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Socioeconomic and Environmental Impacts of the Fall Armyworm and The Striga Weed at Three Stages of the Maize (Corn) Value Chains in Kenya: A Review

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SOCIOECONOMIC AND ENVIRONMENTAL IMPACTS OF THE FALL ARMYWORM AND THE STRIGA WEED AT THREE STAGES OF THE MAIZE (CORN) VALUE CHAINS IN KENYA: A REVIEW

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Abstract
Global food security faces increasing threats from climate change, leading to diseases, pests, drought, water salinity, and rising temperatures. The study broadly addresses global food security challenges, focusing on two pests. The purpose of the study was to assess the socioeconomic and environmental impacts of the fall armyworm and the Striga weed at three stages of maize (corn) value chains in Kenya. The methodology used encompassed a desk review of relevant research and current literature. The results indicated that the Fall Armyworm (FAW) and the Striga weed significantly impact maize (corn) production. The FAW and the Striga weed cause losses in yield, reduce the ability of agricultural lands to respond to shocks, and financially increase the cost of production resulting from the quest to deal with the pests mentioned above.
Keywords: Fall Armyworm, Maize (Corn) Value Chain, Socioeconomic and Environmental Impacts, Striga Weed

Introduction
For a long time, agriculture has held a position as the main livelihood source for many households both locally and globally. Despite its position, the agricultural sector still faces the overwhelming challenge of offering enough food and other items of necessity to the world's population. The world's population is continuously increasing and is expected to grow to approximately nine billion by the year 2050. The rise in income levels and the increase in the urban population, particularly in developing nations that consume a diversified diet, will tremendously increase and cause changes in the need for food and feed. This can affect and compete with other uses of maize (corn), such as biofuel and other industrial services. In Africa and the Americas, maize (corn) is regarded as the most important stable food crop, meeting the dietary needs of humans and livestock. It is rich in energy, proteins, and vitamins. Accordingly, the economic significance of maize (corn) and its role in ensuring food security globally, particularly, in Sub-Saharan Africa is of utmost importance to all agricultural stakeholders.

Indeed, maize (corn) is the primary food crop in Kenya; however, constraints to its production are the Fall Armyworm (FAW), the Striga weed, and declining soil fertility (De Groote et al., 2020). The invasion of the fall FAW and the Striga weed significantly threatens the production of maize (corn). These pests present an issue of concern given the ravenous feeding manner of the worm and the Striga weed and their expected effects on food security. This paper examines the socioeconomic and environmental impacts of the FAW and the Striga weed at three key stages of the maize (corn) value chain. Since the study is mainly literature-based, the "Literature Review"

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does not cover the studies but instead deals with what the FAW and the Striga weed are, while the "Discussion" section highlights the various literature and research reports searched.

Literature Review

The Fall Armyworm

The FAW is a well-recognized pest in the agricultural sector, constantly affecting various crop species, mainly maize (corn), in the Americas for centuries. The FAW has been the major invasive pest in Africa, the Near East, and Asia last few years. This pest was initially reported in early 2016 in West Africa. Since then, the pest has spread across Sub-Saharan Africa. By late 2018, it had been confirmed by almost every country in Sub-Saharan Africa. The existence and spread of the FAW were later confirmed in Yemen and India by late 2018 and in five other Asian countries, including China, by early 2019 (Rwomushana et al., 2018). Unreliable weather patterns and increased invasion of the FAW continue to aggravate food insecurity in developing nations. The UN's efforts to reduce hunger, achieve good health and well-being, and improve standards of living in developing countries by 2030. It is projected that the invasion of the FAW can cause a loss of between 8.3 million to 20.6 million metric tons of maize (corn) per year, an equivalent of \$2.5-6.2 billion, and enough to feed 40-100 million people (Igyuve et al., 2018).

The FAW is an invasive and destructive pest across the world, and if not appropriately and effectively controlled, then the pest will continue to cause immense damage to maize (corn) and worsen the already near moribund food security and living conditions in many parts of the developing world. It directly impacts at the socioeconomic level by negatively influencing food and income and increasing global food insecurity, malnutrition, and poverty among smallholder farmers. The FAW, just like in other African countries, suddenly appeared in Kenya and invaded large portions of productive land, leading to an enormous loss of crops. It has also unexpectedly become a significant pest globally, attributing to losses of approximately 33% of the annual maize (corn) yield. Irrespective of maize (corn) production being relatively high compared to other crops, it is way below its potential (Timilsena et al., 2022).

