid due to the presence of nectar. Tanyi et al., (2020) [42], revealed the control of FAW with dwarf and climbing beans probably because the beans emitted semiochemicals which push the pest away from the maize plants. Infestation of FAW is more in mono-cropping compared intercropping, in Uganda mono-cropping of maize recorded 95% infestation compared to 65 %, 74 % and 64 % recorded for intercropping of bean, soybean and groundnut, respectively [81]. The disparity observed is probably due to the crop morphology, ecosystem, and management practices [63]. The polycropping innovation released exudates at the root rhizosphere which cause abortive germination of some weed seeds e.g striga seeds, a noxious parasitic weed known to drastically reduce maize production [63].

Fertilizer

Healthy plant is an important attribute to withstand pest and disease damage [64]. However, inappropriate use of inorganic fertilizer such as exceed supply of nitrogen to plant can lead to a high update and increase leaf nitrogen. The increase update of nitrogen causes leaves to possess much leaf sap which attracts herbivores insects and the spread of pathogens is fast [65]. Because of the tenderness of the leaves due to adequate moisture required by fungi or bacteria to spread rapidly. Nonetheless, sufficient amount of nutrient is essential for maize growth and production. In Cameroon, farmers applied inorganic fertilizer combined with insecticide two weeks after germination for rapid growth and to avoid damages from insect pests. The possible reasons may be that as plants grow, the vascular tissues get harder which creates a natural defense mechanism against pest damage. Therefore, improving plant nutrition can abate FAW damage. Also, perhaps the maize release exudates (allelopathy), which repel the pest. Farmers used poultry and green manure to improve on the production as well as upgrade soil structure and fertility.

Push-pull farming system

Recently, push-pull farming system is a new farming approach developed in Africa by the International Centre of Insect Physiology and Ecology (ICIPE) in collaboration with Rothamsted Research to promote FAW control [66]. The farming system explored natural processes, including non-chemical application, natural enemies and soil fertility to manage the FAW population in the farm and growth of maize plant. The system explores numerous benefits such as natural chemicals from plants, ecology, agro-biodiversity, plant-plant interaction, insect-plant interactions, and ecological process through companion cropping for crop production [67]. In the system, one of the plants called trap plant (pull) attracts the pest insect to itself while the other plant is called repellent (push) that drives away the pest. The push crop produces a repellent offensive smell (chemical stimuli) that repel the pest insect while the trap plant attracted plant release a chemical stimulus that is favorable and attack pest insect. This reduce pest pressure on the maize plant by deviating pest attention to border plant, thus, increase production. However, push-pull farming system success depends on the family of the crops, crop morphology and natural enemies available. This helps to limit competition in terms of space and nutrient. As an example, intercropping of cereal and legumes such as maize with legume of the genus *Desmodium spp* and the planting of Napier grass (*Pennisetum purpureum* or *Brachiaria cv Mulatoll*) as a border plant (pull). Khan et al., (2018) [67], demonstration reveals that the companion plants, *Desmondium uncinatum* or *D. intortum* and Napier release behaviour modifying chemical stimuli to manipulate the insect population and distribution of FAW, stem borers and beneficial insects (natural enemies) to strategically control the pest (Figure 4). The moths are push away from the maize plant and

attracted by the border plant (Napier) which also attracts natural enemies of the pest insect like wasp parasitoids (*Cotesia sesamiae*). This wasp attacks and parasitized the pest's eggs, larvae and pupae, leading to death of the pest [67].

In Eastern Africa, 176,000 smallholder farmers have benefited from this system with an increase in production from 1 t/ha to 3.5 t/ha with minimal input [68]. Push-pull innovative system has several benefits, including increase soil fertility due to nitrogen fixation by the legume, improve: carbon sequestration, moisture conservation, enhancement of soil biota and organic matter which prevent degradation of soil retention ability. In addition, companion plants are used to feed animals, leading to increased milk production which promotes maximum land surface utilization and multiple sources of income to farmers. Hence, reduce the shock of crop failure. Besides, this innovation is economically affordable because the companion plants are locally available and not expensive.

