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Fall Armyworm in South Asia: Threats and Management

Suraj Lamsal[1*], Shelton Sibi[1] and Sova Yadav[2]

[1]Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj - 211007, India.
[2]Department of Entomology, Chaudhary Charan Singh Haryana Agricultural University, Hisar-125004, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author SL designed the study and wrote the first draft of the manuscript. Authors SS and SY thoroughly revised and prepared the final manuscript. Author SY compiled the field photographs. All authors read and approved the final manuscript.

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ABSTRACT

Fall armyworm arrived on the Indian subcontinent in May 2018 and now it has spread across India, Nepal, Bangladesh, Sri Lanka and approaching more beyond South East Asia. Strong flying capacity, climate adaptability, and wide host range makes them a better colonizing agent than other species of armyworms. Despite maize being primarily infested in this region, infestation on sugarcane, sorghum, cotton and cabbage have already been reported from India, Bangladesh and Sri Lanka. National agricultural research bodies like ICAR, IIMR, NARC, BARI etc. as well as international organizations like FAO, CGIAR, CIMMYT and CABI are working at different levels in effort to develop management strategies to combat the pest. Since it is practically impossible to eradicate the pest now, it is essential to work for long term management and in keeping pest population below economically injury level. Reliance on synthetic pesticides only is a temporary way of dealing with the pest. Educating the farmers themselves about the pest and practicing integrated approach of management compatible and feasible in the region would be

**Corresponding author: Email: lamsalsuraj199@gmail.com;*

more sustainable. Identification and using native species of natural enemies, such as predators, parasites and parasitoids is the current need of research. The experiences of small holder farmers in Africa and South America in fall armyworm management might be relevant to South Asia.

Keywords: Fall armyworm; South Asia; synthetic pesticides; agroecological approach; natural enemy.

1. INTRODUCTION

Fall armyworm (FAW), scientifically known as *Spodoptera frugiperda* (J.E. Smith) is a Lepidopteran (Noctuidae) pest which was first recorded in Georgia in 1797 after which several outbreaks occurred during the nineteenth century in Americas [1]. In late 2016, it was first reported outside Americas from West Africa and within three years it spread to more than 40 countries in Africa [2]. After conquering Africa, it was first spotted in Asia from Karnataka, (India) in May 2018. As of March 2020, it has spread to countries beyond South Asia to South East Asia and even China (2019) and recently in Australia (2020) [3,4]. Despite its wide host range, its infestation in maize crop has been most pronounced across Americas, Africa and newly in Asia [5-9]. The voracious feeding behavior of FAW larvae (caterpillar) poses a threat to food security if its activity is left uncontrolled. SAARC (South Asian Association for Regional Cooperation) countries are responsible for 3.2% of global maize production and India represents the highest maize production area 78.9% in the region [10].

It is highly likely that FAW arrived in Asia through intercontinental trade. Tropical and warm climate with mean annual temperature ranging from 17-35 Celsius and mean annual rainfall ranging from 0-400 mm is reported to be preferable for FAW [3]. The pest is known to migrate from cooler to warmer temperature for overwintering due to its inability to survive in low temperatures below 10 Celsius for extended periods [5,11]. The efficient dispersal and migrating trait make this pest a better colonizing agent among other competitors. Large fraction of the South Asian region experiences tropical wet and dry, humid subtropical, and semi-arid climate which provides favorable environment all-round the year. Economically, it poses a threat on cultivated species of grasses like rice, maize, sorghum, sugarcane, etc. [12]. In this review, we highlight upon the distribution of FAW in South Asia, various aspects of its management, and experiences of Africa that South Asia can look upon.

