Review Article

A comprehensive review on Seasonal incidence of Fall army worm, *Spodoptera frugiperda* (J.E. Smith) and their management

Abstract

The Fall Armyworm (FAW), *Spodoptera frugiperda*, represents a formidable challenge to global agriculture due to its rapid spread and significant impact on crop yields. This comprehensive review focuses on providing an in-depth exploration of FAW's biology, its seasonal dynamics, and the multifaceted strategies employed for its management. Leveraging datasets from multiple geographical regions, we examined the patterns of FAW infestations and their correlation with various climatic and environmental factors. The research emphasized the criticality of predictive modeling tools in forecasting pest incidence and highlighted the potential of machine learning and big data analytics in enhancing the accuracy of these predictive tools. Innovative management solutions, spanning from genetic interventions to the application of nanotechnology, were also discussed, underlining their potential in mitigating FAW damage. Central to our findings was the recurrent theme of international collaboration; the need for globally coordinated efforts in research, monitoring, and the sharing of resources emerged as a pivotal component in the fight against this pest. By incorporating diverse perspectives, including field insights from farmers and advancements in modern technology, this review aims to provide a holistic overview of the present scenario and proffers strategies for future action against the FAW threat.

Keywords: Fall Armyworm, *Spodoptera frugiperda*, predictive modeling, Insect, Armyworm

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1. Introduction:

Spodoptera frugiperda, colloquially known as the Fall Armyworm (FAW), is a lepidopteran pest that has been in the spotlight due to its significant impact on agriculture globally. Originally from the tropical and subtropical regions of the Americas, this insect's potential for devastation is far-reaching, affecting not just the crops directly but cascading down to influence global food security and economies [1]. The biology and behavior of *Spodoptera frugiperda* is paramount for tackling its invasiveness. The adult FAW is a moth with a wingspan ranging from 32 to 40 mm, but it is its larval stage that farmers dread the most. Despite measuring just about an inch, these larvae demonstrate a prodigious appetite, consuming vast portions of crops in their path. While maize is their favored food, their palate is not limited. Over 80 plant species including rice, sorghum, millet, sugarcane, and cotton have been recorded as host plants for these voracious eaters [2]. The global significance of FAW is highlighted by its rapid spread outside its native region. Within a short span, it has managed to invade and establish itself in regions as far as Africa and Asia. By 2018, 44 African countries reported FAW invasions, making it an urgent concern for the international agricultural community [3]. This spread is not a mere accident of nature but rather is facilitated by global trade, changing climatic patterns, and the innate adaptability of the pest. The immediate consequence of a FAW invasion is visible in the form of damaged crops, but to understand the full scope of its impact, one needs to delve into the economic realm. In Africa, where maize is a staple and a major source of livelihood, the potential damage from FAW is estimated to range from USD 2.5 billion to USD 6.2 billion each year [4]. This figure, while overwhelming in itself, is merely the tip of the iceberg. When one contemplates the potential losses in Asia and its traditional territories in the Americas, the numbers become daunting.

To combat the FAW invasion, farmers often resort to chemical pesticides. This solution, though immediate, comes with its own set of challenges. Firstly, the cost of production sees a sharp spike due to the added expense of pesticides. Additionally, repeated and excessive use of these chemicals can result in resistance among FAW populations, rendering these treatments ineffective over time. Environmentally, there is significant concern about soil degradation, water contamination, and a broader ecological imbalance due to excessive pesticide use [5]. From a health perspective, the residual presence of these chemicals in food products is a matter of great concern, potentially leading to long-term health implications for consumers. Beyond these immediate concerns, there is a larger economic and sociological narrative unfolding. The unpredictability of FAW attacks creates a sense of uncertainty among farmers. This unpredictability often discourages them from making long-term investments in their farms, stymying agricultural innovation and growth [6]. For nations where agriculture plays a pivotal role in the GDP, such reluctance has a ripple effect on the broader economy, impacting sectors interconnected with agriculture such as logistics, food processing, and retail. To tackle the FAW challenge effectively, there is a need for a multifaceted approach. Research is central to this. By understanding the biology, behavior, and adaptability of FAW, scientists can devise more effective and sustainable strategies to counter its spread. Policy interventions are equally crucial. Governments, especially in affected regions, need to prioritize FAW management in their agricultural policies, provide subsidies for sustainable pest control methods, and invest in farmer education and training [7]. Grassroot initiatives, focusing on community-based pest management, can serve as an effective buffer, especially in regions where large-scale interventions may be slow to materialize.