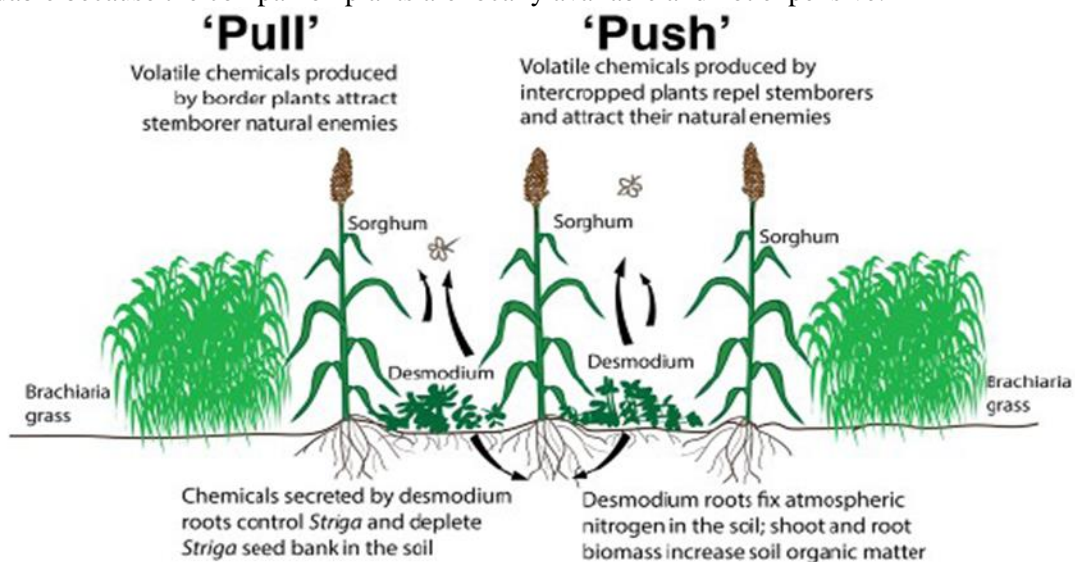


Figure 4. The push-pull farming system for controlling FAW (Khan et al., 2018)

4.2 Biological control

Eilenberg et al., (2001) [69], defines biological control as the use of living organisms to suppress the population density or impact of a specific pest organism, keeping its abundance and damage below the threshold level. It uses multidisciplinary approach by deploying the knowledge of ecology, entomology, weed science, plant pathology, insect pathology and microbiology in effectively solving FAW. There are three biological control approaches namely, the conservative, classical, and augmentation. Conservation biological control involves promoting the activity and survival of natural enemies in the farm by a producer to keep pests below threshold level [69]. Classical biological control is taking a natural enemy from pest origin and introducing it in a new environment to attack the pest insect. The success of this method relies on how quick the introduced pest can increase in population to suppress the pest insect in its environment [70]. Whereas, augmentation biological control is a periodic release of mass-reared natural enemies to supplement limited number of natural enemies in the field to control pest insects [71]. Largely, the conservation bio-control method is demonstrated by small-scale farmers while that of classical and augmentation is performed mostly by researchers and agricultural extension agent. Notwithstanding, farmers need to be empowered to practice all methods so as to broaden the scope of managing the FAW population.

Some of the organisms used for controlling FAW are categorized as predators, parasitoids and pathogens. Natural enemies are insects used to control the population of another insect pest by attacking it to dead. The natural enemies are found in all farmlands though differ in population depending on whether the farm is sprayed or not as well as the rate and the type of pesticides used. The effect of botanical insecticides to the natural enemies is less fatal compared to synthetic insecticides. According

to the survey conducted in 2017, 2019 and 2020 in the agro-ecological zones in Cameroon, *Telenomus remus* was observed as the major and prevalent natural enemies found in the three regions. *T. remus* is an important natural enemy found globally to control FAW in the maize farms and other vegetable crops [7]. *T. remus* lay eggs into the FAW eggs developed to adult within the eggs of FAW [27]. It breaks off from the egg shell after attaining adult stage, which led to death and control of the population. Some of the parasitoids and hyperparasitoids in controlling FAW larvae and host plants are presented in Table 3. *Chelonus insularis* Cresson (Hymenoptera: Braconidae), geographically is the most dispersed biological control agent with the relationship of leaf consumption between healthy and parasitized caterpillar being 15:1, hence, less damage to maize plants [45].

