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Potential Environmental Risks During Fall Armyworm Management Strategies by Gender in Bomet County, Kenya

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Abstract: ***Advent and meteoric rise from the fall armyworm (FAW) Spodoptera frugiperda (J. E Smith) as an invasive pest within Africa possess grave implications to smallholder agriculturalists with reference to potential environmental risks and perceived human ill - health leading to household food insecurity. In Kenya, the first FAW invasion detection reported in Bomet County in 2016 prompted the indiscriminate use of synthetic insecticides that could undermine the environment, human health and food security. Based on gender disparities through food supply network, FAW invasion can obstruct the accomplishment of households' nutrition security with environmental unsustainability. The analysis of data used descriptive statistics. The results showed FAW management practices that were likely to lead to environmental risks and perceived ill health related to chemical use with either male or female farmers being the primary chemical handlers. There is need for research and service providers to create awareness for farmers on better FAW mitigation strategies mainly on the use of chemicals that are more biodegradable and less polluting to the environment. Increasing awareness creation on FAW practices that are less likely to enhance occupational exposures to pesticides and to family members.***

Keywords: fall armyworm, invasive pest, environmental risks, food insecurity, synthetic insecticides

1. Introduction

In 2016, FAW (*S. frugiperda),* a compulsive agricultural pest indigenous to North and South America, was first sighted on the African continent where it proliferated from West Africa across the region, causing great harm to crops and later on escalated across Asia (Kalleshwaraswamy *et al.,* 2018; Malo & Hore, 2020; Ramasamy *et al.,* 2022; Wild, 2017). Consequently, instantaneous response of African governments including Kenya was to plough money into toxicant pesticides since the invasion by FAW, furthermore, the take up continues being major artifice used by farmers controlling FAW (Abro *et al.,* 2021; Kumela *et al.,* 2018; Matova *et al.,* 2020).

From its indigenous habitat, literature indicates FAW feeds on over 80 plant species in 27 plant families including maize crops (Goergen *et al.,* 2016). When considering the food production sector like maize, rice, sorghum and sugarcane, it is been calculated that FAW could cause up to thirteen billion US dollars each year in crop losses across sub - Saharan Africa (SSA) (Abrahams *et al.,* 2017; Ahissou *et al.,* 2021; Day *et al.,* 2017; Harrison *et al.,* 2019). Moreover, due to the high consumption of these cereal crops, particularly maize, in smallholder diets, FAW could have a substantial negative impact on food security (Burtet *et al.,* 2017; Khan *et al.,* 2020; Phambala *et al.,* 2020). Latterly, FAW has broadly escalated throughout Sub - Saharan Africa (SSA) and, presently, its incidences is within forty - four African nations including Asia (Navik *et al.,* 2021; Nyamutukwa *et al.,* 2022; Tambo *et al.,* 2020). In consonance with FAO (2018), several initiatives are being tried which include, sensitization of farmers, increasing surveillance on FAW spread and early planting and chemical spraying targeted at controlling FAW infestations on maize crops (Baudron *et al.,* 2019; Gebreziher, 2020; Maluleke, 2020).

The upsurge of FAW was first sighted in Bomet County, Kenya in the year 2016 (FAO, 2018; MoA, 2018). The pest spread rapidly to all major maize producing zones in the country thereby, affecting food security and trade. Agricultural production is the major business activity in Bomet County with over eighty percent of the county's population carrying out farming and animal rearing (FAO, 2018). According to FAO (2018) if the FAW caterpillar is unmanaged it will cause up to 100 percent maize yield loss rendering many households to being food insecure Kenya including Bomet County.

