ORIGINAL RESEARCH

Impact of fall armyworm invasion on household income and food security in Zimbabwe

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Funding information
Foreign, Commonwealth & Development Office, UK; Directorate-General for International Cooperation, the Netherlands

Abstract

Since 2016, the invasive fall armyworm (FAW), *Spodoptera frugiperda*, has been one of the most rapidly spreading and highly devastating maize pests across Africa and Asia. Although several studies have estimated the effect of FAW on maize yield, little is known about its impact on broader welfare outcomes. Using data from smallholder maize-growing households in Zimbabwe, this article aimed to measure the impact of FAW on household income and food security, as well as the extent to which the adoption of a control strategy can help mitigate the negative welfare impacts due to FAW invasion. Regression results showed that households affected by FAW were 12% more likely to experience hunger, as measured by the household hunger scale. A disaggregated analysis indicated that minor FAW infestation did not exert significant impacts on incomes and food security, but severe level of infestation reduced per capita household income by 44% and increased a household's likelihood of experiencing hunger by 17%. We also found that compared to unaffected households, the FAW-affected households who failed to implement a control strategy had a 50% lower per capita household income, while their counterparts that implemented a control strategy did not suffer a significant income loss. These findings point to the need to promote strategies to prevent high infestation levels of FAW so as to mitigate its detrimental welfare effects.

KEYWORDS

fall armyworm, food security, household income, pest management, Zimbabwe

1 | INTRODUCTION

Invasive plants, insects and diseases are a major threat to achieving the sustainable development goals (SDGs). They reduce crop and livestock production; threaten biodiversity and water quality; adversely affect aquatic animals, tourism and electrical systems; and cause desertification and health problems, among other impacts (CABI, 2018; Nampala, 2020). For instance, Pratt et al. (2017) estimated that five invasive pests (*Chilo partellus*, Maize Lethal Necrosis, *Parthenium hysterophorus*, *Liriomyza* spp. and *Tuta absoluta*) caused a combined annual loss of US$0.9–1.1 billion to smallholder maize production in just six East African countries. Unfortunately, the spread and impact of invasive

species may be further exacerbated due to climate change and increasing levels of tourism and international trade (CABI, 2018; Early et al., 2018). Accordingly, there are increasing calls for action against invasive species, such as underscored by the SDG target 15.8: 'by 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive species on land and water ecosystems and control or eradicate the priority species' (UN, 2016).

In recent years, fall armyworm (FAW), *Spodoptera frugiperda*, has become one of the most damaging invasive species in Africa, posing a significant threat to food security and livelihoods of many households. Native to the Americas, the pest was first reported in West Africa in early 2016 (Goergen et al., 2016). It has subsequently spread rapidly across the rest of sub-Saharan Africa (SSA), and 17 Asian countries and Australia (CABI, 2020), with a high potential for near-global invasion (Early et al., 2018). The FAW is a polyphagous pest that can reportedly feed on over 300 different plant species, including important staple crops such as maize, rice, sorghum, wheat, as well as forage grasses for livestock (Montezano et al., 2018). In SSA, it is particularly causing serious damage to maize, which is a major food security crop in the region. Estimates from 12 maize-producing countries in SSA suggest that unless appropriate actions are taken, the pest has the potential to cause maize losses from 4.1 to 17.7 million tonnes annually (valued at US$ 1.1–4.7 billion) (Rwomushana et al., 2018).

In Zimbabwe, FAW is having a detrimental impact on crop production and is threatening food security (Devi, 2018; FAO, 2020). The pest was reported for the first time in Zimbabwe during the 2016/2017 cropping season and has continued to spread and cause damage to crops in the subsequent seasons (FAO, 2020). Its presence has been confirmed in all of the country's 10 provinces. In the wake of the FAW outbreak, several emergency measures were taken to tackle its menace in Zimbabwe and neighbouring countries. For instance, the Food and Agriculture Organisation (FAO) in partnership with national governments and stakeholders in Southern Africa convened an emergency meeting in Harare, Zimbabwe in the early months following the pest outbreak (February 2017) to strengthen preparedness and coordinate actions against FAW (Wild, 2017). Similarly, a Zimbabwe FAW working group comprising representatives from governments, private input companies, non-governmental organisations, research and academic institutions, and donors was established in July 2017 to enact a strategy to mitigate the impacts of the pest in the country (CIMMYT, 2017).

In view of the widespread infestation of FAW, a small but growing number of studies have sought to provide evidence on its impacts. The existing literature has largely focussed on estimating maize losses due to FAW damage, which was either based on farmers' estimates, without accounting for confounding factors (Chimweta et al., 2020; Day et al., 2017; De Groote et al., 2020; Kumela et al., 2019; Rwomushana et al., 2018) or on field experiments (Baudron et al., 2019). An exception is a study by Kassie et al. (2020), who controlled for confounding variables in their impact estimates and also went beyond farm-level outcomes to quantify impact on maize sale and consumption.

