**Assessing the Role of Market Participation in Enhancing Household Food Security among Smallholder Cereal Growers in Eastern Africa**

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**Abstract**

Food and nutrition insecurity presents a formidable challenge in rural regions of developing nations, aligning with overarching global development objectives. This study investigates the interdependence between technology adoption, market participation and food and nutrition security in Eastern Africa, focusing on cereal farmers using push-pull technology (PPT). The study used data from five countries, and employed a longitudinal survey, while the statistical analysis was done using logit, and multiple regression models. The measures used were Household Dietary Diversity Score (HDDS), Food Consumption Score (FCS), Food Insecurity Coping Strategy Index (FCSI), and Food Insecurity Experience Scale (FIES). The findings underscore the importance of PPT adoption in market participation decisions. Furthermore, resource endowment like land size, off-farm income, Tropical Livestock Units (TLU) enhanced market participation. Moreover, market participation enhances dietary diversity and food security, aligning with existing literature. Notably, credit and extension constraints may impede market participation, thus jeopardizing food security, whereas group membership emerges as a positive influencer. The study concludes that interventions geared towards enhancing farmers' capital base are pivotal for realizing food security objectives. Integration of technologies such as PPT, and advocating for collective action not only facilitates market participation but also augments overall food security for sustainable agri-food systems.

**Key Words: Market participation, Food and Nutrition Security, Push-Pull Technology**

1. **Introduction** 
   1. **Background and problem statement**

Food and nutrition insecurity remains a critical challenge in developing countries, particularly in rural areas, and stand at the forefront of global development discourse. The African Union's Agenda 2063 envisions Africa as a leader in nutrition (AUC, 2015), aligning with Sustainable Development Goal (SDG) 2, which aspires to eradicate hunger, achieve food security, and eliminate all forms of malnutrition by 2030. Food and nutrition insecurity is most prevalent in the rural areas where most of the households dependents on agricultural sector ([Muller, 2009](https://www.sciencedirect.com/science/article/pii/S2211912420301371#bib36); [Pinstrup-Andersen, 2007](https://www.sciencedirect.com/science/article/pii/S2211912420301371#bib40); [Qaim, 2017](https://www.sciencedirect.com/science/article/pii/S2211912420301371#bib43)). However, the sector’s growth has been slow over the years attributed to multi-faceted challenges such as low adoption of improved technologies, limited market access, climate change and other socio-economic disparities ([Hirvonen and Hoddinott, 2017](https://www.sciencedirect.com/science/article/pii/S2211912420301371#bib17)) among other reasons.

In response to the challenges in agricultural sector, research institutions both local and international have undertaken substantial efforts to develop and disseminate innovative solutions aimed at boosting agricultural productivity. These efforts extend beyond addressing the technological gap to encompass broader systemic issues by addressing climate variability, sustainable farming practices to promote environmental conservation, and market-oriented strategies to enhance market access for rural producers. For example, the International Centre of Insect Physiology and Ecology (*icipe*) and partners introduced a novel technology to increase cereal production in Africa by simultaneously controlling stemborer, *Striga* weed and fall armyworm while at the same time improving soil fertility. The technology known as the push-pull technology (PPT) originally involved intercropping of a fodder legume *Desmodium spp*., including *D. uncinatum* (Jacq.), with cereals and a perimeter of Napier grass, *Pennisetum purpureum K.* (Schumach) (Khan et al., 2001). This original PPT was later adapted to climate-resilient push-pull technology (CR-PPT) by intercropping cereals with drought-tolerant Greenleaf desmodium, *Desmodium intortum* (Mill.) Urb., and planting *Brachiaria* cv Mulato II as a border crop around this intercrop (Midega et al., 2015, 2017). A third generation PPT was later introduced with brachiaria cultivars that were more tolerant to red spider mites (RSM) (Cheruiyot et al., 2018a, b, c). The mechanism for operations of PPT has extensively been described by Khan et al., 2001, 2002, 2003, Tsanuo et al., 2003, Midega et al., 2003 and Cook et al., 2007. Over the years, the technology has been introduced and adopted in various eastern African region with significant impacts in cereals yield increase (Khan et al., 2008a, b; Chepchirchir et al., 2017, 2018; Kassie et al., 2018). While this technology has the potential to increase cereal production and therefore support food and nutrition security, it is anticipated that farmers growing PPT can also access rural markets for the excess produce in exchange of other goods in the market. This will further enhance food and nutrition security, leading to sustainable food systems.