The invasion of FAW within the country's farmlands made our smallholder farmers vulnerable to the excessive exposure of pesticide use (Kumela *et al.,* 2018; Wyckhuys & O'Neil, 2007). According to Carvalho (2006), Jallow *et al. (*2017), Kaur *et al.* (2019) and Wilson *et al. (*2001) their studies found out there was an abundance of new pesticide users in agricultural production. The invasion of FAW demands an overuse of insecticides thereby leading to negative consequences to the environment (e. g. soil, water, air and food contamination) and farmers' wholesomeness (Kaur *et al.,* 2019; Kumela *et al.,* 2018). This required attention and

preparedness on the overuse of chemicals for FAW management practices while producing food crops. The findings exploration done during the study were within the confines of five sub - counties of the County. Furthermore, uniqueness to Bomet County's all year round in crop production greatly influenced the thriving of FAW where the researcher anticipated providing contrasting information on FAW management practices that are likely to lead to environmental contamination during food production.

2. Materials and Methods

(i) Description of the Study Area

Bomet County is a creation from the former Kericho district through Kenya gazette supplement no.53 of 1992 (KPHC, 2019). The county borders Nakuru territory into northeast, Narok territory appearing in south, Kericho territory into north along with Nyamira constituency inside west with a land mass of 2, 037.4 square kilometres. Bomet County currently divided into five small divisions called sub - counties namely Chepalungu, Sotik, Konoin, Bomet East, and Bomet Central with a total population of 875, 689 and a gender proportion of 434, 287 females, 441, 379 males and 23 intersex persons (KPHC, 2019). Specific sampling locations was selected pertaining to the 3 major agro - ecological zones in Bomet County (Low Highland Zone^2 (LH2), Low Highland Zone^3 (LH3) and Upper Midland Zone^4 (UM4) taking into consideration food crop producing areas especially maize production being the prominent cultivated food distressed by FAW invasion.

(ii) Sampling Procedure

Respondents for the research study selected using random sampling whereas, the survey form attained through obtaining divisions categorisation inventory out of government agricultural ministry's extension office by classifying each sub - county into AEZ strata namely - Low Highland Zone^2, Low Highland Zone^3 and Upper Midland Zone^4. The MOA extension officers aided in the selection of Self Help Groups through purposive sampling. A total sample representation of 384 households (212 female households and 172 male households) sampled with a gender proportion of 55 female and 45 male smallholder farmer households interviewed. There was emphasis on the different household interrelations where the nuclear family alongside community heads categorized according to married or with spouse, single men and women, bachelor, split up or detached men and women, dowagers and widow - man who were practicing crop farming. The different survey approaches provided complimentary information towards possible FAW management practices that are likely to lead to environmental contamination.

(iii) Data Analysis

Information acquired through interrogations with listing analysed using the Statistical Package for the Social Science (SPSS) version 19 (Asthana with Bhushan, 2016) and EXCEL (Barreto, 2015) whereas, information accordingly both encoded with entry done for analysis. The sampled data from study area yielded both quantitative and qualitative data. Descriptive analysis done using means, percentages and frequency distribution (table charts and bar charts).

3. Results and Discussions

(i) Gender Distribution and Household Composition

The actual response sample size was 393 respondents from which 384 respondents were responsive and provided valid data (Figure 1).

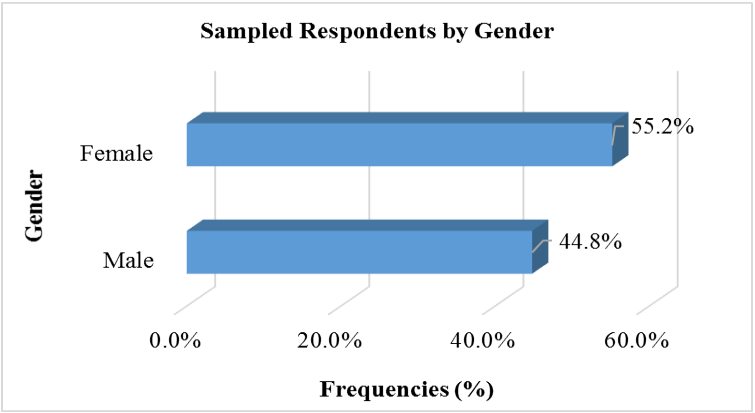

Figure 1: Number of Sampled Respondents by Gender (2020, Kenya)

The results in Figure 1 indicates a gender measure equivalent to 44.8% male with 55.2% female smallholder farmers within the five sub - counties (Konoin, Sotik, Bomet Central, Bomet East and Chepalungu sub - Counties) in Bomet County. These results further indicated a household composition had an average of eight relations (inclusive of parents and children). Nevertheless, sampled households had a minimum of 1 to 3 household members and the highest are 12 to 14 household members (Figure 2).