Table 3. Parasitoids controlling Fall armyworm

SN	Parasitoid	Pest stage	Host plant
1	<i>Archytas incertus</i>	Larva	Maize
2	<i>Archytas marmoratus</i>	Larva/Pupae	Maize/Sorghum
3	<i>Campoletis flavicincta</i>	Larva	Maize
4	<i>Chelonus curvimaculatus</i>	Eggs/larva	Maize
5	<i>Chelonus insularis</i>	Eggs/larva	Maize/Sorghum
6	<i>Cotesia marginiventris</i>	Larva	Maize
7	<i>Cotesia ruficrus</i>	Larva	Maize
8	<i>Euplectrus platyhypenae</i>	Larva	Maize
9	<i>Glyptapanteles creatonoti</i>	Larva	Maize
10	<i>Lespesia archippivora</i>	Larva	Maize
11	<i>Microchelonus heliopae</i>	Eggs/Larva	Maize
12	<i>Brachymeria ovata</i>	Pupa	
13	<i>Telenomus remus</i>	Eggs	Maize/Vegetables
14	<i>Trichogramma achaeae</i>	Eggs	Maize
15	<i>Trichogramma chilostraeae</i>	Eggs	Maize
16	<i>Trichogramma pretiosum</i>	Eggs	Maize
17	<i>Trichogramma rojasi</i>	Eggs	Maize

Source: Abang et al., (2021) and FAO & CABI, (2019)

Predators

Predators are effective in controlling FAW in maize. For example, the earwig, *Doru luteipes* (Scudder) usually attacks the FAW in the maize whorl because is an area most preferred by FAW and also earwig lays eggs there. Meanwhile, in the maize life cycle, earwig nymphs consume 8-12 larvae daily and the adult 10-21 larvae daily. Table 3 shows other predators used in controlling FAW.

Table 4. Predators controlling Fall armyworm

SN	Predator	Pest life stage
1	<i>Calleida decora</i>	Larva
2	<i>Calosoma altermans</i>	Larva
3	<i>Calosoma sayi</i>	Larva
4	<i>Carabidae</i>	Larva/pupa
5	<i>Doru luteipes</i>	
6	<i>Doru taeniatum</i>	
7	<i>Ectatomma ruidum</i>	
8	<i>Geocoris punctipes</i>	
9	<i>Stelopolybia pallipes</i>	
10	<i>Podisus maculiventris</i>	

Source: Abang et al., (2021) and FAO, (2018)

Pathogen

Pathogens such as fungi and bacteria affect the larvae of FAW and its colour changes (Table 4). The FAW dies after a period of attached. For example, baculovirus attacks the larva stage of FAW to dead and frequently it is observed on the upper parts of maize plant and will upside down [45]. In Indonesia, Sartiami, et al., (2020) [34], discovered an important entomopathogenic fungus called *Metarhizium rileyi* during field survey of FAW. This fungal has been reported to cause 95 % mortality of the 3rd larvae instar of FAW [34]. This is a milestone discovery which could be used to start production of entomopathogenic fungus bio-pesticide, and promote adoption by farmers in order to abate damage. The entomopathogenic are useful for the controlling of the pest in maize farm as shown in Table 3. For instance, the production of *Bacillus thuringiensis* (Bt) maize and bio-pesticide spray can strategically reduce the population of FAW. Bt is a bacterium that forms spores comprising of toxic crystals protein (cry proteins). It is found naturally in soils and is toxic to many species of insects. Many insecticidal strains have been isolated from soil samples and effectively used by small-scale farmers as bacterium insecticides spray [72]. Insecticidal pesticide comprised of a single *Bacillus* species or subspecies which may be active against an entire order of insects, or may be effective against only one or a few species. For example, products containing *Bacillus thuringiensis* var. *kurstaki* killed the caterpillar stage of a wide array of butterflies and moths.