2. DISTRIBUTION IN SOUTH ASIA

In Asia, FAW was first detected in Indian state of Karnataka at College of Agriculture, Shivamogga in May 2018 [13]. Based on surveys conducted by ICAR's (Indian Council of Agricultural Research) National Bureau of Agricultural Insect Resources (NBAIR) team in July 2018 it was reported that 70% of maize fields in Chikkabalpura district of Karnataka were infested with FAW and study of larvae confirmed 100% match with FAW samples from Canada and Costa Rica. Within less than five months of first appearance, it was confirmed in other five states: Tamil Nadu, Telangana, Andra Pradesh, Maharashtra and West Bengal in maize as well as sugarcane crops [14]. In another study, the genetic homogeneity between FAW in India and South Africa was found [15]. The wider distribution of FAW within a cropping season is favored by its remarkable flight capacity. This pest is capable of migrating long distances on prevailing winds and can also breed continuously in areas that are climatically suitable [16]. Caterpillars of FAW were reported from Sri Lanka for first time from Damana region of Ampara district of Eastern Province in June of 2018 [17]. The dispersal of the pest in Sri Lanka might have occurred through imported foodstuffs and plant materials although the possibility of pest dispersal through wind currents in Indian Ocean cannot be neglected [9]. The closest proximity of Sri Lanka to the Indian state of Tamil Nadu may have played an important role in the immediate emergence of pest in that country. In Bangladesh, the caterpillar was first detected in November 2018 by the Bangladesh Agriculture Research Institute (BARI) on two different crops, cabbage and maize in different districts [18]. Caterpillar on maize were found in Bogura and Chuadanga districts whereas infested cabbage was reported from Rangpur, Thakurgaon, Bogura and Jashore districts. Scientists from the Nepal Agriculture Research Council (NARC) reported FAW in Nepal for first time in Nawalpur in May 2019 on maize crop. It is believed that the pest might have entered Nepal months before its first confirmation. Within months it was reported from other districts (Kavre, Sindupalchowk, Bhojpur) of mid inner Terai and mid hills [19]. Bangladesh and Nepal share long borders with India which might be the reason for dispersal of pest across the region.

Till this paper was prepared, Pakistan and Afghanistan do not have official report of infestation of FAW but other nearby Asian countries like China, Myanmar, Thailand, Vietnam, Malaysia, Japan and Indonesia have already confirmed cases of FAW in their country. Fig. 1 shows the current distribution status of FAW in the South Asian region. In Americas, two strains of FAW are known, namely R-strain (rice strain) primarily feeding on rice, millet and grass species and C-strain (corn strain) consistently feeding on maize and sorghum [2,20]. The two strains are morphologically indistinguishable and can be differentiated only using DNA barcodes [21]. But the actual distribution track of strains from Americas to Africa and then to Asia is still unclear. Further, strains are capable of cross hybridization in the field which adds uncertainty to the exact geographical distribution of strains [20].

3. BIOLOGY AND IDENTIFICATION

The eggs of FAW are found in clusters of few to hundreds, usually on underside of leaves but at higher population densities oviposition can occur in other parts and even in non-host objects [1,5]. The eggs are dorsoventrally flattened and measure up to 0.4 mm in diameter and 0.3 mm in height [22,23]. On average a female lay about 900-1000 eggs in its lifetime but fecundity can vary considerably [1]. The newly laid eggs are found to be covered with a protective layer of white scales (setae) from the female abdomen, thus takes a moldy appearance as shown in Fig. 2 [24]. The incubation period of FAW eggs ranges from 2-3 days [22].

The larvae feed on the shells as they hatch from the eggs. The larval period of FAW comprises of six larval stages and lasts for 14-21 days [22]. The young larvae are generally identified by their light greenish color with dark black head whereas, the grown-up ones are spotted with a reddish-brown head marked with an inverted 'Y' shape on the head (Fig. 3). The older larvae (fifth and sixth instars) show cannibalistic character to feed upon younger larvae [25]. This behavior was common irrespective of food densities but it was more frequent during low food densities. FAW larvae are marked with four characteristic spots on the second to last segment, forming a square or rectangle [23]. The spots are distinguished from other armyworm species by its tail end where the black spots are bigger and arranged in square pattern on the 8th abdominal segment and trapezoidal on the 9th segment [26]. Larvae are nocturnal and hide in funnel during day time.