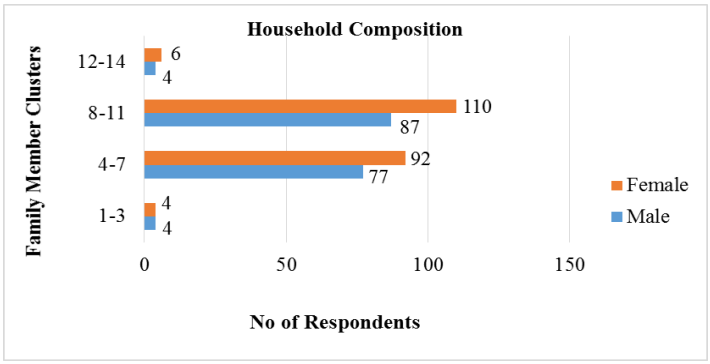

Figure 2: Household Composition of Respondents by Gender (2020, Kenya)

(ii) Perceived Environmental Issues after FAW Invasion by Gender

The results on perceived environmental issues after FAW invasion by gender was from enumerated respondents' as "perceived" or "physically seen" (Table 1). The perceived environmental issues arose from perceptions as well as results obtained from composition of pesticides that were in use towards control of fall armyworm invasion. The result showed fall armyworm invasion had effects on smallholder farmers' resource use with 42.7% calling it economically expensive due to extra money and labour requirement. The finding indicated 29.4% households experienced poor food yields due to FAW invasion with 27.9% households' experiencing ill health due to FAW control strategies (Table 1).

Table 1: Perceived Environmental Issues after FAW invasion by Gender (2020, Kenya)

Perceived and Physical Issues		Frequency (n / %)	Male	Female
	Poor Yields due to FAW invasion	113 (29.4%)	48 (12.5%)	65 (16.9%)
	Perceived ill - health Experiences	107 (27.9%)	51 (13.3%)	56 (14.6%)
	Economically Expensive	164 (42.7%)	73 (19%)	91 (23.7%)
	Total (n)	**384**	**172 (44.8%)**	**212 (55.2%)**

The result in Table 1 showed there were gender differentials on the perceived environmental issues between male (44.8%) and female (55.2%) headed households due to fall armyworm invasion.

(iii) Diversity of pesticides use by Gender

Smallholder farmers in the world including Kenya use synthetic pesticides to control agricultural. In Kenya, pesticides use enacted in 1921 have remained one of the most important agricultural pest management strategy including FAW with different toxicity effects to the handlers and consumers (Bertrand 2019; Larramendy & Soloneski 2019).

The outbreak of fall armyworm in the African region including Kenya has seen a rise in the application of pesticides use during agricultural production. The current option for the control of FAW invasion is the use of chemical pesticides with a likelihood of environmental contamination and human health poisoning. These chemicals known to be contaminants of the environment due to their ability of being transported long distance from the place of use released by wind or water affecting ecosystem and human health (Olisah *et. al.*, 2019).

Literature reviews have shown smallholder farmers in Africa including Kenya produce over 75% of the food consumed (FAO, 2021) whereas, they use pesticides with a highly hazardous formulations without enough capacity building on pesticide handling, disposals of used containers and wearing of protective equipment (PPEs) (Sarkar *et al.*, 2021).