The outbreak of FAW in Zimbabwe has also received some research attention, particularly on the impact of the pest on maize production in the country. For example, Chimweta et al. (2020) recorded FAW-induced maize yield reduction of 58%, based on estimates from a sample of 101 farmers in Zambezi Valley (Mashonaland central province) of Zimbabwe. Using rigorous field scouting methods in two districts of Manicaland province, Baudron et al. (2019) observed maize yield loss of 11.57% and concluded that previous yield loss estimates based on farmers' perceptions could have been over-estimated. Based on household survey data from Ghana and Zambia and agro-ecological similarities, Rwomushana et al. (2018) extrapolated that the pest has the potential to cause an annual reduction in maize production in Zimbabwe of about 264,000 tonnes, translating into revenue loss of US$ 83 million. Given that maize is the primary food crop in Zimbabwe, the pest will endanger food security in the country, if left uncontrolled.

This paper adds to the thin evidence base regarding the economic impacts of FAW and its management (Day et al., 2017; Kassie et al., 2020; Rwomushana et al., 2018). More importantly, the present study is the first to explore the income and food security effects of FAW invasion. While it is useful to assess the impact of FAW on outcomes related to maize (as was done in the above-mentioned studies), it is known that the pest attacks several other food crops in Africa (Rwomushana et al., 2018); hence, it is also important to assess impacts on broader welfare indicators that can capture the spillover effects on other crops. Moreover, FAW invasion may result in household resource reallocation. For instance, in adopting crop protection measures such as pesticides and handpicking for FAW control, the affected households may simply divert financial and labour resources away from alternative economic activities, which may not reflect in outcome indicators related to maize yield, sales or consumption. Using a more comprehensive welfare measure, such as household income, will allow us to capture these possible resource reallocation effects.

The present study aims to analyse the effect of FAW invasion on household welfare indicators, including income and food security. The study also examines whether and to what extent the adoption of control strategies helped to attenuate any observed negative effect of FAW. Such information can help policymakers in developing appropriate strategies to mitigate the economic impact of this highly destructive pest.

2 | MATERIALS AND METHODS

2.1 | Data

We used survey data from 350 smallholder maize-growing households in six provinces across Zimbabwe (Figure 1). The data were collected in September 2018 for the purpose of understanding the impact of and farmers' practices related to FAW during the 2017/2018 cropping season. The survey was conducted by 12 enumerators using tablet-based questionnaires, which contained modules on household composition and farming activities, FAW infestation and control practices, information sources, access to institutional services, as well as household income and food security.

A three-stage sampling approach, involving purposive sampling of provinces and districts, and random sampling of farm households was adopted in the survey. First, six of the country's main maize production provinces were selected. Then, three major maize-producing and FAW-affected districts were sampled from each of the six provinces. The selected districts (provinces) include Mazowe, Centenary and Mt. Darwin (Mashonaland Central); Chikomba, Murehwa and Mudzi (Mashonaland East); Zvimba, Makonde and Chegutu (Mashonaland West); Zvishavane, Gweru and Chirhumhanzu (Midlands); Masvingo, Mwenezi and Gutu (Masvingo); Bubi; Nkayi and Umguza (Matabeleland North). Lastly, about 20 maize-growing households were randomly selected and interviewed in each district.

2.2 | Empirical strategy

The main objective of this paper was to estimate the effect of FAW on household income and food security. This can be expressed as:

$$y_i = \alpha_i + \beta x_i + \varphi \text{FAW}_i + \varepsilon_i \qquad (1)$$

where y_i represents the indicators of income and food security of household i; x_i is a vector of control variables, with the associated parameters β; FAW_i is a dummy variable equal to one if household crop production was affected by FAW and zero otherwise; and ε_i is a random error term. We are particularly interested in the coefficient φ, which measures the effect of FAW on the household income and food security. We hypothesise that FAW infestation is significantly associated with lower household income and food security, but the adoption of control strategies can reduce these negative outcomes.

While we were interested in FAW impact on household income, we recognised that the pest causes enormous damage on maize in particular and thus its effect on total household income may be primarily through maize income. We, therefore, measured the effect of FAW on maize income, in addition to household income. Maize income consists of gross maize income minus production costs, such as seed, fertiliser, herbicide, insecticide and hired labour. Household income comprises income from crop and livestock production as well as profits from off-farm self-employment, wages and salaries from agricultural and non-agricultural activities,
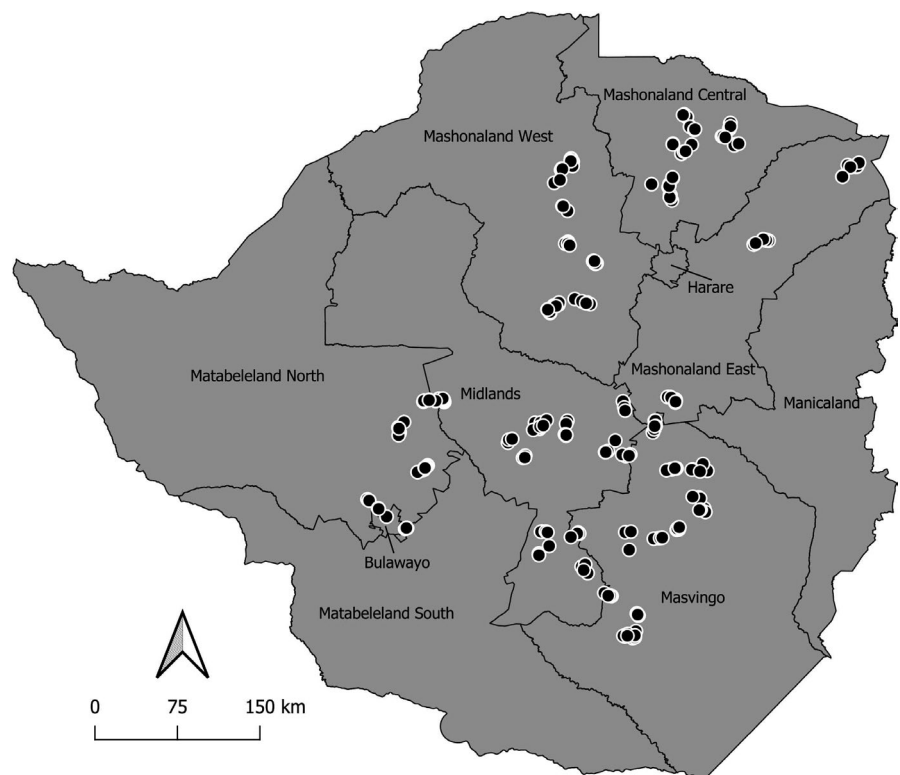
FIGURE 1 Map of Zimbabwe showing survey locations