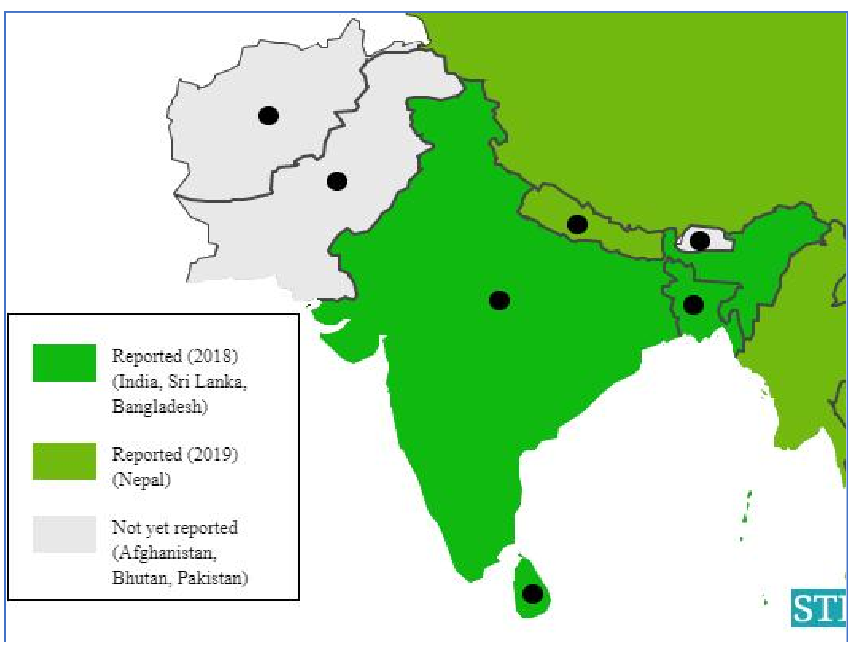

Fig. 1. Distribution of FAW in South Asia

Fig. 2. Egg masses

Fig. 3. Larval identification marks

Fig. 4. FAW Pupae

The sixth instar larva drops to the ground and pupates itself at 1-3-inch depth depending upon soil texture, moisture and temperature [5]. Pre-pupal stage is marked when the fully grown larva stops feeding for 1-2 days [24]. The pupation may occasionally occur on the host plant species when the population density of the pest is high. The pupal stage lasts between 9-12 days after which adult moths are formed [22]. Pupae are shorter than the matured larvae and can be identified with a shiny brown texture (Fig. 4). Female pupa is slightly longer than the male counterpart. The moths after emerging from the pupal case come to the soil surface and cling to the host plant or debris nearby.

Morphologically female moths are bigger than their male counterparts. Both the males and females possess brown-grey colored forewings and dirty white-straw colored hind wings (Fig. 5 and 6). Adult males are often observed with more characteristic markings in the form of white color patches on the distal end of the wings (shown in Fig. 5). Adult life lasts on average for 10 days; 9-12 days for female and 7-9 days for male [22]. FAW adults are nocturnal in nature and are considered strong fliers [1]. The lifecycle of female (34-46 days) is found to be slightly longer than that of male (32-43 days) [22]. FAW adult females like most noctuid, are relatively short-lived but highly fecund [16]. Since the pest lacks diapause mechanism, generations can overlap within a single cropping season. Recent study from Tamil Nadu, India showed that the seasonal abundance of FAW larvae was positively correlated with maximum temperature in both *kharif* maize (sown at beginning of monsoon) as well as *rabi* maize (sown at end of monsoon or beginning of winter) season, however it was negatively correlated with both relative humidity and rainfall [27]. High rainfall accompanied with sunless skies for more than a week can cause soar in FAW activity [28].