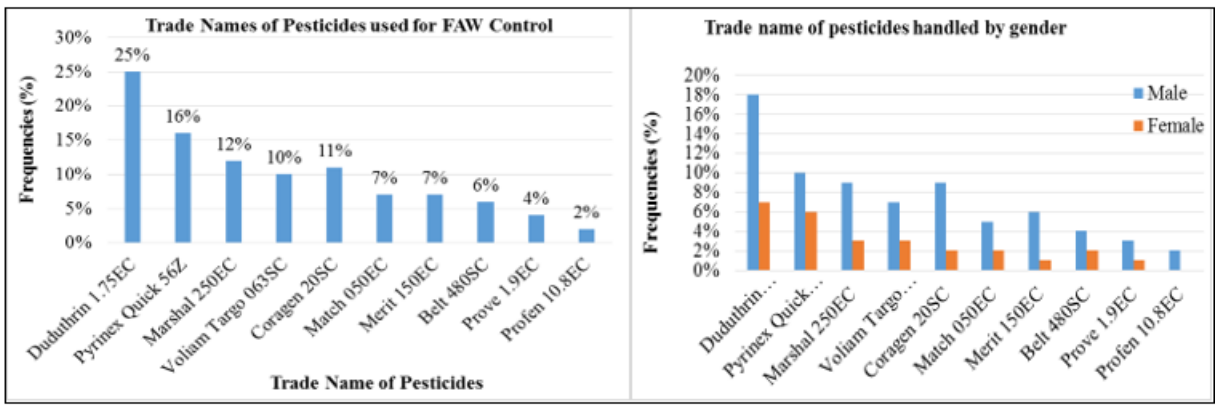

Figure 3: Trade Names of Pesticides used for FAW Invasion Control and by Gender (2020, Kenya)

The finding showed farmers (n=172 male and n=212 female) used different pesticides that were easily available in Kenya's local agro - dealer shops with different active ingredients for the control of FAW invasion during agricultural production (Figure 3). The results on availability and accessibility of

pesticides within the local agro - vet dealer shops encouraged the rampart usage of pesticides.

Results from the study showed a variation of pesticide handling by gender (73% male and 27% female) during FAW invasion control with the likelihood of male handlers being exposed more to ill health as compared to female handlers due to the frequency of contact of the pesticides. The result showed pesticide use was one of the most important FAW control management strategy whereas there are possibilities of erroneous management strategies due to the availability and accessibility of different pesticides with different chemical compositions within the market. This findings support study by Bertrand (2019) and Sarkar *et al.* (2021) whose studies notes that exposure to pesticides frequently occurs during the handling, time of aplication, loading into knapsack sprayer and pesticide disposal of used containers. Potential hazards of Chemical Pesticides used

There was a widespread use of chemical pesticides, used as crop pest control during the production of food crops, thereby leading to the pollution of environment. Studies by Elibariki and Maguta (2017) have shown that smallholder farmers in the developing world, including Kenya continue using banned pesticides several years ago during their agricultural production with no realization on the chemical composition of the pesticides and its harmful effects to the environment through smallholder farmers' practices. From literature reviews, the major pesticides used by smallholder are OCPs, which are divided into three major classes namely DDT, hexachloride (BHC) and cycldiene whereas, the OCPs have been banned in developing countries including Kenya because of its environmental persistent and non - target toxicity (Fiedler *et al.*, 2019). The major health problems arising from usage of OCPs are both chronic and acute health affects human health (FAO, 2021; WHO, 2020).

The invasion of fall armyworm in smallholder farmers crop fields has seen excess usage of pesticides (insecticides) with poor handling strategies due to lack of capacity building on both male and female farmers whereas, the behaviour of fall armyworm hiding itself inside the maize whorl requires technical skills enhancing repeated pesticides exposures during applications (Day *et al.*, 2017; FAO, 2018).

The study result showed smallholder farmers used pesticides during agricultural production with different behavioural actions during spraying. About 21.4% respondents reported drinking water when spraying pesticides with 16.4% eating a snack during spraying. The result further shows 33.2% pesticide handlers did not take a shower immediately after spraying whereas, 20% mixed their chemical directly inside knapsacks and 9% did not watch the direction of wind when spraying (Figure 4).