Generally, the FAW undergoes a four-stage life cycle: egg, larva (caterpillar), pupa, and adult. The larvae, commonly known as armyworms, are the most damaging stage to maize (corn) crops. The larvae feed voraciously on various parts of the maize plant, including leaves, stems, tassels, and developing ears. They can cause severe defoliation and directly damage the reproductive structures, leading to reduced yield and quality. The presence of the FAW can be identified through several signs, including ragged leaves, chewed tassels, holes bored in maize (corn) ears, and frass (insect excrement) on the plant (Food and Agriculture Organization [FAO] and Commonwealth Agricultural Bureaux International [CABI], 2019).

The Striga Weed

The parasitic Striga weed, has invaded many cereal crop fields and threatened food security resulting in huge socioeconomic losses. There are 35 species globally. Africa has 80% of the species of the Striga weed that has become a enormous problem and is responsible for huge yield losses, especially in maize (corn) production (Jamil et al., 2021). It is an infamous biotic constraint and an existential threat to maize (corn) production in Kenya. The sprawling of the Striga weed is a significant problem for many farmers. It causes severe yield losses and consequently has a great economic impact on farmers. Most farming households have been affected by the Striga weed, thus, threatening food security. It is estimated that nearly 70% of Kenyans work in the agricultural sector, and their livelihoods depend on farming (Atera et al., 2013). Many farming households have been affected by the Striga weed, particularly in regions where it is prevalent. The impact is particularly severe for smallholder farmers who rely heavily on crop production for their subsistence and livelihoods. Striga infestations can lead to reduced crop yields, decreased income, and increased vulnerability to food insecurity (Atera et al., 2013). Striga is a persistent and challenging weed to control. Traditional farming practices, such as continuous cropping without proper nutrient management or fallow periods, contribute to its spread and persistence. Moreover, the Striga weed has developed resistance to certain herbicides, making chemical control methods less effective (Kasozi et al., 2015).

Materials and Methods

A desk review of the impacts of the FAW and the Striga weed was conducted to thoroughly scrutinize the research and literature to date. According to Petticrew and Roberts (2006), a desk review identifies, appraises, and synthesizes all the relevant studies on a given topic in an exhaustive manner. Teddlie and Tashakkori (2009) discussed eleven steps for a desk review. These steps are: (1) identification of a research topic; (2) identification of the descriptors useful in locating materials; (3) developing an overall search strategy for the literature review; (4) searching preliminary sources; (5) selecting relevant primary and secondary sources; (6) searching the library for the secondary and primary sources that have been identified; (7) establishing a computer and paper trail including research summaries; (8) repeat the aforesaid steps to refine the search; (9) developing themes and concepts that synthesize the literature; (10) relating the themes to one another through an outline of the literature review or literature map to produce final literature that structure or organize the literature thematically or by important concept; (11) develop or refine the research questions and hypotheses. The problem being investigated and presented in this review is to determine the socioeconomic and environmental impacts of the FAW and the Striga weed on the maize (corn) value chain. The inclusion and exclusion criteria are shown in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• For articles reporting identical studies, the most recent one was selected • For articles describing more than one study, each study was individually evaluated • The articles had to describe the impact of the FAW and/or impacts of the Striga weed	• Full text not available within the selected database • Article that was not written in English • Article or review published in a book

Results

This desk review identified the effects of the FAW and the Striga weed on maize (corn) value chain that, have both socioeconomic and environmental dimensions. Twenty-four journal articles focused on the socioeconomic impacts of the FAW at the production stage. Nineteen articles that focused on the socioeconomic the impacts of the FAW at the post-production stage. One article focused on the environmental impacts of the FAW at the production stage, two articles focused on the environmental impact at the pre-production stage, and one article focused on the environmental impact at the post-production stage.