2. Biology and Life Cycle of Spodoptera frugiperda:

Spodoptera frugiperda, the notorious Fall Armyworm (FAW), is a pest of significant agricultural concern, owing much to its reproductive agility and adaptability. This lepidopteran has garnered international attention, not just for the havoc it wreaks on crops but also due to its fascinating biology and life cycle. Its ability to produce multiple generations in a year and its voracious feeding habits during its larval stages make it a formidable adversary to crops.

Egg Stage: The life of the FAW begins as a tiny, dome-shaped egg, delicately laid by the female moth on the host plant. These eggs, typically a creamy white when freshly laid, darken as they mature, offering a visual cue to their developmental stage. The underside of leaves is often the chosen site for oviposition, perhaps offering some protection from natural predators and environmental factors [8]. A single female moth can lay several egg masses, with each mass comprising up to 200 eggs, highlighting the species' prolific reproductive potential [9].

Larval Stage: After 2-10 days, depending on the environmental conditions, these eggs give birth to the next stage in the life cycle – the larvae. This stage is the primary cause of concern for farmers. Over the course of 14 to 30 days, these larvae will undergo six instars or developmental

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stages, each characterized by rapid growth and voracious feeding [10]. Starting as tiny green caterpillars, they gradually grow in size, reaching up to 1.5 inches in length, with distinct markings and color variations based on their instar and environmental influences.The larvae boast an eclectic diet, with maize being their primary food choice. They also feed on a myriad of other crops, including rice, cotton, and sorghum. Their feeding habits, combined with the sheer number of larvae that can infest a field, lead to significant crop losses [11].

Pupal Stage: Post the exhaustive feeding regime of the larval stages, the FAW enters the pupal stage. This transformative phase lasts for about 8-15 days, wherein the larva burrows a few centimeters into the soil to form a pupal chamber. Here, protected from the elements and potential predators, it undergoes metamorphosis. The resultant pupa, a reddish-brown capsule-like structure, is the penultimate phase before the moth emerges [12].

Adult Stage: From the confines of the pupa, the adult FAW moth emerges, completing the life cycle. The adult moths, with their distinct wing patterns - a combination of earthy tones with noticeable markings - are nocturnal in their habits. They have a wingspan of about 32-40 mm. While they might seem innocuous compared to their destructive larval counterparts, their role in the propagation of the species cannot be underestimated [13]. The adults live for about 10 to 21 days, with their primary objective being reproduction.

Lifespan and Reproduction: The entire lifespan of the FAW, from egg to adult, spans about 30 to 40 days, depending on environmental factors such as temperature and humidity. What truly sets the FAW apart is its reproductive potential. A single female moth can lay up to a staggering 1,500 eggs during her brief adult life, ensuring the rapid proliferation of the next generation [14]. This prolific nature, coupled with the ability to produce multiple generations within a year, especially in tropical and subtropical climates, underlines the challenges in managing FAW invasions.