Fig. 5. Adult male

Fig. 6. Adult female

4. NATURE OF DAMAGE

FAW exhibits polyphagous host range including cropped and non-cropped plants. A total of 353 host plant species belonging to 76 families has been reported from Americas [29]. Though maize is the primary target of FAW, in its absence the pest may attack sorghum and other poaceous crops like sugarcane, rice, wheat, millet, bermuda grass, crabgrass and other fodder grasses [1,26,30]. In maize, FAW feeds on all growth stages from seedling emergence to ear development and can even defoliate and kill young plants [2]. Preliminary symptoms of FAW resembles to that of other stem borers damage (like small holes and window pan feeding) [31]. The younger instars are involved in feeding on leaves (Fig. 7) whereas late instars burrow into maize tassel and ears (Fig. 8) causing extensive damage [32]. Appearance of windowing like structure on developing leaves near the funnel and presence of moist saw dust like frass (fecal matter) near the feeding area and upper leaves as seen in Fig. 9 is the characteristic symptom of FAW larval feeding [12]. The appearance of skeletonized leaves during the vegetative stage of the maize plant, depicts a clear sign of active feeding by the larvae. Rigorous feeding of larvae on the foliage can cause injury to the growing cob. The attack of larvae on young maize can even kill the 'growing point' resulting 'dead heart' which prevents further development and fruit formation thereby inducing yield damage [12]. However, the foliar damage caused in maize doesn't necessarily cause yield reduction since plants are capable of compensating foliar damage if adequate nutrition and moisture management are practiced. The nature of damage on sugarcane exhibited similarity with damage on maize crop but no dead heart symptom was observed in sugarcane [30].

The severity of infestation and yield loss has displayed significant variation depending upon crop species, cropping season and site in the Indian subcontinent as well as Africa and America. Preliminary studies from the Indian subcontinent have reported infestation level up to 49.2% on maize [8,24,31,33] except [34] who reported infestation level up to 100% from Karnataka. The infestation level on summer maize was found to be higher compared to spring maize [33]. Apart from maize, infestation level up to 30.86% on sugarcane [30] and up to 10% on sorghum [8] has been reported so far. The studies from Africa have shown that the infestation level can be severe up to 95% in maize monocropping [35,36]. First ever case of FAW infestation on cotton in South Asia was reported from Maharashtra, India in September of 2019 [37]. This shifting of FAW larvae from poaceous to other crop appears as a daunting challenge to farmers. In Sri Lanka FAW was reported in 9 out of 10 provinces of which Eastern, Uva and North Central provinces had infestation levels of respectively 81.6%, 73% and 58.3% of the total corn cultivated during the cropping season of 2018/19 [9]. One year after the first appearance of this pest in West Africa in 2016, the potential yield loss in 10 maize

Fig. 7. Windowing of leaves

Fig. 8. Ear feeding

Fig. 9. Moist frass near feeding area

producing countries in the region excluding South Africa and Kenya was estimated to be around 8.3 M to 21M tons per year which worth between US$ 2.5-6.3 billion [16]. Any official estimation of losses due to FAW in South Asian countries hasn't been made yet. In one of the victim states of Tamil Nadu, state government distributed IRS. 1.86 billion as compensation to 239 thousand farmers following pest attack in 2018 [38].