Table 5. Pathogens controlling Fall armyworm

SN	Pathogen	Pest stage
1	<i>Bacillus cereus</i>	Larvae
2	<i>Bacillus thuringiensis</i>	Larvae
3	<i>Bacillus thuringiensis alesti</i>	Larvae
4	<i>Bacillus thuringiensis darmstadiensis</i>	Larvae
5	<i>Bacillus thuringiensis thuringiensis</i>	Larvae
6	<i>Bacillus thuringiensis kurstaki</i>	Larvae
7	<i>Beauveria bassiana</i>	Eggs/Larvae
8	<i>Granolusis virus</i>	Larvae
9	<i>Metarhizium anisopliae</i>	Eggs/Larvae
10	<i>Nucleopolyhedrosis virus</i>	Larvae

Source: FAO & CABI, (2019)

Botanical control

These are pesticides produced locally from plant or plant extracts to manage the population of FAW. Therefore, plant derived liquid is called plant-based pesticides botanical pesticides, which do not affect natural enemies, human health and environment friendly. Plants use for botanical pesticides, are Neem, *Aglaia cordata* Hiern, *Annona mucosa* Jacquin, *Vernonia holosenicea*, long pepper (*Pepper hispidinervum*), *Jatropha gossypifolia*, Castor (*Ricinus communis*), *Chromolaena chaseae*, *Cedrela salvadorensis*, *Cedrela dugessi*, Chinaberry (*Melia azedarach*). Botanicals derived from plant extracts in Cameroon is effective in controlling FAW with similar efficacy like pesticides and also increase production [41];[42]. In West region of Cameroon, Neem (*Azadirachta indica*) oil extract recorded the highest reduction incidence of dead hearts of maize plant from 23 % to 0 % for 34 DAP to 62 DAP respectively, this was followed by Lamb-cyhalothrin from 36 % to 10 %, leaves of *Chenopodium ambrosioides* extract 38 % to 20 %, cypermethrin: 60 % to 25 % with the least reduction efficacy of incidence of dead heart registered by control: 65 % to 33 % for 34 DAP to 62 DAP, respectively [41]. There was no significant difference of the effect of the types of insecticides in controlling FAW and stem borer on leaves and stem of maize. In contrast, Tanyi et al., (2020) [42], results revealed that West Africa black pepper (WABP) (*Piper guineense*) extract registered the least severity of FAW larvae on maize plants within weeks after planting (WAP) and across WAP compared to control. Obviously, the week was able to significant confirm the efficacy of bio-insecticide in controlling FAW. Therefore, botanical control is a breakthrough in the sustainable management of FAW. Besides reducing the maize

infestation on the farm, WABP improved yield [42]. The botanical efficacy is most likely due to plant secondary metabolites such as isobutyl amides, piperine, natural lipophilic amides, which function as a deterrent, neurotoxin and antifeedant [73];[74].

Some farmers in Cameroon used wood ash obtained from burned wood mixed with mocap (Ethoprophos) or counter (Terbufos) for controlling FAW and stem borer [43];[28]. It is a bio-pesticide composed of insecticidal, fungicidal and nutritional properties including soil liming ability [75]. Annet, (2014) [76], stated that the insecticidal property in wood ash responsible for killing FAW is potash. Contrary to the knowledge that potash is used to increase fruiting and fruit size. Nevertheless, more research is needed to ascertain the active insecticidal property responsible for protection. Further, some farmers use soil obtained from the rhizosphere to pour into the maize whorl for controlling FAW. Some farmers mixed soil and mocap. In Nigeria, Wahedi et al., (2017) [75], research results showed that wood ash was more effective in controlling vegetable insect pests than Neem leaf extract.

4.3 Chemical control

Chemical control is the use of synthetic pesticides to manage the increase of the pest population. Generally, in the implementation of IPM, pesticides are commonly used as the last option of defence after others have failed or limited to suppress the increase in population. This is because synthetic pesticides produce quick results either as knockdown or ingestion poison and are broadly categorised into contact and system mode-of-actions. Unfortunately, most farmers have insufficient knowledge about pests of economic importance like the invasive FAW such as the biology of the pest: when does the pest emerge? When does the population increase? At what stage is the pest vulnerable to control? And what type of pesticide is suitable for use? The obvious lack of adequate answers has led to the misuse of pesticides, resulting in pesticides resistance, resurgence, negative environmental externalities and increased cost of production. These phenomena are experienced both in developing and developed countries simply because pesticides application is knowledge-intensive. For example, in the Americas, pesticides resistance occurred with several chemicals with different mode-of-actions namely; carbamates, organophosphates and pyrethroids [77]. However, FAW has been successfully controlled in the US because of their well-organized agricultural system [67]. This observation is in sharp contrast with many developing countries which are still battling with it. According to Midega et al., (2018) [58], the successful use of pesticides depends on farmers' access, purchasing power, knowledge on the correct use, choice and consistency in using. The service of an extension officer and or a researcher to empowering farmers with this knowledge in developing countries is absolutely necessary particularly in fighting this pest. Justice et al. Tambo et al., (2020) [60], reported that small-scale producers of maize in Ghana and Zambia in contact with agricultural extension agents significantly control FAW than those without. The difference is because of empowerment through skill transfer from extension officers who disseminated research results through demonstration in farmers' farms specifically on integrated strategies for pest management. Therefore, synergy among researchers, agricultural extension officers, farmers and donors are needed for efficient control of FAW in Cameroon and other developing countries.