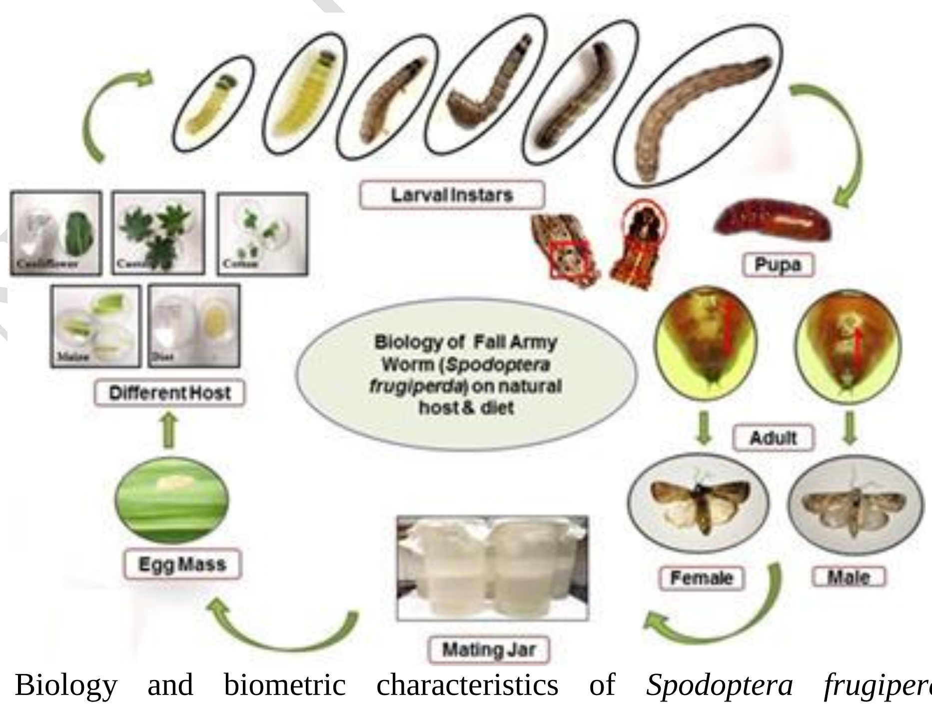

Image 1: Biology and biometric characteristics of *Spodoptera frugiperda Source:*

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3. Seasonal Incidence of Fall Armyworm:

The Fall Armyworm (FAW), *Spodoptera frugiperda*, though native to the tropical and subtropical regions of the Americas, has garnered global attention due to its rapid invasion across continents and its potential to inflict devastating damage to a plethora of crops. Among the myriad of factors influencing its occurrence and intensity, the seasonality stands out as a crucial determinant. Just as with many other pests, the seasonal incidence of the FAW is shaped by various abiotic and biotic factors, impacting not only its population dynamics but also its consequent interaction with the crops it infests. Multiple factors interplay in dictating the seasonal fluctuations of FAW. At a primary level, temperature and humidity emerge as key determinants. The FAW thrives in a specific range of temperature, with the optimal being between 27°C to 28°C, and its lifecycle accelerates within this range. Extreme temperatures, both high and low, can be detrimental. Humidity, particularly its role in egg survival, is equally vital. High humidity levels promote better survival rates of FAW eggs, ensuring a more substantial next-generation [15]. Apart from these, the photoperiod, or the duration of daylight, also affects the physiology and behavior of the FAW. As days get longer or shorter, depending on the transition between seasons, the reproduction, migration, and feeding behavior of FAW show variations [16]. Climatic factors often interweave to produce conditions either favorable or unfavorable for the proliferation of FAW [17]. Rainfall, for instance, has a dual role. While moderate rainfall can be beneficial, providing a conducive environment for larval development, heavy rainfall can be destructive, leading to the washing away of eggs and young larvae [18]. The FAW populations also exhibit a relationship with broader climatic events such as El Niño and La Niña. Such events, characterized by fluctuations in temperature and precipitation patterns, can either boost or diminish the population dynamics of FAW in regions affected by these climatic phenomena [19]. The global spread of the FAW means that its seasonal incidence varies widely based on geography. In its native regions in the Americas, FAW often displays two peaks, one during the spring and another during late summer, coinciding with crop plantings. In newly invaded territories such as Africa and Asia, the seasonal patterns are still emerging and are influenced by local climatic conditions and cropping patterns [20]. Seasonal fluctuations of FAW populations have direct implications on crops. As populations peak, often synchronized with the planting seasons, the damage inflicted on young crops can be extensive. Maize, being a favorite, suffers greatly, with larvae boring into the stem and devouring the plant from within. Other crops like rice, sorghum, and cotton, too, aren't spared, especially if their planting coincides with a FAW population surge [21].

4. Detection and Monitoring:

The successful management of the Fall Armyworm (FAW), *Spodoptera frugiperda*, in agricultural landscapes hinges significantly upon early detection and continuous monitoring. Over time, the methods employed for these crucial processes have evolved, transitioning from traditional practices to more advanced techniques with the advent of technological advancements. Historically, field scouting has been the foundational stone of FAW monitoring. Farmers, agricultural professionals, or trained scouts would systematically examine plants, often maize given its preference by FAW, for the tell-tale signs of infestation. This includes the