pensions, remittances and income from other sources. The incomes were expressed in annual per capita basis.

To assess food security, we used items from the household hunger scale (HHS). The HHS is a simple perception-based measure of the access dimension of food security. It is a subset of the household food insecurity access scale (HFIAS) and has been validated for cross-cultural use (Ballard et al., 2011). It is based on three questions that reflect severe food insecurity experiences. The questions include whether or not in the past 30 days: (1) there was no food of any kind in the house; (2) a household member went to sleep hungry; and (3) a household member went a whole day without eating, due to lack of resources. Our main food security indicator (hunger) is a binary variable that is equal to one if a household responded 'yes' to any of these three HHS questions and zero otherwise. In addition, we separately examined responses to the three questions.

The control variables (x_i) include household characteristics (e.g. age, gender, and education of the household head and household size); maize plot area; wealth and institutional-related factors (e.g. wealth index, access to credit and off-farm activities, group membership and proximity to inputs and extension information); and location dummies to control for geographical differences (see Table 1). The choice of these control variables was motivated by previous literature on the economic impact and management of FAW (e.g. Kassie et al., 2020; Tambo, Day, et al., 2020). The FAW variable was determined by

TABLE 1 Summary statistics of surveyed households

Variable	Description	Mean	SD
Fall armyworm	Household experienced fall armyworm attack on crops (1/0)	0.53	0.50
Age	Age of household head (years)	48.65	17.06
Gender	Gender of household head (1 = male)	0.66	0.47
Education	Household head has secondary education (1/0)	0.64	0.48
Household size	Number of household members	6.51	5.19
Maize area	Total area planted with maize (hectares)	2.22	5.83
Off-farm activity	Household member has off-farm job (1/0)	0.39	0.49
Credit access	Household has access to credit (1/0)	0.20	0.40
Wealth index	Household wealth index[a]	−0.01	1.52
Distance to agro-dealer	Distance from household to the nearest agro-dealer (km)	14.73	12.84
Distance to extension	Distance from household to the nearest extension office (km)	8.62	9.18
Farmer group	Household member belongs to a farmer group (1/0)	0.17	0.37
FAW info from extension	Household received information on FAW from extension agents (1/0)	0.33	0.47
FAW info from neighbours	Household received information on FAW from neighbours (1/0)	0.07	0.25
Mashonaland Central	Household is located in Mashonaland Central province (1/0)	0.15	0.35
Mashonaland East	Household is located in Mashonaland East province (1/0)	0.15	0.35
Mashonaland West	Household is located in Mashonaland West province (1/0)	0.19	0.40
Midlands	Household is located in Midlands province (1/0)	0.15	0.35
Masvingo	Household is located in Masvingo province (1/0)	0.17	0.37
Matabeleland North	Household is located in Matabeleland North province (1/0)	0.20	0.40

[a]The wealth index was computed based on household ownership of 10 durable assets using principal component analysis (Filmer & Pritchett, 2001).

showing pictures of FAW at different reproductive stages to the sample households and asked to confirm if they observed the pest in their fields during the season under study. Similar to Kassie et al. (2020), we considered FAW infestation to be an exogenous shock; hence, we estimated equation 1 using ordinary least squares (OLS) regression when the outcome is income and probit regression for the binary hunger outcome variables.

In equation 1 above, all FAW-affected households were lumped together (regardless of whether or not they implemented a control strategy) and compared with unaffected households. To analyse the potential mitigating effect of the adoption of control practices, we re-express equation 1 as:

$$y_i = \alpha_i + \beta x_i + \vartheta \text{FAW1}_i + \delta \text{FAW0}_i + \varepsilon_i \qquad (2)$$

where FAW1 and FAW0 represent FAW-affected households who did or did not implement a control strategy, respectively. The coefficients ϑ and δ compare the income and food security levels of these two groups of FAW-affected households with those of households unaffected by the pest. While FAW shock is reasonably exogenous, a household's decision to implement a control strategy is potentially endogenous. For instance, it is possible that some unobservable factors influence both the decision to implement a FAW control strategy and our outcome variables; hence, using OLS or probit regression models may yield biased estimates. Consequently, to address the potential endogeneity problem in equation 2, we employed the control function approach (Smith & Blundell, 1986; Wooldridge, 2015).