5. CONSORTED MANAGEMENT ISSUES

5.1 Chemical Control of FAW and Associated Risks

Chemical control is regarded as an emergency control measure for the outbreak of unprecedented FAW in the region. ICAR-Indian Institute of Maize Research has recommended group of pesticides like emamectin benzoate, spinosad and chlorantraniliprole against FAW [26]. Delayed insecticide application results in inefficacy of insecticides to stop active larval feeding [39]. Since the larvae stays inside the funnel of maize plants the pesticide may not come in contact with the larvae and hence control might not be effective. It is suggested therefore to spray the pesticides at dusk so that pesticide might contact the larvae coming out at night. It's not appropriate to adopt chemical control measures if the crop is in reproductive stage since damage to tassel would not affect the yield while in contrast damage to corn ears could not be prevented as larvae hide inside the ears. Chemical control of FAW combined with handpicking of larvae has shown to have positive impacts and resulted in a grain yield of 125% [40]. Some of the common pesticides used in Africa for FAW management include methomyl, methyl parathion, endoasulfan and lindane but all of these pesticides are classified as highly hazardous pesticides and pose irreversible threat to health and environment [12]. Although the chemical control of FAW seems to be effective within a short time interval, the broad-spectrum pesticides are equally harmful to natural enemies of FAW and is therefore not a recommended pest management procedure [11]. Farmers in South Asia practice unprotected, hand application of pesticides, so controlling FAW only through chemical application would result in massive scale health hazard in farmers. It is suggested to use ground equipment to apply insecticide in large volume of water (278-467 l/ha) to improve efficacy and decrease frequency of applications in management of FAW [41]. However, it is essential to train and advise farmers about rational use of pesticides to prevent any negative impacts on human health and environment. In addition to that majority of farmers in South Asia are small holders and management of FAW through chemical control might not be affordable to all unless subsidized by governments. So, it is essential that South Asian farmers do not exclusively rely on synthetic chemicals for long term.

5.2 Field Evolved Resistance against Synthetic Pesticides in FAW

FAW is known to develop resistance against synthetic pesticides if chemical control is exclusively employed for its management [6,41]. Resistance against pyrethroids (permethrin, cypermethrin, cyhalothrin etc.) ranged from 2-216 folds, resistance to organophosphorus insecticide (chlorpyrifos, methyl parathion, diazinon, dichlorvos, malathion) ranged from 12-271 folds and resistance to carbamates (methomyl, carbaryl, thiodicarb) ranged from 14 - >192 folds compared to pesticides unexposed susceptible strains in the samples collected from Florida [42]. In a similar study remarkable field evolved resistance of FAW against common pesticides like chlorantraniliprole (160 folds), flubendiamide (500 folds), methomyl (223 folds), chlorpyriphos (47 folds), deltamethrin (25 folds) etc. was reported [43]. However, Spinosad, emamectin benzoate and abamectin induced lower resistance ratio (RR_{50}). Pest developed resistance to pesticides through exposure of successive generation to chemicals with the same mode of action [16]. The susceptibility or resistivity of FAW to a particular insecticide , in a specific area can depend upon the extent of FAW migration from an overwintering area to non-overwintering fields [41]. It does not necessarily mean that these pesticides can no longer be used in concerned areas but their effectiveness is however reduced. Studies from Americas have shown that, with time FAW develops field evolved resistance even with transgenic Bt maize (TC1507) which is incorporated with Cry 1F protein [44,45,46]. Insecticides were integrated in the management strategies even with Bt maize due to control failure against FAW in Brazil [6]. Migration of *S. frugiperda* among different crops creates serious impact on management of the pest unless the adjacent crop in the same landscape is Bt crop [47]. So, taking lessons for experiences of Americas, it is wise for South Asia not to rely only on synthetic pesticides for FAW management.

5.3 Potential of Parasites and Parasitoids in FAW Management

Biocontrol approach of pest management broadly involves three concepts; classical/inoculative (an exotic species of natural enemy is introduced into the invaded region), augmentative/inundative (periodic release of natural enemies against the target pest) and conservation biological control (manipulation of environment & agronomic practices in a way that favors natural enemies) [48]. A thorough understanding of the behavioral ecology and the population dynamics of natural enemies before introduction and colonization in to new agro-agroecosystem is a foremost step in this process. A total of 150 species of parasitoids and parasites of FAW belonging to 14 families: 9 in Hymenoptera, 4 in Diptera and 1 in Nematoda was reported [49]. The distribution of a particular parasitoid varies according to different crop habitat [50]. Since the pest is new to Asia, currently there is very low probability of natural enemies multiplying themselves in the fields. For successful colonization of exotic natural enemies (parasites/parasitoids/entomopathogen/predator) it is crucial to release them when appropriate stage of the prey or host (FAW) are available. Augmentation of appropriate parasitoid species during period of low host density favors effective management of FAW in their overwintering areas [51]. Recent studies from Africa have reported identification of native species of predators and parasitoids of FAW [2,52]. Parasitoids act as a natural bio control agent; they lay eggs on the egg masses, larvae or adult of FAW and destroy their host by multiplying inside them. However, their activities are negatively affected by application of pesticides by either direct toxicity or due to death of the host [53].