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presence of egg masses, young larvae on the underside of leaves, or feeding damage on the foliage, such as the characteristic windowing effect or pinholes caused by FAW feeding [22]. In many places, the timing of these scouting missions was aligned with the crop's growth stage, especially during its more vulnerable early stages. Pheromone traps are another conventional means that have been employed for many years. Male FAW moths are lured into these traps using synthetic versions of the female FAW's sex pheromone. The number of moths captured serves as a proxy for the local population density and activity, thereby aiding in predicting potential outbreaks [23]. As technology has evolved, so too have the tools for FAW detection and monitoring. DNA barcoding, for instance, allows for the rapid identification of FAW from other similar-looking pests. This molecular technique uses a specific fragment of an organism's DNA to pinpoint its species, ensuring accuracy and speed [24]. Advances in bioacoustics have enabled the detection of FAW larvae based on the sounds they make while feeding. Highly sensitive microphones can pick up these feeding noises, offering a non-invasive means to detect the presence of FAW in a field [25]. Arguably, some of the most exciting advancements in FAW detection come from the field of remote sensing and artificial intelligence (AI). Remote sensing, primarily through satellites or drones, allows for the large-scale monitoring of agricultural lands. These technologies can capture a range of data, from visual imagery to near-infrared, which can be used to deduce plant health and potential pest activity [26]. AI, with its capacity to process and analyze vast amounts of data quickly, complements remote sensing. Machine learning models, a subset of AI, can be trained on datasets to recognize the subtle signs of FAW damage on crops from the imagery. As the AI model improves its accuracy over time and with more data, it can predict FAW infestations with remarkable accuracy, often before they're visible to the human eye [27]. Moreover, the integration of these advanced monitoring systems with digital communication tools, like mobile applications, can offer real-time alerts to farmers about potential FAW activity in their vicinity. Such systems have the potential to revolutionize pest management, making it proactive rather than reactive.

5. Management Strategies:

Controlling the Fall Armyworm (FAW), *Spodoptera frugiperda*, has become a priority for many countries, given the devastating effects it can have on various crops. Over time, numerous management strategies have emerged. They range from time-tested cultural techniques to cutting-edge biotechnological approaches. One of the primary management strategies centers on modifying the environment and farming practices. This makes it less conducive for FAW to thrive. Rotating crops disrupts the life cycle of many pests, including FAW. Different crops may not provide the necessary nutrients for the armyworm larvae, or they may be unsuitable for egg laying [28]. This results in reduced pest populations in subsequent seasons. Keeping fields clean and free from crop debris post-harvest can reduce the number of overwintering pests. Destroying stubble and plowing the soil can bury armyworm pupae, reducing their survival rates [29]. Synchronizing planting schedules to avoid peak FAW activity can reduce crop losses. Late or early planting can help dodge periods when armyworms are most active and reduce potential damage [30]. Birds, beetles, and predatory bugs are known to feed on FAW larvae and eggs. Encouraging these predators in fields can help control FAW populations [31]. These are insects that lay their eggs in or on the FAW, with their offspring eventually killing the host. Examples include wasps of the family Braconidae which parasitize FAW larvae [32]. Bacteria such as Bacillus thuringiensis (Bt) produce toxins lethal to FAW but safe for other organisms. Applying

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these bacteria can be an effective, environmentally-friendly way to manage FAW [33]. Various insecticides, both contact and systemic, are used against FAW. They are typically applied as sprays, with some being soil-applied to target pupating larvae. Over-reliance on chemical insecticides can lead to resistance in FAW populations. Moreover, they can negatively affect non-target species and disrupt the natural ecosystem [34]. Crops like Bt maize have been engineered to produce proteins toxic to pests like FAW. These crops can offer significant protection against FAW infestations [35]. This cutting-edge technique involves disrupting FAW gene activity using RNA molecules. By targeting essential genes, FAW larvae can be killed or their development stunted [36]. Principles of IPM for Fall Armyworm: IPM combines cultural, biological, chemical, and physical methods based on current information about the pest and its environment. The aim is to manage pests economically, with the least possible hazard to people and the environment [37].