The control function approach involves two steps. First, a reduced-form probit model for the adoption of a FAW control strategy was estimated to obtain the generalised residual. The control variables are similar to those included in x_i in equation 2, but we also require at least one instrumental variable that affects households' decisions to adopt a FAW control strategy but is not directly correlated with our outcome variables. Motivated by the application of information sources as instrumental variables in impact studies on FAW control strategies (Tambo,

Day, et al., 2020), agricultural innovations (Ahimbisibwe et al., 2020; Asfaw et al., 2012) and adaptation to shocks (Di Falco et al., 2011), we used two sources of information on FAW (i.e. extension workers and neighbours) as our excluded instruments. The first-step regression results in Table A1 in the appendix show that the two FAW information sources' variables significantly affect the decision to adopt a FAW control strategy. However, these two variables do not exert significant effects on any of the outcome variables of interest (see Table A2 in the appendix), and thus lending support to the validity of our instruments. In the second step, we estimated equation 2 using OLS and probit estimators (for income and food security outcomes, respectively), where the generalised residual from the first-step regression is included as an additional regressor. In estimating equation 2, we used bootstrapping to adjust the standard errors for the two-step estimation procedure.

3 | RESULTS AND DISCUSSION

3.1 | Descriptive statistics

Table 1 shows that 53% of the households reported experiencing FAW attack on their crops during the 2017/2018 cropping season. While maize was the most affected crop, about 7% of the FAW-affected households also mentioned sorghum, millet, soybean and tomato as other crops infested by the pest. A similar pattern of FAW-infested crops was observed in surveys in Ghana and Zambia by Rwomushana et al. (2018). As is typical in developing countries (Arslan, 2019), the average age of the farm household heads in our sample was about 49 years. Nearly two-thirds of the households were headed by male who had attained at least secondary level of education. The average maize farm size was roughly two hectares, reflecting a sample of smallholder maize-growing households. Maize was generally grown as a sole crop, with only 5% of the sampled households intercropping it with other crops (mostly groundnut, common bean or cowpea).

TABLE 2 Outcome variables by FAW infestation

Outcome variables	Full sample (n = 350)	Affected by FAW (n = 185)	Unaffected by FAW (n = 165)	Difference
Maize income per capita (USD/year)	221.01 (816.58)	193.14 (765.66)	252.33 (872.60)	−59.19
Household income per capita (USD/year)	527.32 (1231.62)	405.69 (884.28)	664.53 (1523.18)	−258.84**
Ran out of food (1/0)	0.23	0.28	0.18	0.10**
Went to bed hungry (1/0)	0.19	0.25	0.13	0.12***
Whole day without eating (1/0)	0.18	0.24	0.11	0.13***
Hunger (1/0)	0.23	0.29	0.17	0.12**

** and *** indicate that the difference is statistically significant at the 5% and 1% level, respectively.

Values in parentheses are standard deviations.

Our data also suggest limited access to institutional support services in the study area. For instance, only 20% and 39% of the households had access to credit and off-farm income-generating activities, respectively. Moreover, only about one-sixth of the households had participated in farmer-based groups. The farm households had to travel nearly 9 km and 15 km to access sources of agricultural extension services and farm inputs, respectively. One-third of the households relied on extension workers for information on FAW, while only 7% obtained similar information from neighbouring farmers.

Table 2 presents the descriptive statistics of our outcome indicators, disaggregated by whether or not a household was affected by FAW. The average annual per capita household income was almost 530 USD, with about 42% of this income coming from maize production. As expected, FAW-affected households earned less maize and household income per capita compared to unaffected households, with significant difference in terms of household income. The results also show that nearly one-fourth of the households experienced some form of hunger in the 30 days prior to the survey. In particular, 23% of the households reported to have run out of food, 19% went to bed hungry, and 18% went a whole day without eating. Hunger was more prevalent among FAW-affected households compared to their unaffected counterparts. For example, the share of FAW-affected households that experienced hunger was 12 percentage points significantly greater than the households unaffected by the pest. Overall, these unconditional results suggest that households affected by FAW experienced food insecurity and reduced income than those that were unaffected. In the ensuing section, we present the estimated impacts of FAW conditional on covariates.

3.2 | Effects of FAW on income and food security

Table 3 reports results of the effects of FAW invasion on our three main outcome variables. We find that after controlling for other determinants of income, there is a negative but statistically insignificant relationship between FAW infestation and both per capita maize and household income. Conversely, there is a positive and significant relationship between FAW and hunger, implying that households affected by FAW were more likely than unaffected households to experience hunger. Specifically, the FAW invasion increased a household's likelihood of suffering hunger by about 12%. The estimated impacts on the three items that constitute the hunger scale are presented in Table A3 in the appendix. We