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Forty-two journal articles were reviewed on the socioeconomic impacts of the Striga weed. Five articles were reviewed on the socioeconomic impacts of the Striga weed at the pre-production stage. Nineteen articles on the socioeconomic impacts of the Striga weed were reviewed at the production stage, and eighteen were reviewed at the post-production stage. Seven articles were reviewed on the environmental impacts of the Striga weed, with two focused on the pre-production stage and five at the production stage.

Discussion

The Socioeconomic and Environmental Impacts of the Fall Armyworm

The FAW is a migratory insect pest that causes enormous damage to maize (corn) crops in humid and warm conditions (Assefa and Ayalew, 2019). The FAW reproduces very quickly and feeds on a wide variety of plants (Smith, 2018). Usually, the FAW migrates from farm to farm and has a high dispersal capacity, allowing it to spread quickly (Kumela et al., 2019). The pest's eggs are laid in mass on the upper surface of the plant's leaves, and each mass can have 100–200 eggs with up to a total of 1,000 eggs production per female (Kumela et al., 2019). The infestation of the pest later increases as the maize grows by 55-100% (Assefa and Ayalew, 2019).

Depending on the crop type and variety, stage of crop development, and age of the larvae, eat different parts of the host plant. On maize (corn), for instance, a young larva normally feeds on the leaves, causing a windowing effect (Day et al., 2017). As the number of larvae increases, they tend to defoliate their host plant, acquiring the typical 'armyworm' behavior and dispersing in groups, destroying all types of vegetation in their path (Prasanna et al., 2018). The adult moth feeds on suitable flowers when dark enters for up to two hours before females start emitting pheromones and attracting the males to mate. Adult FAWs migrate by night and are usually attracted to lights, particularly those containing strong ultraviolet components (Day et al., 2017).

The early and mid-whorl infestations by the FAW larvae cause defoliation (Cruz et al., 1999). However, the yield of field maize (corn) pest-ridden with second instar larvae is not reduced when 20% of the crops in the mid-whorl stage of growth are infested with FAW egg masses (Assefa and Ayalew, 2019). Generally, a single larva can consume approximately 140 cm^2 of maize (corn) leaf area while undergoing the larval development stage. The larval stage takes about 14 days in warm conditions and about 30 days in humid conditions (Rwomushana et al., 2018). As indicated earlier, the young FAW larva usually feeds on leaves, causing a windowing and holed effect. The process of the larvae feeding leads to the release of moist sawdust-like grass, forming lumps around the funnel and upper leaves, giving farmers the signs of larval existence. As the larvae grow older, they mostly stay inside the funnel, feeding on the host plant at night.

The maize (corn) plant can recover from foliage damage caused by the FAW larvae; however, the damage done on the ear of the leaves is permanent and has an instantaneous impact on crop yield. In maize (corn) mono-crop fields, levels of damage caused by the FAW larvae range from high (50-75%) to severe (>75%) (Pickett et al., 2018). In Ghana, the infestation of the FAW mainly occurs in the early and mid-stages of the crop, while in Zambia, the moth attacks the maize (corn) plant while at its vegetative stage (Rwomushana et al., 2018). In Zambia and Ghana, between June 2016 and July 2017, approximately 98% of farmers' maize (corn) was affected by the pest, while only 2-4% of attack was on millet, sorghum or Napier grass (Early et al., 2018). Maize is the most impacted host plant by the FAW. In Kenya and Ethiopia, farmers reported the FAW in their fields for roughly two months, between May and July 2017, with approximately 32%-47% infestation (Kumela et al., 2019). The proportion of farmers affected by the FAW was 63% in 2017 (short rains), 83% in 2018 (long rains) and 63 % in 2018 (short rains) (Donato et al., 2020). A 2017 survey of parasitisation by the FAW ranged from 4.6% in Ethiopia to 8.3% in Kenya (Sisay et al., 2018).

Given its ability to spread quickly and cause widespread damage in fields, the FAW presents a real threat to food security, nutrition and livelihoods of households globally. In Southern Africa, for instance, the 2016-17 FAW invasion arrived just as the region was experiencing the effects of the 2015-16 El Niño-induced drought, which impacted approximately 40 million people. The FAW is likely to directly affect capital costs, including increased labor and expertise needed to manage the pests (Day et al., 2017). The effect can be seen in the ability of agricultural fields to respond to shocks, and financially, through the increase of the cost of production and its impact on income levels.