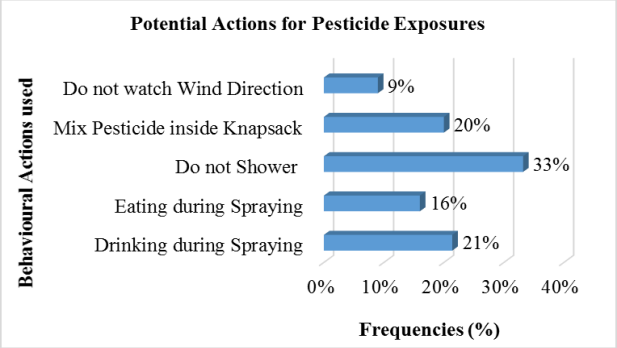

Figure 2: Potential Hazards of Organochlorines Pesticides used (2020, Kenya)

On the potential hazards of organochlorines used (Figure 4), smallholder farmers' potential hazard impacts was compounded by the behavioural actions used during spraying thereby, enhancing occupational exposures. Furthermore, the findings is in agreement with a study done by Tsimbiri *et al.* (2015) on health impact of pesticides on residents and horticultural workers in the Lake Naivasha Region, Kenya, indicated subsequent impacts of pesticides on human health through occupational exposure was through pesticide misuse and mishandling during agricultural production.

The result showed the gender handling in pesticide use varied greatly within different headed households depending on household needs, decision making patterns and labour availability during fall armyworm management whereas, the decisions regarding pesticide handling were made by household heads, in lieu of the gender. About 15% male and 6% female farmers reported drinking water when spraying pesticides with 7% male and 9% female ate a snack during spraying. The result further showed 5% male and 28% female pesticide handlers did not take a shower immediately after spraying whereas, 13% male and 7% female mixed their chemical directly inside knapsacks using a hand and 4% male and 5% female did not watch the direction of wind when spraying (Figure 5).

On the potential hazards of OCPs used by gender (Figure 5), the highest pesticides impacts to the handlers' (human) body was through ingestion (drinking or eating during chemical spraying) and re - using chemical containers whereas, inhalation by not watching wind direction was the least hazard. The action by different gender on mixing different chemicals at once together and poor disposal of chemical containers was likely to contaminate the food and the environment (soils and waterways). This was in agreement with Kolani *et al.* (2016) noting Africa landscapes' adversely polluted by agricultural chemicals (pesticides) including soils and waterways.

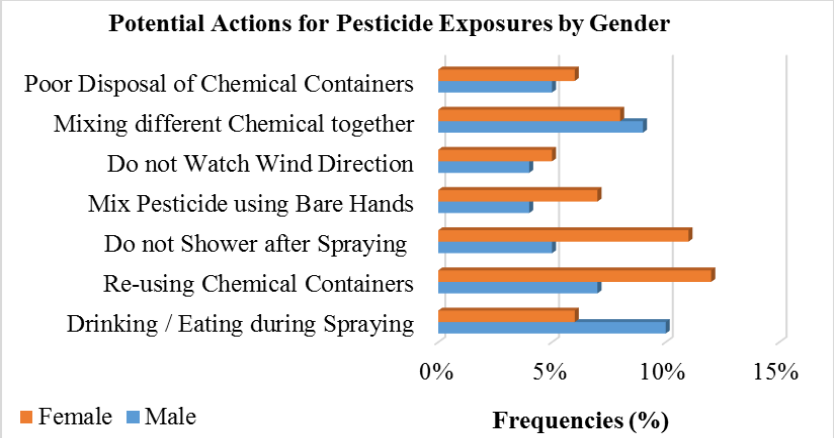

Figure 3: Potential Hazards of Organochlorines Pesticides used by gender (2020, Kenya)

Different headed households by gender made decisions to use pesticides during FAW invasion in achieving better agricultural yields irrespective of the potential hazards to the environment and their personal well - being. This is an indication that despite pesticides offering smallholder farmers' with an increase in agricultural yields, gender roles plays a key role during pesticide usage with a likelihood of environmental pollution and ill health exacerbating household food insecurity.