TABLE 3 Effects of FAW infestation on income and food security

	Ln (Maize income/capita)		Ln (HH income/capita)		Hunger (1/0)	
	Coefficient	Robust SE	Coefficient	Robust SE	Marginal effect	Robust SE
Fall armyworm	−0.520	0.328	−0.237	0.222	0.118***	0.041
Age	0.011	0.010	0.003	0.006	0.003**	0.001
Gender	0.440	0.354	0.152	0.236	−0.006	0.046
Education	−0.020	0.378	0.281	0.268	−0.047	0.043
Household size	−0.071**	0.032	−0.056**	0.026	0.004	0.004
Maize area	0.030	0.023	0.009	0.019	−0.069***	0.024
Wealth index	0.384***	0.126	0.541***	0.068	−0.066***	0.019
Off-farm activity	−0.909***	0.350	0.647***	0.209	0.017	0.043
Credit access	1.024***	0.371	0.424**	0.210	−0.082	0.061
Farmer group	−0.398	0.445	−0.134	0.288	0.076	0.057
Distance to agro-dealer	−0.014	0.016	0.004	0.008	0.000	0.002
Distance to extension	−0.010	0.018	−0.019	0.016	−0.004	0.002
Mashonaland East	−1.437**	0.617	−1.032***	0.372	0.155*	0.084
Mashonaland West	0.555	0.491	−0.198	0.371	0.029	0.080
Midlands	0.706	0.468	−0.158	0.281	−0.117	0.076
Masvingo	0.635	0.503	−0.073	0.348	−0.152**	0.070
Matabeleland North	−0.614	0.533	−0.656*	0.362	0.035	0.077
Constant	4.052***	0.797	5.657***	0.517		
No. of observations	350		350		350	

*, ** and *** represent 10%, 5% and 1% significance level, respectively.

see that households affected by FAW were 11% more likely to experience food shortage, and their members had a 13% higher probability of going to bed hungry or going a whole day without eating because of household food insufficiency. Taken together, these results suggest that while FAW damage on yield may not cause a significant shock to household income, it is likely to worsen household food insecurity in the short run. These results are compelling, given that about 5.5 million people in rural Zimbabwe are estimated to be food insecure (Government of Zimbabwe, 2020). Thus, FAW will compound the country's food security problem, if left uncontrolled.

The results on the other covariates in Table 3 are informative. Larger households have lower per capita incomes, possibly reflecting high household dependency rates. An increase in the area allocated to maize production is significantly associated with a 7% reduction in the likelihood of hunger. This is likely because households that cultivate larger maize plots may have greater amount of maize (a key staple crop in Zimbabwe) available for staving off hunger. Household asset wealth is significantly correlated with higher per capita incomes and lower probability of experiencing hunger. Similarly, access to credit, which can help household to relax their liquidity constraints and invest in productivity-enhancing technologies, is significantly associated with higher per capita incomes. The results also show that off-farm activity exerts a significant but differential effect on the two-income variables. Specifically, off-farm employment is related to a decrease (increase) in maize income (household income). A plausible explanation is that participation in off-farm activities reduces labour available for maize cultivation while the income earned from off-farm activities, which are less likely to be affected by FAW incidence, contributes to total household income.

In the above analysis of the welfare effects of FAW, the FAW-affected households were compared with unaffected households without taking into consideration that the effects may differ depending on the level of FAW infestation. Consequently, we also examined the differential effects of the pest by disaggregating the affected households into two groups (minor and severe infestation) based on self-reported severity of FAW infestation. A household was considered to have experienced minor FAW infestation if it reported that less than half of the cultivated area was affected with FAW during the season under study, while severe infestation denotes that at least half of the farm area was attacked by the pest. It should be stressed that an ideal method to estimate the level of infestation would have been to do field scouting during the growing season but this was not possible in the current study, and thus the reliance on self-reported information. According to our data, about 24% and 29% of the households suffered from minor and severe FAW infestation, respectively, and these were compared with the unaffected households (47%) in the disaggregated analysis below.

Table 4 presents the estimation results of the impact of FAW, disaggregated by the level of infestation (see Table A4 in the appendix for the full results). The coefficients on the minor infestation variable have the expected signs but are statistically insignificant, suggesting that households that observed minor FAW infestations did not suffer significant reductions in incomes and food security compared to households that were unaffected by the pest. On the other hand, households that reported severe infestation were significantly worse-off in terms of all our outcome indicators. In particular, households that experienced severe FAW attack achieved 64% and 44% significant declines in per capita maize and household income, respectively. In addition,

TABLE 4 FAW effects by severity of infestation

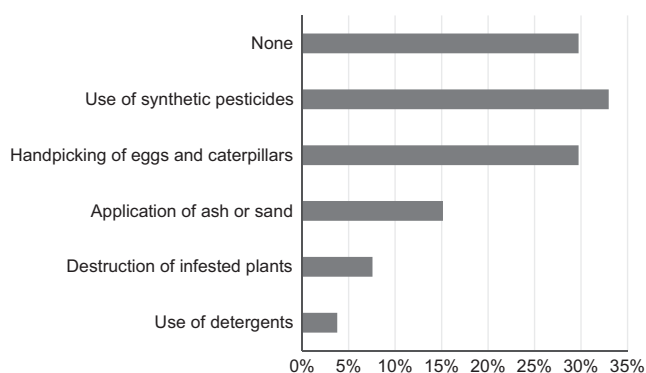|	Ln (Maize income/capita)		Ln (HH income/capita)		Hunger (1/0)	
	Coefficient	Percentage effect[c]	Coefficient	Percentage effect[c]	Coefficient	Marginal effect (%)
Minor FAW infestation[a]	−0.210 (0.363)	−24.07	−0.007 (0.226)	−3.24	0.321 (0.230)	7.10
Severe FAW infestation[a]	−0.920** (0.432)	−63.69	−0.531* (0.309)	−43.92	0.687*** (0.212)	16.61
Control variables included[b]	Yes		Yes		Yes	
No. of observations	350		350		350	
Estimation method	OLS		OLS		Probit	

Notes: Robust standard errors in parentheses.