The average total loss in 2017 during the long rains was 924,000 tonnes, 34% of the average maize (corn) production. The loss was 257,000 tonnes during the short rains, 32% of average maize (corn) production in 2017, and 883,000 tonnes in 2018 during the long rains, also 32% of average maize (corn). Yield loss percentage among affected farmers was 54% in 2017 during the long rains, over 53% during the short rains, and 42% during the long rains in 2018. Also, the average maize yield on the FAW-infested fields was 3.04t/ha, while it was 3.48 t/ha on the non-infested plots (this difference was not statistically significant (Kassie et al., 2020). Infestations at the mid and late development stages of the maize (corn) plant can lead to yield losses of between 15–73%. The average loss in a typical sample was 11% (Assefa and Ayalew, 2019).

Replacing multiple locally adapted and genetically diverse crop varieties with a smaller number of modern varieties reduces local and regional agrobiodiversity (Reynolds et al., 2015). One potential alternative appropriate for small farmers to control biotic and abiotic stresses is to utilize seed treatment with low doses of acetolactate synthase (ALS)-inhibiting herbicides (imidazolinone herbicides) such as *imazamox, imazapic*, and *imazapyr*. Imidazolinone resistance (IR) genes were incorporated into tropical maize lines that adapted to the growth conditions in Africa, and the imazapyr-coated seeds of these IR maize lines planted under *S. hermonthica* infestation (Samejima and Sugimoto, 2018).

Also, common responses to production constraints such as applying chemical fertilizers, water extraction and irrigation, and applying pesticides and herbicides often present great environmental risks and costs for crops, wildlife, and human populations, (Reynolds et al., 2015). Post-harvest losses of crops carry the burden of all resources used in the production process harvest that is lost. By minimizing the post-harvest losses from ineffective processing or storage pests, farmers get to maximize the availability of food and reduce the per-unit weight or per-unit area environmental effect of a particular harvest.

Socioeconomic and Environmental Impacts of the Striga Weed

Striga *Hermonthica* (hereafter referred to as “Striga”), is a major biotic stress to grain production in Sub-Saharan Africa (Mbula, 2018). The parasitic plant is a socioeconomic constraint that has forced some resource-poor farmers to leave their farms because of the high infestation (Atera et al., 2013). Overall, the most effective strategy farmers used to control the existing persistent weed flora and invasion levels was a stubble cultivation period before plowing. *C. arvense* and *S. arvensis* represent the group in which the season of cultivation was fundamental. As previous studies show, the cultivation of soil in the spring provided a more effective way of controlling *C. arvense* relative to similar soil cultivation treatments in autumn (Brandsaeter et al., 2017).

Usually, after germination of a crop, the Striga weed attaches itself to the roots, significantly interfering with the plant's photosynthesis process and its productivity (Mudereri et al., 2020). Besides the interference of the host plant's photosynthesis, the parasitic weed uses the nutrients of the crop and causes nutrient deficiency, thereby slowing the growth of the crop (Andersson and Halvarsson, 2011). The Striga weed causes severe stunting and yield loss, thereby affecting crop production (Mbuvi et al., 2017). Fruitful haustorial attachment to the host leads to irreversible damage during a large part of the crop life cycle, reducing the crop value by lowering the yield and infecting it with parasitic seeds (Fernández-Aparicio et al., 2020). Losses in yield due to Striga damage range from 20-80% in Africa, with a potential 100% loss in worst situations, and can cause grain loss of approximately $40.8 million (Teka, 2014).