To achieve food and nutrition security goals, it is crucial not to overlook the dual focus on productivity enhancement and market participation. Smallholder farmers predominantly adopt improved technologies to achieve self-sufficiency in food production and subsequently sell the surplus in the market (Bird 2023). The adoption of improved technologies not only enhances food security through increased production but also empowers farmers to pursue market-oriented farming, allowing them to earn additional income. This additional income can be utilized to procure food items or reinvested in the farm, thereby improving productivity and ultimately ensuring food security. The interdependence between technology adoption, market participation, and food and nutrition security underscores the intricate relationship where farmers' decisions to adopt technologies influence their participation in markets, subsequently impacting household food and nutrition security. Bird (2023) also highlights that farmers can self-select their market participation roles as sellers or buyers, influencing their decisions to adopt new technology. This interdependence can be explored from both the perspectives of market participation and technology adoption literature and this forms part of the motivation of this paper.

While numerous studies on PPT have demonstrated its benefits in terms of increased production, income, and socio-economic advantages (Khan et al., 2008; Chepchirchir et al., 2017, 2018; Kassie et al., 2018), the question of whether the adoption of PPT motivates farmers to engage in crop and livestock markets remains unanswered, particularly in the context of Eastern Africa where the technology has recently been scaled up. Furthermore, the information on how participation in crop and livestock markets by PPT adopters impacts their household food and nutrition security is lacking. Previous studies have emphasized the critical role of market access in enhancing household nutrition diversity (Lenjiso et al., 2016; Qaim and Sibhatu, 2018; Ssajakambwe et al., 2020; Mulenga et al., 2021). Additionally, Usman et al. (2021) noted that interventions that enhance market accessibility can lower transaction costs, facilitating farmer participation. While these studies have highlighted the crucial importance of markets in shaping dietary diversity, there is a notable gap in evidence-based information linking other elements of food and nutrition security to market participation. Furthermore, the studies did not clearly delineate whether farmers participated in the market as sellers or as buyers. This paper addresses whether technology adoption motivates farmers to participate in the market as sellers, using the case of PPT farmers in Eastern Africa. The paper further investigates the nexus between market participation and sustainable household food and nutrition security using the four indicators: Household Dietary Diversity Score (HDDS), Food Consumption Score (FCS), Food Coping Strategy Index (FCSI), and Food Insecurity Experience Scale (FIES), following the approach suggested by Maxwel et al. (2008) for triangulation.

* 1. **Objectives**

This paper has two objectives: i). To investigate the role of PPT adoption on influencing farmers' participation in the markets; and ii). The measure the impact of market participation on the food and nutrition security of households in Eastern Africa

1. **Methodology**
   1. **Study design**

Data was corrected in five UPSCALE[[1]](#footnote-1) project study countries namely; Ethiopia (North Shewa, Oromia Special zone, South Welo in Amhara), Kenya (Kisumu, Vihiga, Siaya and Homabay counties), Rwanda (Nyagihaya Sector), Tanzania (Butiama, Bunda, Tarime and Rolya districts in Mara region), and Uganda (Iganga, Kamuli, Namutumba districts). Data was corrected between June and October 2021. The study adopted a longitudinal survey design where PPT and non-PPT farmers within the landscape of the study area were sampled and interviewed individually. A total of 1556 farmers were samples; 304 in Kenya, 308 in Ethiopia, 317 in Tanzania, 319 in Rwanda and 308 in Uganda. The map of the study sites is shown in figure 1.

Map

Description automatically generated

**Figure 1: Map of the study sites**

* 1. **Analyticalmodels**

The study assesses the connection between technology adoption, market participation, and the food security status of cereal farming households. In the initial phase, a logit model was employed to examine technology adoption and market participation, while a multiple regression analysis was utilized to investigate the relationship between market participation and household food and nutrition security.