[a]The comparison group is 'no FAW infestation', that is, households unaffected by FAW.

[b]The full regression results are presented in Table A4 in the appendix.

[c]Percentage effect of dummy coefficients in models with a log-dependent variable is computed as $100 * \exp\{c - 0.5\,V(c)\} - 1$, where c denotes the dummy coefficients and $V(c)$ is the variance of c (Kennedy, 1981).

their members were about 17% more likely to go hungry relative to the unaffected households. This suggests that the negative welfare effects reported earlier in Table 3 were largely driven by households whose farms were severely damaged by the pest. This is intuitive as severe FAW infestation may result in significant yield losses, which will in turn reduce the amount of self-produced food available for household consumption. Moreover, minor FAW infestation may not require the implementation of control measures, while severe infestation may stimulate the use of costly pest control options, such as synthetic pesticides, which will translate into reduced household income and less money available for food.

Overall, the above results imply that besides the previously reported negative yield effects of FAW in Africa (e.g. Chimweta et al., 2020; De Groote et al., 2020; Kassie et al., 2020; Kumela et al., 2019), the pest is also significantly associated with worsening household income and food insecurity, which is consistent with our hypothesis.

FIGURE 2 Percentage of FAW-affected households that adopted control measures (*n* = 185). Note: Multiple responses recorded

3.3 | The potential mitigating role of farmers' control strategies

We now look at whether households affected by FAW were able to mitigate the negative impact on incomes and food security through the adoption of FAW control practices. Figure 2 displays the FAW control strategies implemented by the affected households. It shows that out of the 185 households who reported FAW infestation in their farms, about 30% did not implement any intervention to control the pest. Consistent with previous studies (e.g. Kumela et al., 2019; Tambo, Kansiime, et al., 2020), we see that the most commonly used control methods were the application of synthetic pesticides, and handpicking of egg masses and larvae. The most popular pesticides used include lambda-cyhalothrin, carbaryl, and emamectin benzoate.[1] Other control options used include pouring ash or sand into maize whorls, roguing and burning of infested plants, and the application of detergents. Similar control methods have been reported in the literature on how Zimbabwean and other African farmers are responding to the FAW invasion (Chimweta et al., 2020; Kassie et al., 2020; Tambo, Kansiime, et al., 2020).

The results for the heterogeneous welfare effects according to whether the FAW-affected households implemented control practices are presented in Table 5 (see Table A5 in the appendix for the full results). We observe that FAW-affected households that did not put in place any control intervention obtained about 65% and 51% lower per capita maize and household income, respectively, compared to households that were not affected by the pest. These effect sizes are statistically significant. On the contrary, the unaffected households did not achieve significant income gains relative to the FAW-affected households that implemented control measures. In terms of food security implications, we find that the affected

TABLE 5 Effectiveness of FAW control adoption

	Ln (Maize income/capita)		Ln (HH income/capita)		Hunger (1/0)	
	Coefficient	**Percentage effect[c]**	**Coefficient**	**Percentage effect[c]**	**Coefficient**	**Marginal effect (%)**
Affected by FAW but did not apply a control measure[a]	−0.955** (0.486)	−65.36	−0.630* (0.353)	−50.78	0.621** (0.281)	14.44
Affected by FAW and implemented a control measure[a]	−0.091 (0.562)	−20.41	0.419 (0.344)	42.78	0.428** (0.296)	9.94
Control variables included[b]	Yes		Yes		Yes	
No. of observations	350		350		350	
Estimation method	Control function		Control function		Control function	

Notes: Bootstrapped standard errors in parentheses.

* and ** represent 10% and 5% significance level, respectively.

[a]The comparison group is households unaffected by FAW.

[b]The full regression results are presented in Table A5 in the appendix.

[c]Percentage effect of dummy coefficients in models with a log-dependent variable is computed as 100* exp {*c*—0.5 *V*(*c*)} −1, where *c* denotes the dummy coefficients and *V*(*c*) is the variance of *c* (Kennedy, 1981).

households without control action had nearly a 15% higher likelihood of experiencing hunger, while their counterparts that applied control measures were 10% more likely to experience hunger, compared with households unaffected by FAW. Thus, while FAW infestations contribute significantly to hunger, the likelihood of hunger is lesser when a control measure is applied.

In line with our hypothesis, the results in Table 5 suggest that the FAW control actions employed by the sample households significantly helped to cushion the negative impacts of the pest on household income and food security. These findings lend support to recent studies that have shown that certain pest control strategies (especially using a combination of control strategies) may help to reduce yield losses caused by FAW (Kassie et al., 2020; Tambo, Day, et al., 2020). Unfortunately, due to limited observations, we were unable to investigate which individual or combination of control strategies was particularly important in mitigating the FAW-induced income and food security shocks.