In the Sub-Saharan Africa and South Asia regions, the production of crops can be affected by various factors, including environmental factors, like inadequate access to soil nutrients, water shortages, and drought, and direct damage from pests, weeds, and diseases (Reynolds et al., 2015). Unlike all other agricultural weeds that compete with crops for the space to obtain water, nutrients, and light, the Striga weed is predominantly harmful as it also directly draws out valuable water and nutrients from the host plant. The parasitic weeds have developed a multicellular structure known as the haustorium that attacks the host, forming connections with the host's vascular system, and withdraws its needed water and nutrients. Striga, like other plant herbivores and pathogens, reduces the host productivity by reducing rates of crop photosynthesis (Fernández-Aparicio et al., 2020). While several Striga plants may attach themselves to one host plant, some do not emerge from the ground and still compete for nutrients from the host. Striga spp. are obligate parasitic weeds that attach to the roots of crops and other plants, rob them of nutrition and cause several other incapacitating effects, earning them their common name of "witchweeds" (Ayensu et al., 2019). There is more than 2.6-fold higher S. hermonthica biomass when the parasite is attached to CML 144 than when attached to KSTP'94 (Mbula, 2018). Controlling Striga and other root parasites is difficult since the weed can do much damage to the host crop before emerging above the ground (Elisaba, 2006).

Following attachment, Striga remains subterranean for six to eight weeks (Sibhatu, 2016). In this period, the weed depends entirely on the host plant and is most damaging. In some cases, the host plants, may have striga resistance, which enables them to encourage Striga germination while at the same time preventing them from attaching themselves to the roots or killing the seedlings when connected (Sibhatu, 2016). Striga parasitism and other physiological changes that follow the infestation result in a substantial loss in crop yields. The physiological changes include weakening of the host plant, wounding of its outer root tissues, and absorption of its supply of moisture, photosynthates, and minerals (Midega et al., 2017). Generally, agricultural weeds play a significant role in restricting the sustainability of crop production. Often, they outdo crops in competition for nutrients, soil moisture, radiation, and space, and offer surfaces where pests and diseases breed

(Mudereri et al., 2019). Striga poses a substantial threat to food security given their capacity to cause yield losses ranging from 65-100% (Murage et al., 2019; Esilaba, 2006).

Research in Striga-infested areas shows that farming with weed-resistant crops leads to reduced Striga plants and increased crop yield compared to using non-resistant genotypes. In the study, various species of the Striga plant were controlled by the cultivation a variety of Striga-resistant crops, fertilizers, and tied ridges on farms. Local farmers had extreme invasions where the average yield of the resistant variety was 1,718 kg/ha against 216kg/ha from the local variety (Sibhatu, 2016). Plants can alter the nutritional availability, structure, and chemistry of the soil they grow. These soil changes can positively or negatively influence the growth and metabolism of other plants that co-occur or grow later in the conditioned soil (Mutyambai et al., 2019). Generally, low yields in the rows under Striga attack were linked to increased Striga damage symptoms, the number of emerged Striga plants, poor ear-aspect scores, and a reduced number of ears per plant under Striga infestation. Poor lands, poor management, and fewer inputs lead to more significant Striga damage (Ayensu et al., 2019).

The willingness to adopt various methods of weed control shows that women are likely to make quick decisions in applying new technologies that benefit them by eliminating farming constraints (Murage et al., 2019). The decision-making process regarding the adoption would otherwise require more time if women were to wait for information from the male members of their households, especially if males have minimal knowledge of the farming activities. The wave effects in the adoption of technologies, particularly among poor households, would be greater if the women received extensive agricultural training.

With the increase in demographic pressure and demand for food, the need to use land has intensified through monocropping, and consequently leading to a reduction in soil fertility. Arable fields are usually abandoned because of the exorbitant parasite or weed population (Esilaba, 2006). The increase in the incidence of Striga has been because of poor soil fertility and structure, low soil moisture, intensification of land use through continuous cultivation, and an expansion of cereal production (Sibhatu, 2016).

In Kenya, almost half of the arable land (49%) is under maize (corn) cultivation; the crop accounts for roughly 0.3% of the maize (corn) production globally. Maize (corn) supplies about 365 kilocalories per 100g and accounts for 35% of the total caloric intake (FAO, 2019). Maize (corn) is a staple crop that accounts for up to 3% of the country's agricultural gross domestic product and 21% of the total value of primary agricultural commodities. The crop is cultivated in six agroecological zones: highland tropical, moist transitional, dry transitional, moist mid-altitude, dry mid-altitude, and lowland tropical. Generally, maize (corn) yield/hectare is low: 1,440-1,836kg compared to 5,751kg globally and 2,070kg in other African countries (FAO, 2019).