### ***Logit regression for determinants of market participation***

In the first objective of evaluating the factors influencing market participation, the dependent variable was assessed as a binary variable, denoted as Y = 1 if farmers engaged in selling their produce in either the crop or livestock market, and Y = 0 if the farmer did not sell their produce in either the crop or livestock market. The binary Logit statistical model was chosen, as it is commonly employed to evaluate the impact of external factors on individual choices, a method extensively utilized in prior research (Washington et al., 2020; Afghari et al., 2020). It is anchored in the theory of random utility which posits that individuals make choices between two (or more) alternatives considering both observed and unobserved factors (Greene 2012). The utility model is presented as;

 (1)

Where U is the utility that the ith farmer derived from participating in the crop of livestock market as a seller, Vij are the observable characteristics and ɛij is the error term capturing the unobservable components. The observed logit equation when a farmer participates in a market is presented as follows:

 (2)

Where Y\*i presents the decision by the farmer to participate in either crop of livestock market as a seller, Xi are the vector of variables influencing market participated, βi are parameter estimates and ɛi is the stochastic error term assumed to be independently and identically distributed (iid) with mean = 0 and variance = δ2. Two models were estimated; the crop market participation model, and the livestock market participation model.

### ***Multiple regressions for market participation and food and nutrition security***

For the second objective, the initial step involved computing the four food and nutrition security scores (HDDS, FCS, FCSI, and FIES), which would serve as dependent variables, as elaborated in the next section. All the four scores were inherently continuous invoking the use of a multiple regression model to ascertain the influence market participation had on household food and nutrition security. Other socio-economic, farm, institutional and locational variables were also included in the model to control for their effect. The general model for multiple regression is expressed as follows:

 (3)

Where the dependent Y represents the food security scores (HDDS, FCS, FCSI, and FIES), α indicate the value of the dependent variables when all the values of independent variable are zero and each β estimate indicated the average change in Y in relation with a unit of change in X, whereas controlling other explanatory variables in the model. Four models were estimated with each of the scores as a dependent variable.

### ***Household dietary diversity score (HDDS)***

Household dietary diversity score (HDDS) is a qualitative measure of food consumption that reflects household access to a variety of foods (FAO, 2011). It is a simple count of food groups that a household has consumed over the preceding 24 hours and an important indicator of food security (Swindale and Bilinsky, 2006). HDDS was calculated by summing up the number food groups consumed over a reference period. The HDDs which ranges between 0-12 was ranked accordingly into high dietary diversity (8-12), medium dietary diversity (6-8) and low dietary diversity (0-5). The twelve (12) food groups included in the HDDS were cereals; roots and tubers; vegetables; fruits; meat, poultry, offals; eggs; fish and sea foods; legumes, nuts and seeds; milk and milk products; oils and fat; sugar/honey; condiments; and beverages (FAO, 2011).

### ***Food Consumption Score (FCS)***

This score was calculated by multiplying the frequency of foods consumed by the households in the past seven days with the weighting as prescribed by World Food Programme (WFP) as follows (WFP, 2008).

*FCS* = (4 × *meats)* + (2 × *staples-cereals*) + (3 × *pulses*) + (1 × *vegetables*) + (1 × *fruits*) + (4 × *milk and milk products*) + (0*.*5 × *oil/fats*) + (0*.*5 × *sugar and honey*) + *(0.5*× *Miscellaneous) (*4)

The calculated score was then then classified into three thresholds as follows: 0-21 poor; 21.5-35 Borderline; and above 35 Acceptable.

### ***Food Insecurity Coping Strategy Index (FCSI)***

This is a measurement tool designed to assess individuals' actions when faced with insufficient access to food in the short term. It explores how households navigate and adapt to a shortage of food for consumption using a set of questions. The CSI is based on the many possible answers to a single question: “*What do you do when you don’t have adequate food and don’t have the money to buy any*?”. The score is calculated as follows (Sassi, 2021):

 (5)

Where fCS are frequency of coping strategy used; wCS is the weight of the coping strategy used and *n* is the number of coping strategies. The obtained score was classified into 3 levels as follows: 0-50 low, 51-100 medium and > 100 as high.

### ***Food Insecurity Experience Scale (FIES)***

This is an experience based metric tool developed by FAO to measure food insecurity severity (Data4Diets, 2023). It is composed of eight (8) questions with binary responses (Yes/No) that covers people’s direct responses about their experiences on food access. The tool is administered on surveys to help elicit the severity and prevalence of food insecurity ranging from food secure to severe food insecurity. The tool is useful for cross country comparison of food insecurity prevalence.