Native species of egg and larval parasitoids, native to Ethiopia, Kenya and Tanzania was reported [2]. The observed parasitism rates ranged up to 69.3% (*Telenomus remus* (Nixon)-egg parasitoid) followed by 42% (*Cotesia icipe* (Triana and Fiaboe)-larval parasitoid). In South Asia egg parasitoids like *Telenomus* sp. (Hymenoptera) & *Trichogramma* sp. (Hymenoptera), larval parasitoids *Glyptapanteles creatonoti* (Viereck) (Hymenoptera), *Campoletis chlorideae* (Uchida) (Hymenoptera) & *Forficula* sp. (Dermaptera) and an undetermined larval-pupal parasitoid of the family Ichneumonidae (Hymenoptera) have been identified from different locations of Karnataka [28]. Apart from these parasitoids, entomopathogenic fungus *Nomuraea rileyi* (Farl.) Samson which infected the larvae of FAW was identified. Initially ICAR-IIMR has recommended release of *Trichogramma pretiosum* (Riley) or *Telenomus remus* at the rate of 50000/acre at weekly intervals, starting within a week of maize germination till harvest [26] but assessment of its efficacy and practical impact has not been reported yet. Parasites and parasitoids provide comparatively long-term efficacy at low cost, without inducing significant resistance or imposing any harm to environment [49]. Further extensive research is required to identify the native parasitoids that are effective in keeping FAW population under threshold level on consistent basis.

5.4 Application of Botanical Extracts

Biopesticides can be broadly categorized in to three categories as biochemical biopesticides (plant extracts, pheromones, microbial extracts etc.), microbial biopesticides (bacteria, virus, fungi etc.) and macrobial pesticides (predators, parasitoids, EPNs) [12]. Botanical extracts contain specific active ingredient which possesses properties such as insecticidal, insectistatic, larvicidal or acute toxicity in pest population. For instance, 5% Neem Seed Kernel emulsion (NSKE) acts as repelling agent against FAW [26]. In a recent literature authors reviewed 69 plant species having insecticidal activities against FAW from Americas [54]. Most of these plants are cosmopolitan and are encountered in Africa as well as Asia. Larval mortality of >95% was observed by application of botanical extracts of *Azadirachta indica*, *Schinnus molle* and *Phytolacca dodecandra* against FAW [55]. Efficacy of *Nicotiana tabacum* and *Lippia javanica* was reported to cause up to 66% larval mortality in maize [56]. The efficacy and performance of homemade botanical insecticide made up of garlic extract, neem and detergent were comparable with that of the commercial botanical insecticide Solaris 6 SC [57]. So, there is an immense opportunity to supervene upon synthetic pesticides by identification of such locally available pesticidal plant species. Botanical extracts of pesticidal plants do not produce mortality rates as of synthetic pesticides but they can be used as substantive component of sustainable agro-ecological pest management approach. Unlike synthetic pesticides, botanical extracts have lower impacts on natural enemies of FAW. Before commercial recommendation of an active ingredient as a bio-pesticide, it should be critically evaluated based on five criteria namely; efficacy, risk to human health and environment, sustainability, practicality and local availability [12]. Economic viability and cost effectiveness of botanical extracts should be compatible with small holder farmer's ability for sustainable applicability. Varying the modes of action with time slows down the buildup of resistance in pest. It is recommended to apply biopesticides at frequency higher than chemical pesticides because of their shorter residual effect.