Kenya experiences extreme rainfall events twice every three years. The country has also experienced severe droughts in the last decade and variable annual rainfall. The extreme weather, together with the country's overreliance on rain-fed regions, increases Kenya's vulnerability to food insecurity. Extreme weather can have a severe effect on crop and feed production. Additionally, the global financial and economic crisis, high prices of food items and fuel, and an unstable political landscape have consistently disrupted supply chains and markets in the

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agricultural sector, threatening growth, and the sector's ability to ensure food safety and lessen poverty levels (D'Alessandro et al., 2015).

The maize (corn) value chain is multifaceted and incorporates several players in Kenya, including the consumers, marketers, suppliers, and farmers. The mentioned four categories also consist of many sub-players known for integrating the value chain vertically or horizontally. The existing integration thwarts food security and the value chain, given the different roles played by the stakeholders. The Eastern Africa Grain Council is a regional organization of grain value chain players. The organization's membership consists of millers, traders, farmers, service providers such as banks, warehouse operators, and input suppliers from the East African Community and the Common Market for Eastern and Southern Africa. Extension service providers who focus on providing extension services, such as technology dissemination, may also join the Eastern Africa Grain Council (Chenevix et al., 2012).

About 96% of farming households grow maize, particularly for home consumption, with the surplus vended to assemblers. This result occurs because a majority of the rural households possess small farms, usually less than five acres and can barely produce enough for their own consumption needs. On the average, 45% of household-grown maize is transported to the market for sale (Kirimi et al., 2011). Nearly 18% of farmers are involved in the sale and purchase of maize in the same year (Kirimi et al., 2011), and most of them are not able to meet their maize (corn) needs throughout the year. Almost 20% of farmers who sell their maize (corn) own large chunks of land and have vast amounts of land (more than 20 acres) under maize (corn) plantations. Such farmers mainly sell their maize (corn) to large commercial millers and the National Cereals and Produce Board (Chenevix et al., 2012).

Conclusion

The main purpose of this study was to assess the socioeconomic and environmental impacts of the FAW and the Striga weed at three stages of maize (corn) value chains in Kenya. The study used a desk review approach to appraise extant knowledge on the issues being assessed. The review revealed that the FAW has three main cost effects. First, general high-cost effects, mainly due to high yield losses, increased labor required, and the type of knowledge needed to fight the pest. Second, the ability of agricultural lands to respond to shocks and its associated costs of increasing the cost of production. These costs are related to the cost of technology and its application) and its effect on income. Third, the pest also affects household social and physical capital (the household's assets) indirectly. Regarding the Striga weed, it slows down the growth of the maize (corn) plant in two ways: one, by destroying its photosynthesis and using its nutrients. Consequently, there stunting results from insufficient nutrients and extremely low crop yields. Additionally, it is shown to exacerbate aflatoxin infestation in postharvest maize (corn).

Controlling the FAW and the Striga weed by applying pesticides poses serious environmental risks and costs for crops, wildlife, and human populations. The Striga weed can also change the chemistry of the soil where they grow. It is evident that both FAW and Striga weed have negative socioeconomic and environmental impacts on maize value chains in Kenya. Therefore, care must be taken to eliminate or reduce their impacts on food security and nutrition. Early detection and control are recommended. The chosen control practices and measures should be affordable, economical, practicable, and sustainable for poor farmers. Some suggested solutions are (1) using suitable companion and trap crops, such as those suggested in push-pull technology, to reduce the Striga weed seed bank; (2) developing and using resistant crop varieties to control the Striga weed and FAW; (3) the proper timing of planting seasons to ensure that planting is done when the conditions are not favorable to the pests; (4) leveraging on planting materials that are aflatoxin-resistant, including conventional and transgenic breeding; (5) using bio-controls like Aflasafe™ to fight fungi responsible for producing aflatoxins in soil; and (6) practicing sustainable postharvest handling of maize to control moisture, for example, solar drying, tarp drying, and promoting hermetic storage.

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