1. **Results and Discussions** 
   1. **Descriptive analysis of model variables**

Table 1 presents the results of the descriptive analysis of variables expected to impact on market participation and food security. Across the study countries and in the entire sample, the majority of farmers were men (85%), with an average age of 50 years. The variable of age is expected to exhibit ambiguity, as older farmers, with established relationships with buyers, are more likely to participate in the market. Conversely, older farmers might be classified as risk-averse compared to their younger counterparts, and they may prefer storing their produce rather than selling it in the market in certain situations (Akrong et al., 2021). The literacy level was moderate with the average years of schooling standing at 6 years. Education enhances skills and the ability to utilize market information effectively, potentially reducing marketing costs and making market participation more profitable (Olwande and Mathenge, 2011). The average household size was 6 members, with the highest recorded in Uganda. The relationship between household size and participation in high-value markets is considered ambiguous. Akrong et al. (2021) found that market participants were mainly from small families, while large families are expected to enhance production through labor provision and consequently increase market participation.

At least 40% of farmers adopted PPT in the overall sample, with the highest adoption reported in Rwanda (55%). It is expected that PPT adopters would participate in the livestock market to sell fodder and other livestock products. Additionally, they would engage in the crop market to sell excess cereals resulting from increased production due to stemborer, striga weed, and Fall armyworm control. The average land size was 1.2 hectares, which may be a motivation for market participation, especially if farmers can cultivate large portions.

The Tropical Livestock Unit (TLU) was used as a proxy for herd size, with the results showing an average of 2 in the overall sample. Degefa et al. (2022) showed that market participants had larger livestock herd compared to non-market participants. Farmers with off-farm income are expected to have a higher chance of participating in the market, as it enables them to cultivate larger land sizes and access improved inputs and technology that enhance productivity (Abu, 2015). At least 56% of farmers had off-farm income, with the highest percentage in Kenya (82%).

About 40% belonged to agricultural groups, hypothesized to positively influence market participation. Farmers often find it easier to sell their produce in groups and cooperatives rather than individually (Fischer and Qaim, 2012). At least 60% participated in crop markets, and 46% in livestock markets. The average distance to the market was 7 km, with only 13% indicating credit constraints, implying that the majority did not face issues, and this is likely to positively influence market participation.

**Table 1 Descriptive analysis of the model variables**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Variables | Kenya  (n = 304) | Uganda  (n= 308) | Tanzania  (n = 317) | Rwanda  (n= 319) | Ethiopia  (n =308 | Overall  (n= 1556) |
| PPT adoption (Yes) | 0.47 | 0.31 | 0.38 | 0.55 | 0.30 | 0.40 |
| Gender of decision maker (Male) | 0.77 | 0.84 | 0.85 | 0.83 | 0.96 | 0.85 |
| Age of decision maker(Year) | 54.54 | 50.33 | 52.56 | 48.74 | 46.59 | 50.54 |
| Education level of decision maker (years) | 9.23 | 7.00 | 6.50 | 5.09 | 3.20 | 6.19 |
| Household size (number) | 5.61 | 7.50 | 6.98 | 4.99 | 5.86 | 6.18 |
| Total land size (Ha) | 1.02 | 1.33 | 1.96 | 0.55 | 0.76 | 1.12 |
| Tropical livestock units | 1.91 | 1.16 | 3.66 | 0.69 | 2.61 | 2.01 |
| Off farm income (Yes) | 0.82 | 0.58 | 0.70 | 0.30 | 0.41 | 0.56 |
| Group membership (Yes) | 0.38 | 0.35 | 0.36 | 0.40 | 0.57 | 0.41 |
| Crop market participation (Yes) | 0.51 | 0.65 | 0.70 | 0.52 | 0.59 | 0.60 |
| Livestock market participation (Yes) | 0.54 | 0.44 | 0.58 | 0.18 | 0.58 | 0.46 |
| Distance to nearest market (Km) | 5.30 | 8.13 | 5.10 | 10.38 | 6.87 | 7.17 |
| Credit constraint (Yes) | 0.06 | 0.14 | 0.24 | 0.03 | 0.17 | 0.13 |
| Extension constraint (Yes) | 0.16 | 0.42 | 0.54 | 0.52 | 0.39 | 0.41 |

* 1. **Measures of food and nutrition security**

The study computed four food and nutrition security scores, as detailed in the methodology section. The findings outlined in Table 2 shows the percent of household that fall under different scales of household food security based on the calculated scores. Concerning HDDS, the results indicate that just over half (54%) of the households fell into the medium diversity category, consuming 3 to 9 food types per day (Table 2). Rwanda had the highest percentage of households with a low HDDS score (41%). Regarding the FCS score, the results demonstrate that the majority (over 80%) of households, except in Rwanda, were within the acceptable range. This pattern is also evident in the FCSI measurement, with Rwanda recording a higher percentage of households in the medium and high FCSI categories (23% medium and 12% high), indicating a tendency toward insecurity. The FIES also reveals that Rwanda had the highest percentage of food-insecure households (77%).