4 | CONCLUSION

Since its arrival in West Africa in early 2016, the invasive fall armyworm (FAW) has spread rapidly across the entire sub-Saharan Africa and several Asian countries, causing significant damage to staple food crops, particularly maize. Using survey data from maize-growing households in six provinces across Zimbabwe, this article explored the impact of FAW on household income and food security, and the extent to which the control measures implemented by farm households helped to mitigate the impact of the pest. In doing so, we extend recent literature on the effect of the FAW invasion in Africa on crop yields and intermediate outcomes such as maize sale and consumption (Baudron et al., 2019; Kassie et al., 2020; Rwomushana et al., 2018). Insights gained from this research can also be useful in efforts to alleviate the impact of this destructive pest on farmers' livelihoods.

Regression results showed that households affected by FAW were 11% more likely to experience food shortage, and their members had a 13% higher probability of going to bed hungry or going a whole day without eating, compared to households unaffected by the pest. A disaggregated analysis according to the level of FAW infestation showed that households that suffered minor FAW infestation did not see significant reductions in income and food security compared to unaffected households. Conversely, households that reported severe level of FAW infestation observed a 44% significant decrease in per capita household income and their members were about 17% more likely to go hungry relative to their unaffected counterparts.

These results imply that while FAW cannot be eradicated, taking actions to at least prevent severe level of infestation can significantly reduce welfare losses in terms of income and food security. Potential FAW prevention measures include rotation and intercropping with non-host plants such as beans and cassava, timely planting or avoiding staggered planting, regular weeding, and balanced fertilisation so that the maize plants can compensate for FAW damage (Durocher-Granger et al., 2018). Further studies are, however, needed to determine the threshold level of infestation that does not lead to significant welfare losses, as the present study applied a simple binary disaggregation of FAW infestation into minor and severe infestation based on farmers' self-reported information.

We also found that compared to unaffected households, the FAW-affected households who failed to implement a control strategy had a 50% significantly lower per capita household income and their members were 15% more likely to go hungry, while the affected households that implemented a control strategy were not significantly worse-off with respect to per capita incomes and were only 10% more likely to experience hunger. This implies that the FAW control strategies employed by the sample households helped to significantly reduce income risks and stave off hunger. The FAW control measures used include spraying of synthetic pesticides, physical control methods such as handpicking of caterpillars and roguing of infested plants, as well as traditional practices such as placing ash or sand into maize whorls.

Further research is necessary to determine which of the currently applied control measures helped to mitigate the negative welfare impacts of FAW, given previous mixed evidence on their effectiveness in controlling FAW and protecting yield (Baudron et al., 2019; Kassie et al., 2020; Kumela et al., 2019; Tambo, Day, et al., 2020). More importantly, it would be useful to investigate which of the control measures can achieve the most positive outcomes that are cost-effective, safe and environmentally sustainable. Some of the farmers in our sample used pesticides such as lambda-cyhalothrin and emamectin benzoate that are considered to be effective against FAW but are of high risk to human and environmental health, while a few households used carbaryl, dimethoate and methamidophos, which besides posing high risk to humans and the environment, their efficacy against FAW are either unknown or have been rated as poor to fair (Jepson et al., 2020).

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ENDNOTE

[1] Two households used methamidophos pesticide, which is highly hazardous to human and environment health.

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How to cite this article: Tambo JA, Kansiime MK, Rwomushana I, et al. Impact of fall armyworm invasion on household income and food security in Zimbabwe. *Food Energy Secur*. 2021;10:e281. https://doi.org/10.1002/fes3.281

APPENDIX

TABLE A1 Determinants of adoption of FAW control strategy

	Coefficient	Robust SE
FAW info from extension	1.682***	0.200
FAW info from neighbours	1.666***	0.377
Age	0.002	0.005
Gender	−0.027	0.182
Education	−0.303	0.191
Household size	0.054**	0.024
Maize area	0.016	0.015
Asset index	−0.054	0.061
Off-farm activity	−0.011	0.172
Credit access	0.146	0.213
Farmer group	0.190	0.217
Distance to agro-dealer	−0.005	0.006
Distance to extension	−0.020*	0.012
Mashonaland East	−0.064	0.306
Mashonaland West	−0.110	0.263
Midlands	−0.169	0.296
Masvingo	0.050	0.301
Matabeleland North	−0.009	0.290
Constant	−0.956**	0.407
No. of observations	350	

*, ** and *** represent 10%, 5% and 1% significance level, respectively.

TABLE A2 Test of exclusion restriction

	Ln (maize income/ capita)	Ln (HH income/ capita)	Hunger (1/0)
FAW info from extension	−0.116 (0.338)	0.137 (0.269)	0.202 (0.192)
FAW info from neighbours	0.177 (0.566)	0.659 (0.452)	0.195 (0.356)
No. of observations	350	350	350
Estimation method	OLS	OLS	Probit

Note: Robust standard errors in parentheses.