(iv) Sources of pesticide for FAW management

The result indicated during fall armyworm invasion in the country, efforts on control strategies was the use of synthetic pesticides the application with different sources. The results showed 41.4% smallholder farmers sourced pesticides from local agro - chemical dealers with 21.3% receiving free pesticides from the county government whereas, 17.2% sources pesticides from Ministry of Agriculture, Livestock and Fisheries (MOALF), Kenya (Table 2). The result further showed 10.2% sourced pesticides from other farmers/ neighbours with 9.9% receiving from research institutions. The result on the gender proportion on pesticides sourcing indicated 20.6% male and 20.8% female farmers acquiring their pesticides from local agro - chemical dealers whereas, 8.3% male and 13% female farmers' sourced from county government. The result further showed 6.5% male and 10.7% female farmers sourced their pesticides from MOALF with 5% male and 5.2% female farmers sourcing from other farmers/ neighbours with 4.4% male and 5.5% female farmers sourcing from research institutions (Table 2). These findings showed gender differences during pesticides sourcing with a higher proportion of female farmers sourcing pesticides more as compared to male farmers.

Table 2: Source of pesticides with respect to gender (2020, Kenya)

Source of pesticide	Gender of farmer		Total (n)
	Male	**Female**	
Agro - input Dealers	79 (20.6%)	80 (20.8%)	159 (41.4%)
County Government	32 (8.3%)	50 (13%)	82 (21.4%)
MOALF	25 (6.5%)	41 (10.7%)	66 (17.2%)
Other Farmers	19 (5%)	20 (5.2%)	39 (10.2%)
Research Institutions	17 (4.4%)	21 (5.5%)	38 (9.9%)
Total (n)	**172 (44.8%)**	**212 (55.2%)**	**384**

The result in Table 2 indicates there are gender differential between male and female smallholder farmers during decision making on pesticide acquisition. The sourcing of pesticides determination by the household head irrespective of the gender. This finding supports a study by Botreau and Cohen (2020) on gender inequality and food insecurity by noting there are differences between rural male and female during pest and disease control in agricultural production due to households' social gender differences.

(v) Self - Reported Healthy outcomes

The results on self - reported outcomes show 33.3% experiences sneezing and coughing, 25% gets eye sores or teary eyes, 17% gets skin itching, 11% gets mild headaches, 7% receives stomach bloating with 7% experiencing heavy chest and constrained breathing (Figure 6).

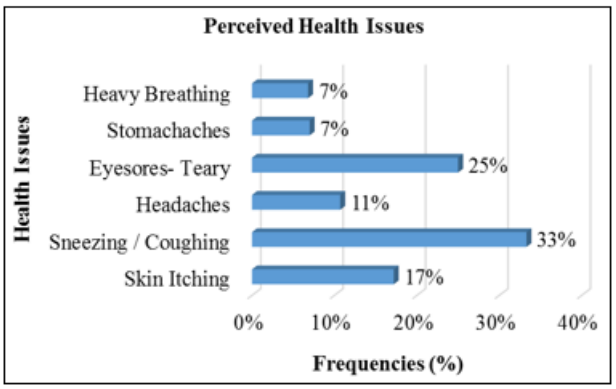

Figure 6: Differential perceived health problems associated with pesticides use (2020, Kenya)

The implication of result (Figure 6) is that smallholder farmers' pesticides' exposure was likely through inhalation, ingestion and skin absorption leading to perceived health problems. On self - reported ill health experiences due to pesticides use by gender (Table 3), sneezing and coughing affected both male (16.9%) and female (16.4%) farmers highly an indication that inhalation exposure is the potential hazard of pesticides to smallholder farmers.