**Table 2: Percent (%) of households in different food and nutrition security levels**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Classification of scores | Kenya  (n = 304) | Uganda  (n= 308) | Tanzania  (n = 317) | Rwanda  (n= 319) | Ethiopia  (n =308 | Overall  (n= 1556) |
| **HDDS levels** |  |  |  |  |  |  |
| Low | 17.76 | 28.57 | 23.66 | 41.38 | 32.47 | 28.86 |
| Medium | 65.13 | 47.73 | 55.52 | 46.39 | 54.22 | 53.73 |
| High | 17.11 | 23.7 | 20.82 | 12.23 | 13.31 | 17.42 |
| **FCS levels** |  |  |  |  |  |  |
| Poor | 0.33 | 0.32 | 0.32 | 14.42 | 2.6 | 3.66 |
| Borderline | 2.96 | 11.36 | 5.36 | 22.88 | 9.09 | 10.41 |
| Acceptable | 96.71 | 88.31 | 94.32 | 62.7 | 88.31 | 85.93 |
| **FCSI levels** |  |  |  |  |  |  |
| Low | 94.41 | 87.66 | 95.58 | 65.2 | 97.73 | 87.98 |
| Medium | 4.28 | 10.06 | 3.79 | 22.88 | 1.62 | 8.61 |
| High | 1.32 | 2.27 | 0.63 | 11.91 | 0.65 | 3.41 |
| **FIES levels** |  |  |  |  |  |  |
| Food secure and mild | 20.07 | 9.74 | 18.93 | 9.72 | 49.35 | 21.47 |
| Moderate food insecure | 22.37 | 38.31 | 40.38 | 13.17 | 26.95 | 28.21 |
| Severe food insecurity | 57.57 | 51.95 | 40.69 | 77.12 | 23.7 | 50.32 |

* 1. **Determinants of PPT adoption on crop and livestock market participation**

Table 3 presents the results obtained from the logistic regression, examining the determinants of crop and livestock market participation. Both models demonstrated significance at the 1% level (Prob>chi = 0.000). The PPT adoption variable showed significance in the livestock market participation model but was insignificant in the crop market participation model. This suggests that PPT farmers might prefer storing the cereal produce obtained from their farms for personal consumption rather than selling it in the market. Previous studies on the economics of PPT utilized the quantity of harvest multiplied by the prevailing market price as a proxy for revenue generated (Chepchirchir, 2017, 2018; Kassie, 2018). Nevertheless, both PPT and non-PPT farmers participated in the livestock market, possibly to sell excess fodder obtained from their plots, especially for those farmers without livestock. Furthermore, farmers adopting PPT were likely to obtain more milk by feeding their livestock with PPT fodder, which they could then sell in the market. Additionally, PPT adopters tended to expand their livestock herd due to the availability of fodder and were likely to later sell the surplus livestock in the market (Ouya et al., 2023). This finding aligns with the positive coefficient of TLU, indicating that farmers with larger livestock herds were indeed more likely to participate in the livestock market, either by selling the animals or their products (e.g., eggs, milk) (Olwande and Mathenge, 2011; Degefa et al., 2022).

* 1. **Determinants of other factors on crop and livestock markets participation**

The positive influencers of crop market participation were land size, TLU and country variables, while the age of the farmer was significant but negative. The positive coefficient for land size suggests that farmers with larger land holdings were more inclined to engage in the crop market to sell the surplus they obtained from the rest of the farm other than the PPT plots. This finding aligns with similar observations made by Degefa et al. (2022) and Belete & Nigatu (2023) regarding market participation among smallholder teff farmers in Western and central Ethiopia, respectively. Likewise, the positive correlation observed between TLU and crop market participation suggests that farmers with larger livestock holdings are more inclined to engage in crop market to sell their surplus crop produce. TLU serves as a significant resource for farmers, allowing them to generate additional income by selling livestock and related products like milk and eggs. This supplementary income becomes instrumental in acquiring improved technologies to enhance crop production. Consequently, farmers become capable of selling surplus crop products. Furthermore, larger livestock herds offer the advantage of providing manure, which can be employed to augment crop production, leading to a surplus available for sale. The analysis further reveals that older farmers are less likely to participate in the crop market (Coefficient -0.008). Abu et al. (2014) found similar results on maize farmers’ participation in the market in Ghana, arguing that such farmers are more concerned about food security from the farm produce than selling it to the market. The country variables indicate that farmers in Uganda and Tanzania had a higher likelihood of participation in crop market compared to Kenya, which served as the reference variable.