6. Challenges in Management:

The management of the Fall Armyworm (FAW), *Spodoptera frugiperda*, is an intricate and multifaceted task. While numerous strategies, both ancient and modern, are available to counteract the threat of this pest, several challenges can hinder the effective control of FAW. This article delves into the critical issues of resistance development, the implications of climate change, and the economic constraints, especially in developing nations. Resistance is an evolutionary response of pests to repeated exposure to a single or multiple types of pest control methods [38]. As pest populations are exposed to a control measure, the individuals that naturally possess the genetic makeup to withstand or evade this measure survive and reproduce [39]. Over time, the proportion of resistant individuals in the population can increase, rendering the control measure less effective [40]. Chemical control, particularly the use of insecticides, has been a primary method for managing FAW populations in many regions [41]. Continued reliance on a narrow range of insecticides can lead to resistance. For instance, FAW populations in Puerto Rico developed resistance to a specific class of insecticides, thereby significantly reducing their efficacy [42]. The use of genetically modified (GM) crops, specifically Bt crops, which produce toxins lethal to many pests, has been championed as a solution to many pest problems, including FAW. But just as with insecticides, there's a risk. Bt-resistant FAW populations have already been reported in parts of the globe, underscoring the need for diversified management strategies [43]. Climate change has broad and multifaceted effects on agricultural pests like the FAW. Changes in temperature, rainfall patterns, and atmospheric carbon dioxide levels can alter the behavior, distribution, and life cycle of these pests [44]. A warmer climate may allow FAW to have more breeding cycles in a year or expand its range to regions previously too cold for its survival [45]. Similarly, changes in rainfall patterns could influence the availability of its preferred crops, potentially forcing FAW to switch to alternative crops or move to more favorable locations. Elevated carbon dioxide levels can stimulate plant growth, potentially increasing the availability of food for FAW larvae [46]. While the threat of FAW is global, developing nations often bear the brunt due to various economic constraints [47]. For starters, access to advanced technologies and tools for pest management might be limited in these countries. Genetically modified crops, modern insecticides, and advanced monitoring tools might be either too expensive or not available at all [48]. The small-scale farmers predominant in many developing nations might lack the knowledge or training to implement effective pest management strategies. This is exacerbated by weak extension services and limited access to

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timely information [49].

7. Future Perspectives:

The Fall Armyworm (FAW), *Spodoptera frugiperda*, has emerged as one of the most critical agricultural pests, having a significant impact on crop yields across the globe [50]. With the challenges of climate change, resistance to pesticides, and the varying economic capabilities of affected countries, the need for a future-focused perspective in managing FAW is imperative [51]. This paper delves into predictive modeling for pest incidence, explores novel technologies in the pipeline, and underscores the importance of policy recommendations and global cooperation in our ongoing battle against this formidable pest [52]. Predictive modeling is the usage of statistical techniques to predict future outcomes. In the of pest management, these models use current and past data on pest populations, weather conditions, and other relevant factors to forecast future pest incidences [53]. These predictions can be invaluable for farmers and policymakers, allowing them to prepare in advance and thus reduce the potential damage caused by these pests. Recent advancements in machine learning and big data analytics have given a significant boost to the accuracy and capabilities of these predictive models. By analyzing vast datasets that include historical pest infestations, weather patterns, crop cycles, and more, algorithms can provide highly accurate predictions about when and where pest outbreaks are likely to occur [54]. The models developed for FAW have already shown promise in Africa. These models utilized remote sensing data and seasonal climate forecasts to give early warnings about potential FAW outbreaks, allowing farmers to take preventive actions [55]. The increasing challenges in managing FAW have spurred research into new and innovative technologies. One of the most promising avenues is genetic engineering. For example, the use of CRISPR/Cas9 technology to edit the genes of FAW, making them less virulent or even sterile, is being explored. This approach, termed gene drives, could significantly reduce FAW populations in affected areas [56]. Additionally, advancements in nanotechnology are paving the way for more efficient pesticide delivery systems [57]. Nanopesticides, which are essentially nano-sized particles of conventional pesticides, can be more effectively absorbed by pests, reducing the amount of pesticide needed and thus the environmental impact [58]. The use of drones or unmanned aerial vehicles (UAVs) is being investigated for pest monitoring and management [59]. These drones can be equipped with cameras and sensors to monitor vast areas of farmland quickly and efficiently. They can also be used to release biological control agents, such as parasitoid wasps, directly over FAW-infested areas [60].

Conclusion

The management of Fall Armyworm (FAW), *Spodoptera frugiperda*, necessitates a proactive, technologically-driven, and internationally collaborative approach given its global agricultural impact. The prospects of predictive modeling offer actionable foresight, enabling better preparedness and timely interventions. Innovations such as genetic editing, nanopesticides, and the deployment of drones underscore the growing technological arsenal against this pest. The linchpin of effective FAW management lies in international cooperation. Coordinated monitoring systems, shared research initiatives, farmer training, and stringent trade regulations are integral components of this global strategy. Collectively, these measures not only serve as a bulwark against the immediate threats posed by FAW but also set a precedent for managing

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agricultural challenges in an increasingly interconnected world.

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