Table 3: Self - reported ill - health experiences due to Pesticide use by Gender (2020, Kenya)

Perceived Health Problems	Totals (n)	Gender	
		Male	Female
Sneezing / Coughing	128 (33.3%)	65 (16.9%)	63 (16.4%)
Eyesores - Teary	96 (25%)	39 (10.2%)	57 (14.8%)
Skin Itching	66 (17.2%)	26 (6.8%)	40 (10.4%)
Headaches	41 (10.7%)	20 (5.2%)	21 (5.5%)
Stomach gas flatulence	27 (7.1%)	11 (2.9%)	16 (4.2%)
Heavy Chest/Breathing	26 (6.8%)	11 (2.9%)	15 (3.9%)
Totals (n)	384	172 (44.8%)	212 (55.2%)

The gender factor on the perceived health problems (Table 3) indicates sneezing and coughing was the highest impact on farmers by both male and female an indication of either poor handling of pesticides or a likelihood of exposure during pesticide preparation and mixing for spraying and spraying time. This is in agreement with a study by Damalas and Eleftherohorinos (2011) and Lekei *et al*. (2014) who stated that pesticides extensively used for pest control in agriculture whereas, the usage and unsafe handling practices is likely to expose the farmer to ill - health effects.

(vi) Application Time of Pesticides Spraying

The study findings showed 39.3% farmers applied their pesticides during the early morning hours with 4.4% farmers applying pesticides at nightfall whereas 26% applied in the evening just before sunset with 30.2% farmers applying at mid - day time (Table 4). However, the gender indicator showed 22.1% male and 17.2% female farmers applied pesticides in the morning with 12.2% male and 18% female smallholder farmers applying pesticides during the mid - day hours. The result further indicated 8.3% male and 17.7% female applied their pesticides during the evening just before sunset with 2.1% male and 2.2% female farmers applying their pesticides at nightfall (Table 4).

Table 4: Pesticide application time by gender (2020, Kenya)

Time applied	Gender of farmer		Total (n)
	Male	**Female**	
Early morning	85 (22.1%)	66 (17.2%)	151 (39.3%)
Mid - day	47 (12.2%)	69 (18%)	116 (30.2%)
Evening	32 (8.3%)	68 (17.7%)	100 (26%)
Night past 7.00pm	8 (2.1%)	9 (2.3%)	17 (4.4%)
Total (n)	**172 (44.8%)**	**212 (55.2%)**	**384**

The result in Table 4 indicates 65.3% smallholder farmers apply pesticides at the correct timing (39.3%, early morning and 26%, evening) with a gender proportion of 30.4% male and 34.9% female applying at the correct time. The appropriate timing of pesticide application ensures not only maximum control of the pest but also least damage on the environment due to less frequency of sprays of pesticides whereas, the wrong timing of pesticides spray is a trajectory towards ineffectiveness use of pesticides during the control of fall armyworm invasion. Another view, female farmers are likely to contribute to more environmental contamination by pesticides use as compared to male farmers requiring the gender perspective in regulatory frameworks for pesticides management and capacity building on safe handling of pesticides being gender specific.

From previous studies by Day *et al. (*2017) and FAO (2018), have shown that fall armyworm hibernates deep in the whorl of maize plants and covers itself with its waste and only comes out during the early hours of the morning and evening when the temperatures are ideal for feeding. This clearly indicates that there are implications of ineffective spraying due to wrong timings enhances repeated pesticide spraying to kill the FAW caterpillar. Moreover, the study result did not give a clear picture on the gender whose practices are more effective than the other during fall armyworm management or the use of more pesticides rather, both male and female farmers use pesticides towards households' food security. The frequency of pesticides spraying is likely to pollute the environment through spray drift of the pesticides to the unintended targets like the water sources and close human neighbours.