In the livestock model, the other significant variables were land area, off-farm income, age of the farmer (negative), and the country variable representing Rwanda. The positive coefficient on land size may suggest that farmers with larger land holdings may cultivate more extensive proportions or keep more livestock, thus participating more in the market. our results demonstrate that off-farm income was associated with participation in the livestock market. As previously noted by Abu (2015), off-farm income provides farmers with additional resources to enhance productivity and consequently increasing their market participation.

**Table 3: Factors determining decision to participate in crop and livestock markets**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variables | Crop market model | | Livestock market model | |
|  | Coefficient | P>z | Coefficient | P>z |
| PPT adopter | 0.100 | 0.419 | 0.361 | **0.006\*\*\*** |
| Land area | 0.149 | **0.004\*\*\*** | 0.087 | **0.066\*\*** |
| Credit constraints | 0.239 | 0.161 | 0.239 | 0.158 |
| Extension Constraint | 0.122 | 0.285 | -0.113 | 0.354 |
| Gender of farmer | -0.159 | 0.311 | 0.019 | 0.907 |
| Household size | -0.028 | 0.211 | 0.013 | 0.592 |
| Distance to the market | 0.004 | 0.454 | -0.005 | 0.457 |
| Off-farm income | -0.032 | 0.782 | 0.321 | **0.009\*\*\*** |
| Group membership (Agriculture) | 0.179 | 0.141 | 0.156 | 0.222 |
| Age of the farmer | -0.008 | **0.060\*\*** | -0.011 | **0.018\*\*\*** |
| Education level of the farmer | -0.001 | 0.908 | 0.018 | 0.110 |
| Tropical Livestock Unit (TLU) | 0.050 | **0.024\*\*** | 0.249 | **0.000\*\*\*** |
| Uganda | 0.580 | **0.002\*\*\*** | -0.168 | 0.369 |
| Tanzania | 0.601 | **0.001\*\*\*** | -0.046 | 0.811 |
| Rwanda | 0.015 | 0.936 | -1.232 | **0.000\*\*\*** |
| Ethiopia | 0.222 | 0.257 | 0.183 | 0.382 |
| \_cons | 0.389 | 0.252 | -0.480 | 0.180 |
| Number of obs |  | 1556 |  | 1556 |
| LR chi2(16) |  | 72.23 |  | 306.14 |
| Prob > chi2 |  | **0.000** |  | **0.000** |
| Pseudo R2 |  | 0.034 |  | 0.143 |

* 1. **Effects of Market participation on food and nutrition security**

To examine the impact of market participation on food and nutrition security, four multiple regression models were estimated, and the results are outlined in Table 4. All the four models demonstrated significance at the 1% level (Prob>F=0.000). In the HDDS model, participation in the livestock market exhibited a positive impact on dietary diversity (coeff = 0.564) at 1% level of significance. The FCS model revealed that participation in both the crop market (coeff = 1.990) and the livestock market (coeff = 5.296) had a positive impact on food security.

The positive coefficients in the HDDS and FCS models signify that participating in the market enhances household food diversity and improves security. This corresponds with the results of Simphiwe et al. (2023), who noted improved nutritional status among smallholder farmers participating in the market in South Africa. Additionally, Usman et al. (2021) similarly concluded that market access reduces transaction costs (time), motivating households to purchase food from the market and, consequently, attain food security.

In the FCSI model, the negative coefficient of participation in the crop market (coeff = -7.386) is interpreted to mean that these farmers employed fewer coping strategies (FCSI), indicating that they were already food secure and did not require additional coping mechanisms. This observation is also mirrored in the FIES model, where the two market participation variables were significant with negative coefficients (-0.090 and -0.042 for crop and livestock market participation, respectively), implying that the majority of households were in the lower scale of food insecurity. The results from the four models suggest that market participation, particularly in the livestock and crop markets, is associated with greater dietary diversity, improved food consumption, and reduced reliance on coping strategies, indicating a positive impact on food and nutrition security for participating households.