5.5 Agroecological Approach to FAW Management

Agroecological approach to FAW management is based on three strategies: sustainable soil fertility management, promoting biodiversity and specific management practices designed to prevent outbreaks or reduce impacts [58]. South Asian countries being naturally rich in biodiversity could benefit from this approach. Intercropping of maize with other crops creates diversity of plants in the field and this diversity confuses FAW in selecting preferred hostplants (maize). If intercropped with repelling plants, it creates push-pull system. This system prevents or reduces oviposition on maize plant. A 'climate smart push pull system' in maize where *Desmodium intortum* (Mill) was 'push' intercrop and attractive trap plant *Brachiaria cv* Mulato II a 'pull' crop around the border of intercropped area was found to be effective in reducing average number of larvae per plant by 82.7% and plant damage per plot by 86.7% [35]. Polycropping creates shelter and avails resources for growth of natural enemies (parasitoids and predators). This finding concurs with similar literature in which authors reported that climate smart push-pull technology (PPT) was most effective in controlling FAW, stemborer and parasitic weed striga infestation compared to conventional PPT and other legume intercropping practices [36]. Also, maize intercropping with legume was found to be more resilient than maize monocropping alone in combating FAW. Push-pull system can be integrated with night time light trap to significantly bring down the population of FAW moths in maize field [59]. Maize intercropping with sugarcane should be avoided since the larva shift from maize to sugarcane after 40-50 days [8]. If the intercrop is legume it advances maize by fixing nitrogen in soil thereby increasing compensating capacity against foliar damage.

FAO recommends avoiding late planting and staggered planting as this would continue to provide favorite food for FAW. For smallholder farmers it is feasible to crush young larvae and egg masses before they hatch. Many farmers in Africa have successfully managed FAW by using ash, sand, sawdust and even soil into whorls to desiccate young larvae. But there is no any scientific evidence regarding efficacy and scalability of such applications yet and further research is necessary to make such practice more dependable [48]. Soil may contain entomopathogenic nematodes and other parasitic bacteria and virus of FAW. However, in a recent experimental study it was reported that ash, soil as well as soap treatments were inefficient in reducing larval number and crop damage significantly in maize [60]. Immature leaves are more vulnerable to early infestation and are more likely to be seen with cluster of egg masses. Therefore, finding and destroying these egg masses at the earliest will bring down the active pest population below economic injury levels.

5.6 Integrated Pest Management (IPM): An Unavoidable Practice

It is not pragmatic to control FAW population by depending only on a single management practice but rather on an integrated pest control strategy [61]. IPM involves application of combined pest management strategies at a time so as to keep pest population below economic injury level without causing any harm to soil health and environment. Results from Ghana and Zambia showed that households which adopted at least one FAW management practice gained grain yield of 43% higher than those which didn't adopt any specific practice [40]. IPM practices involve not only curative measures but also prophylactic measures adopted before the occurrence of infestation. Regular and active monitoring enables farmers to control the egg masses of FAW before hatching to larvae. Monitoring of FAW population is essential for forecasting potential outbreak situation and planning the management strategy. Monitoring of pest status can be done through simple practices like scouting, light traps, sticky traps and pheromone traps. Sticky traps are generally most effective in sampling adult FAW in and around preferred host crops [62]. Currently FAO is promoting 'Fall Armyworm Monitoring and Early Warning System (FAMEWS) mobile application to collect and share information on FAW population level analyzed by field scouting and use of pheromone traps in the region. Adoption of viable cultural methods, healthy soil and crop management practices and promoting natural enemies along with other biological control methods can naturally suppress the FAW population. Promoting diversity on the farm through simple agronomic modifications (i.e. intercropping, mixed cropping and alley cropping) would encourage multiplication of natural enemies. FAO, CIMMYT, CABI and many national agricultural research institutes are working at different levels in the region to combat FAW. The government in Sri Lanka has adopted short term, medium term and long-term strategies to fight against FAW [9]. For a long-term solution there is no other way except making farmers themselves expert in understanding FAW and adopting IPM components according to the requirement.