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TABLE A3 Effect of fall armyworm on hunger indicators

	Ran out of food		Went to bed hungry		Whole day without eating	
	Marginal effect	Robust SE	Marginal effect	Robust SE	Marginal effect	Robust SE
Fall armyworm	0.113***	0.041	0.129***	0.039	0.130***	0.038
Age	0.003**	0.001	0.002	0.001	0.003**	0.001
Gender	−0.010	0.046	−0.018	0.043	−0.036	0.042
Education	−0.052	0.043	−0.015	0.042	0.017	0.040
Household size	0.004	0.004	0.004	0.004	0.005	0.003
Maize area	−0.064***	0.023	−0.052**	0.022	−0.037**	0.017
Wealth index	−0.067***	0.020	−0.068***	0.020	−0.075***	0.018
Off-farm activity	0.022	0.043	−0.026	0.040	−0.022	0.039
Credit access	−0.081	0.060	−0.073	0.057	−0.075	0.056
Farmer group	0.079	0.057	0.017	0.055	0.010	0.054
Distance to agro-dealer	0.000	0.002	0.000	0.002	0.000	0.002
Distance to extension	−0.004	0.002	−0.004	0.003	−0.005	0.003
Mashonaland East	0.153*	0.084	0.154*	0.081	0.059	0.077
Mashonaland West	0.027	0.080	0.028	0.072	0.044	0.073
Midlands	−0.120	0.076	−0.059	0.071	−0.060	0.072
Masvingo	−0.155**	0.070	−0.108*	0.064	−0.116*	0.063
Matabeleland North	0.021	0.077	0.075	0.071	0.051	0.071
No. of observations	350		350		350	

*, ** and *** represent 10%, 5% and 1% significance level, respectively.

TABLE A4 FAW effect by severity of infestation (full regression results)

	Ln (Maize income/capita)		Ln (HH income/capita)		Hunger (1/0)	
	Coefficient	Robust SE	Coefficient	Robust SE	Marginal effect	Robust SE
Minor FAW infestation	−0.210	0.363	−0.007	0.226	0.071	0.052
Severe FAW infestation	−0.920**	0.432	−0.531*	0.309	0.166***	0.054
Age	0.511	0.360	0.206	0.229	0.003**	0.001
Gender	0.010	0.010	0.002	0.006	−0.019	0.046
Education	−0.130	0.389	0.203	0.267	−0.031	0.044
Household size	−0.072**	0.032	−0.056**	0.025	0.004	0.004
Maize area	0.033	0.023	0.011	0.019	−0.067***	0.024
Wealth index	0.373***	0.127	0.533***	0.069	−0.066***	0.019
Off-farm activity	−0.912***	0.348	0.643**	0.208	0.019	0.043
Credit access	1.006***	0.366	0.411*	0.207	−0.075	0.060
Farmer group	−0.416	0.440	−0.147	0.289	0.077	0.057
Distance to agro-dealer	−0.014	0.016	0.003	0.008	0.000	0.002
Distance to extension	−0.011	0.018	−0.020	0.016	−0.004	0.002
Mashonaland East	−1.359**	0.620	−0.975*	0.378	0.143*	0.086
Mashonaland West	0.594	0.494	−0.170	0.372	0.020	0.081
Midlands	0.729	0.479	−0.141	0.286	−0.120	0.076
Masvingo	0.623	0.510	−0.081	0.351	−0.155**	0.070
Matabeleland North	−0.472	0.535	−0.558	0.366	0.014	0.078
Constant	4.135***	0.797	5.710***	0.511		
No. of observations	350		350		350	

*, ** and *** represent 10%, 5% and 1% significance level, respectively.

TABLE A5 Effectiveness of FAW control adoption (full regression results)

	Ln (maize income/capita)		Ln (HH income/capita)		Hunger (1/0)	
	Coefficient	**Bootstrap SE**	**Coefficient**	**Bootstrap SE**	**Marginal effect**	**Bootstrap SE**
FAW attack (no control)	−0.955**	0.486	−0.630*	0.353	0.144**	0.063
FAW attack (adopted a control measure)	−0.091	0.562	0.419	0.344	0.099	0.069
Age	0.011	0.010	0.003	0.006	0.003**	0.001
Gender	0.455	0.367	0.160	0.233	−0.008	0.046
Education	0.034	0.395	0.362	0.267	−0.051	0.044
Household size	−0.078**	0.035	−0.066*	0.040	0.005	0.004
Maize area	0.028	0.088	0.005	0.060	−0.069***	0.023
Asset index	0.388***	0.132	0.548***	0.075	−0.067***	0.019
Off-farm activity	−0.867**	0.338	0.703***	0.191	0.016	0.043
Credit access	0.982**	0.385	0.367*	0.217	−0.079	0.061
Farmer group	−0.448	0.464	−0.206	0.282	0.079	0.058
Distance to agro-dealer	−0.014	0.015	0.004	0.008	−0.001	0.002
Distance to extension	−0.005	0.021	−0.013	0.017	−0.004	0.002
Mashonaland East	−1.454**	0.616	−1.040***	0.377	0.155*	0.085
Mashonaland West	0.558	0.463	−0.167	0.362	0.029	0.080
Midlands	0.760	0.472	−0.070	0.297	−0.121	0.076
Masvingo	0.699	0.459	−0.014	0.345	−0.156**	0.071
Matabeleland North	−0.554	0.490	−0.572*	0.326	0.028	0.077
Generalised residual	−0.280	0.395	−0.548**	0.277	0.010	0.052
Constant	3.890***	0.844	5.383***	0.536		
No. of observations	350		350		350	

*, ** and *** represent 10%, 5% and 1% significance level, respectively.