The results for the other variables which were included in the models were mixed. The variable for PPT adoption was significant and negatively associated with FCSI and FIES models implying that these farmers were more food secure compared to non-adopters. Kassie et al. (2018) noted that adoption of PPT led to increase maize field which lead to an increase in food availability at household level as well as extra income from sale in the market. Land size positively influenced the HDDS and FCS models but had a negative correlation on the FCSI model, suggesting that households with larger land holdings were more food secure. This aligns with previous discussions by Olwande and Mathenge (2011) and Degefa et al. (2022), who illustrated that farmers with larger land sizes tend to cultivate more and increase productivity. On the other hand, the variable of credit constraints exhibited a positive correlation with the FIES model, implying that households without access to credit were more food insecure. A similar trend was observed in the extension constraints variable, which was positively linked to the FCSI model. The absence of credit and extension services diminishes farmers' capacity to invest in improved technologies, ultimately lowering their productivity and compromising food security. Wezi et al. (2023) highlighted that farmers lacking access to credit consumed less food than they would have if they had access to such credit.

Gender exhibited a positive influence on HDDS, FCS, and FCSI models, indicating that male-headed households were more likely to be food secure compared to female-headed households. This aligns with the findings of Kassie et al. (2012), who observed that, in general, female-headed households in Kenya were more likely to be food insecure than their male counterparts. Household size demonstrated a positive impact on FCSI and FIES, suggesting that larger families were more likely to be food insecure. Oluwatayo (2009) acknowledged that a large family size imposes an additional burden on food consumption, making them more susceptible to food insecurity compared to households with a smaller family size. The variable for off-farm income had a positive effect on the HDDS model but a negative effect on FCSI and FIES models, implying that families with off-farm incomes were more likely to be food secure. It has been noted that off-farm income not only enhances household resources for investing in productive farming but also allows them to purchase extra foodstuffs from the market (Abu, 2015).

Group membership was positively associated with the HDDS model implying that households who participated in groups were more food secure. As noted by Fischer and Qaim, (2012), household prefer marketing their produce in group as this give them a bargaining power. This is likely to enhance food security and diversity through increase income from high prices. Alternatively, participation from groups helps households learn from each other on how to diversify their diets.

Age of the farmers had a negative impact on the FIES model, implying that older farmers were more food secure. This corroborates the finding of Abu et al. (2014) who observed that older farmers preferred storing maize in their farms to secure their families against hunger than selling it to the market. Education variable on the other hand was positive for HDDS and FCS models but negative for FCSI and FIES models, suggesting that more educated farmers were more food secure. These finding were consistent with those of De Muro and Burchi (2007), Faye et al. (2011) and Mutisya et al. (2016) who noted that increased household education attainment was associated with an increased probability of being food secure.

TLU had a positive impact on HDDS and FCS models but a negative impact on FCSI and FIES models, suggesting that farmers with more livestock were likely to be more food secure. As demonstrated in the previous section, we established that farmers with a larger herd of livestock are more likely to participate in the market (Degefa et al., 2022), implying that they will generate more income to purchase additional food for their families, thereby enhancing their food security.

The country variables presented varied outcomes. In the HDDS model, Ethiopia demonstrated a negative correlation in comparison to Kenya. However, in the FCS model, all countries were projected to be less food secure than Kenya. In the FCSI and FIES models, only Rwanda appeared to be more food insecure.