Some insecticides reported to control FAW include carbamate insecticides namely Methomyl, pyrethroid insecticide, Methyl parathion, and Cyfluthrin and Organophosphate insecticide (Fotso et al., 2019). In Cameroon. Pesticides with different active ingredients have been reported, including Lambda-cyhalothrin, Cypermethrin, Lambda-cyhalothrin plus acetamiprid, Ethopropos, Carbofuran, Emamectine, Acetamiprid, Chloropyriphos-ethyl, Imidacloprid and Lindane [28];[41];[43]. Amongst them, the frequently used for mitigating the damages caused by FAW are; Emamectin benzoate (16%), Cypermethrin (15%) and Lamdacyhalothrin (10%) [28]. The efficacy could be compromised if the information on the label is not strictly adhered to, such as the recommended dose, interval of spray, season, and the period of application [45].

4.4 Future actions

An automatic system with the Internet of Things is absolutely needed and paramount to monitor FAW in order to automatically monitor the population density and when to intervene to keep it below the threshold level. Sütő, (2021) [78], reported automatic insect count with deep learning algorithm embedded system-based sticky paper. The intercropping of legumes with maize is essential for reducing yield loss encountered by small-scale farmers and also it enhances soil nutrients through nitrogen fixation. For resource-poor farmers, push-pull technique is indispensable for improving production with limited input and management. The push-pull farming system should be promoted in all African countries by researching on local plants that produce chemicals, serving as push and pull crops. When these crops are identified in local communities, the adoption and dissemination of the farming system will be fast. On the other hand, plant extract can be used in mono-cropping against FAW and or used alternatively with synthetic pesticides combined with cultural practices. The production of bio-pesticides from fungi or bacteria strain to control FAW is a laudable initial to be spearheaded by the government of developing countries.

Furthermore, the FAW population could be managed well when farmers are updated with the weather and climatic forecast. They will target early planting of maize and when to spray either bio-pesticide or synthetic pesticides. Particular useful in this era of climate change. Meanwhile, mitigating the current harsh and unstable nature of the climate, farms in the tropics and sub-tropics farmers are encouraged to practice organic farming and agro-forestry. From all those, agricultural extension and advisory services are urgently needed in controlling the pest. These services include training and informing farmers on new and improved technologies and providing feedback to researchers [79]. The government of developing countries are encouraged to deploy these agents in rural communities to provide farmers with the necessary skills needed to improve production particularly disseminating research results in the best possible approach. In Wareng District-Kenya, studies revealed that years that extension officers frequently visited farmers' farms, they registered increased production [80]. Extension officers make available research findings to farmers and channel problems faced by farmers to researchers for more search.

5. Conclusion

FAW is an invasive pest ravaging smallholder farmers' maize farms in all agro-ecological zones in the world due to its ability to adapt to diverse environmental conditions. Currently, it is present in all ten regions of Cameroon in small-scale producers' maize farmers. Many types of synthetic pesticides have been used to suppress FAW damage but were unsuccessful due to misuse, leading to pest resistance and resurgence. A single pest control measure is inadequate for the control of FAW because of population overlap. Therefore, integrated pest management is absolutely the approach, including understanding the biology of FAW, use of synthetic chemicals control, botanical, biological control, push-pull technique, handpicking and indigenous techniques. The results revealed that the push-pull farming system is beneficial to maize plants by protecting natural enemies and improving plant nutrition. Pest population growth differs across the cropping seasons in Cameroon because the environmental conditions were different. Nonetheless, further investigation is needed to ascertain the dynamics per cropping season and across seasons. The result will provide a clue on what strategies could be used for a particular season. Plant extract and entomopathogenic fungi production should be encouraged to better control FAW as a sustainable and environmentally friendly approach.

Conflict of interest

Authors declare no conflict of interest

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