6. WHAT CAN SOUTH ASIA LEARN FROM EXPERIENCES OF AFRICA

The experiences of Americas in addressing *S. frugiperda* may not be relevant to Asia, peculiarly South Asia because the maize cultivated in Americas is largely genetically modified. For instance, unlike South Asia, 80% of maize cultivated in Brazil are Bt maize [6] and farming is extensive and highly mechanized in Americas. But agriculture in South Asia resembles to that in Africa in many perspectives such as size of land holdings, subsistence farming, monsoon dependence, mechanization, crops cultivated etc. The experiences of farmers, researchers and policy makers in Africa could be valuable assets to farmers and policymakers in South Asia. The grass level bodies like 'plant clinics' and 'farmers field schools' created in Africa could equally be worthful in Asia. Teaching farmers to espouse integrated pest management process by understanding the pest and the resources of local agro-ecosystem could be the practical way of handling FAW. Ignorance of specific management guidelines obliges farmers to indiscriminately apply chemical pesticides, detergents and ash [61]. Farmers knowledge of the pest, socio-economic circumstances and current pest management strategies need to be wisely taken into consideration before designing technologies and developing strategies to combat FAW under subsistence farming [32]. Active and persistent monitoring through approaches like scouting (inspection), pheromone traps and light traps will be the foundation for forecasting pest outbreak and adopting appropriate control measures [63].

- **Agriculture advisory and aiding services at farmer's doorstep**

Since FAW is a new pest to Asia, it offers a lot of challenges to the farmers to seek for the right piece of knowledge. Therefore, building a sustainable communication and advisory units are essential to communicate with farmers facing pest ordeal and disseminate the best strategies to overcome the situation. A multi-faceted channel system with diverse sub-branches would ultimately reach the targeted audience. Deploying of mass-media is an inexpensive and effective way to reach larger audience. Call centers and plant clinics with trained scientists could be used to close down the communication gap among the farmers. Field experts, extension service agents and pest forecasting groups must be given the opportunity to work under a single umbrella for the underprivileged rural farmers.

- **Monitoring of pesticide application based on its biological properties and hazardousness so as to create minimal impact on human health and environment**

Farmers tend to select more toxic category of pesticide with expectation of eliminating the pest. Even Highly Hazardous Pesticides (HHP) as designated by World Health Organization like carbosulfan and methyl parathion are leveled for use against FAW by some African countries [48]. Other pesticides like chlorpyrifos, cypermethrin, lamda-cyhalothrin etc. which are associated with natural enemy toxicity are used against FAW in many countries of Africa. The channel of informal/illegal selling of pesticides poses great threat of distribution of such hazardous pesticides in South Asian countries. Carbamates and organophosphate pesticides are highly toxic and exposure can cause pesticide acute poisoning to the handlers. It is equally important to aware and encourage farmers for use of Personal Protective Equipment (PPE) during pesticide application. Even upon the availability of safety equipment, resource poor farmers are unwilling to buy the equipment [16]. Therefore, it is necessity for respective governments to strictly monitor the distribution of pesticides based on their hazardousness and farmers socio-economic status.

7. CONCLUSION

As an immediate solution government authority are promoting application of pesticides to limit the yield losses but for a long-term solution it is requisite to develop integrated pest management strategy compatible with farming system and farmer's socio-economic status in South Asian region. Relying on pesticides cannot hold for long since the chance for the FAW to develop resistance is high. It is current necessity to identify potential native natural enemies of FAW and discover pragmatic biological strategies that are effective and compatible with the agronomic practices in the region. Unlike Americas, use of GM maize for preventing FAW damage is unforeseen and might be a highly debatable option in South Asian countries. Countries need to enhance their research capacity. The financing of agriculture research in South Asian countries is relatively low in relation to the huge population they have to feed. A vast majority of the farmers living in the rural part of the society are totally alien to extension services, plant clinics, field trials, and government's subsidy schemes. Therefore, to combat this inerasable pest it is of the essence to train and educate farmers themselves about pest and feasible integrated pest management strategies for a sustainable solution.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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