**Table 4: The effect of market participation and other variables on food and nutrition security**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | HDDS |  | FCS |  | FCSI |  | FIES |  |
|  | Coefficient | P>t | Coefficient | P>t | Coefficient | P>t | Coefficient | P>t |
| Crop market participation | 0.166 | 0.103 | 1.990 | **0.033\*\*** | -7.386 | **0.000\*\*\*** | -0.090 | **0.000\*\*\*** |
| Livestock market participation | 0.564 | **0.000\*\*\*** | 5.296 | **0.000\*\*\*** | -1.071 | 0.471 | -0.042 | **0.063\*** |
| PPT adopter | 0.170 | 0.138 | 1.458 | 0.164 | -5.517 | **0.001\*\*\*** | -0.053 | **0.026\*\*** |
| Land area | 0.000 | **0.057\*\*** | 0.003 | **0.055\*\*** | -0.004 | **0.102\*** | 0.000 | 0.152 |
| Credit constraint | -0.062 | 0.686 | 0.282 | 0.840 | 1.105 | 0.600 | 0.053 | **0.092\*** |
| Extension constraint | 0.088 | 0.401 | 0.837 | 0.384 | 2.585 | **0.075\*** | -0.014 | 0.522 |
| Gender of the farmer | 0.422 | **0.004\*\*\*** | 3.692 | **0.005\*\*\*** | -5.433 | **0.007\*\*\*** | -0.047 | 0.122 |
| Household size | -0.017 | 0.392 | -0.025 | 0.893 | 0.974 | **0.001\*\*\*** | 0.016 | **0.000\*\*\*** |
| Distance to the market | -0.004 | 0.365 | 0.050 | 0.242 | -0.068 | 0.293 | -0.001 | 0.407 |
| Off-farm income | 0.593 | **0.000\*\*\*** | 1.451 | 0.139 | -6.791 | **0.000\*\*\*** | -0.077 | **0.001\*\*\*** |
| Group membership (agriculture) | 0.199 | **0.075** | 0.879 | 0.390 | -1.055 | 0.495 | -0.028 | 0.227 |
| Age of the farmer | 0.005 | 0.200 | 0.057 | 0.115 | 0.004 | 0.942 | -0.002 | **0.024\*\*** |
| Education of the farmers | 0.020 | **0.036\*\*** | 0.266 | **0.003\*\*\*** | -0.478 | **0.000\*\*\*** | -0.005 | **0.018\*\*\*** |
| Tropical livestock units | 0.040 | **0.011\*\*\*** | 0.840 | **0.000\*\*\*** | -0.735 | **0.001\*\*\*** | -0.012 | **0.000\*\*\*** |
| Uganda | 0.203 | 0.231 | -10.650 | **0.000\*\*\*** | 0.002 | 0.999 | -0.115 | **0.001\*\*\*** |
| Tanzania | 0.031 | 0.855 | -3.079 | **0.047\*\*\*** | -1.724 | 0.461 | -0.170 | **0.000\*\*\*** |
| Rwanda | -0.242 | 0.183 | -26.598 | **0.000\*\*\*** | 22.041 | **0.000\*\*\*** | 0.103 | **0.006\*\*\*** |
| Ethiopia | -0.349 | **0.058\*\*** | -16.713 | **0.000\*\*\*** | -13.032 | **0.000\*\*\*** | -0.400 | **0.000\*\*\*** |
| \_cons | 5.119 | 0.000 | 54.731 | 0.000 | 32.671 | 0.000 | 0.898 | 0.000 |
| Number of observation |  | 1556 |  | 1556 |  | 1556 |  | 1556 |
| F(18, 1537) |  | 9.950 |  | 43.69 |  | 25.620 |  | 21.870 |
| Prob > F |  | **0.000** |  | **0.000** |  | **0.000** |  | **0.000** |
| R-squared |  | 0.104 |  | 0.339 |  | 0.231 |  | 0.204 |
| Adj R-squared |  | 0.094 |  | 0.331 |  | 0.222 |  | 0.195 |
| Root MSE |  | 1.922 |  | 17.606 |  | 26.596 |  | 0.399 |

1. **Conclusions and Recommendation**

The challenges of food and nutrition security in rural Eastern Africa persist, exacerbated by slow agricultural growth. Research institutions' efforts have gradually shown positive impacts in achieving food security. This study aimed to assess whether technology adoption motivates market participation and whether this ultimately enhances sustainable household agri-food systems. The results indicate varying levels of food security among Eastern African countries, with Rwanda lagging behind Kenya, Uganda, Tanzania, and Ethiopia. The findings from the market participation model illustrate that farmers are motivated by various factors to participate in the market, primarily related to resource endowments such as land size, off-farm income, and TLU. These factors positively contribute to enhancing farmers' capital endowments, allowing for increased investment in farm productivity and fostering a more commercial orientation, ultimately positively impacting food security. Technology adoption positively influenced participation in the livestock market but was insignificant in crop-market participation. The implication is that interventions that enhance technology adoption and those that improve farmers' capital base are crucial for achieving food security.

Further results from the multiple regression models affirm that participation in the market can enhance household food and nutrition security. The study confirms that farmers self-select themselves to participate in either the crop or livestock market after achieving household food self-sufficiency. By participating in the market as sellers, these households can generate extra income, enabling them to purchase diversified food for their families and achieve food and nutritional security. Advancing improved technologies, as demonstrated by the positive correlation of the adoption variable, can facilitate food and nutrition security. Specifically, in this study, PPT motivates farmers to participate in the livestock market by selling surplus produce beyond the cereals produced from PPT farms. The compounding effect of technology adoption and market participation is a significant contributor to sustainable agri-food systems.

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**Conflict of interest**

There is no conflict of interest

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