(vii) Personal protection equipment (PPEs) during pesticide application

The study results showed smallholder farmers used different types of PPEs, against exposure to pesticides. The finding indicated 47.9% wore gumboots when applying pesticides with 19% putting on old clothing which included tattered trousers and shirts whereas, 21.6% wore top coats when carrying knapsack - pumps with 11.5% wearing overalls (Table 5). The result on the gender preferential on PPEs use during pesticide application showed 23.2% male and 24.7% female smallholder farmers wore gumboots with 8.1% males and 13.5% female farmers wearing top coats. The results further showed 5% male and 6.5% female wore overall with 8.6% male and 10.4% female wearing old clothing (Table 5).

Figure 7: Comparative pictures showing PPEs worn for demonstration (circled) with a farmers spraying using minimal PPEs, Kenya. PPEs use was not a gender preferential choice rather was due to the availability and accessibility of the PPEs within different headed households.

Table 4: Personal Protection Equipment used by farmers with respect to gender (2020, Kenya)

PPE used (Single)	Gender of farmer		Total (n)
	Male	Female	
Top Coats	31 (8.1%)	52 (13.5%)	83 (21.6%)
Gumboots	89 (23.2%)	95 (24.7%)	184 (47.9%)
Overalls	19 (5%)	25 (6.5%)	44 (11.5%)
Old clothing	33 (8.6%)	40 (10.4%)	73 (19%)
Total (n)	172 (44.9%)	212 (55.1%)	384

On PPEs used by farmers with respect to gender (Table 5) displays a low gender variation of PPEs wearing during pesticide spraying with a low percentage of male farmers wearing minimal respective PPEs as compared to female farmers. Low wearing on PPE during pesticides application in this study defined as wearing only either one or two of the aforementioned PPEs used - gumboots, top coats, old clothing and overalls during pesticides application. The result on farmers' not wearing their PPEs during pesticides spraying enhanced the chances of the farmers' exposure to pesticides through body contact (Figure 7).

Field finding showed the PPEs that smallholder farmers used towards protection against pesticide exposure did not protect them rather exposed them to harm (Figure 7). The findings demonstrated a knowledge gap on how smallholder farmers perceived PPEs either not having enough resources (money) to buy PPEs or a masking of ignorance. On the same narrative, either smallholder farmers were not conversant of the self - health implications or environmental potential negative impacts likely associated with using poor personal protective equipment literally not designed for pesticides handling during agricultural pest management especially FAW control.

There was an indication showing limited understanding amongst smallholder farmers 'on' the health implications and environmental effects that arose from not wearing PPEs during pesticide spraying to control FAW invasion. The study findings agrees with different studies by Abro *et al.* (2021), Otim *et al.* (2021) and World Health Organization (2020) revealed pesticide use posed health hazards to the handler and the environment requiring the handler to wear appropriate personal protective equipment (PPEs) for protection from harmful pesticide exposures and environmental contamination.

4. Conclusion

The study findings found that FAW management were likely to lead to environmental risks with relation to chemical (synthetic pesticides) use. Smallholder farmers used organochlorines that take long period to biodegrade in the environment. Practices that were likely to lead to environmental risks include mixing of different chemicals together, poor disposal of pesticide containers, spraying at the wrong time of day and spraying against the wind. Those that were likely to enhance occupational exposures to the farmers' included mixing pesticides using bare hands, eating and drinking during spraying without washing hands. The practices that were likely to expose the farmers' families to the chemicals included not showering after spraying and re - using of chemical containers. The findings concludes that an effective network of extension and advisory that provide technical advice on the safe use of pesticides can be of great value in preventing health effects and environmental risks among the smallholder farmers during fall armyworm management.

5. Recommendations

There is need for research and service providers to create awareness for farmers on better FAW mitigation strategies mainly on the use of chemicals that are more biodegradable and less polluting to the environment. Increasing awareness creation on FAW management practices that are less likely to enhance occupational exposures to pesticides and to family members.

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Author's Contributions
"'Author 1' designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. 'Author 2' managed the analyses of the study and edited the manuscript and 'Author 3' managed the literature searches and edited the manuscript. All authors read and approved the final manuscript."

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