The Impact of Push-Pull Technology Adoption on Food Security among Smallholder Cereal Growers

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Abstract

One of the most important puzzles in developing countries is identifying relevant and sustainable mechanisms to increase and sustain agricultural productivity. Using data obtained from a field survey of 319 households that grow maize, this paper tests the effect of adopting Push-Pull Technology on cereal yield and household food security and also examines whether the spillover effect of the adoption of Push-Pull Technology on household food security through cereal yield is economically and statistically significant. This paper finds a positive and statistically significant direct impact of Push-Pull Technology on cereal yield and food security. The tested spillover effect is statistically significant. Push-Pull Technology improves cereal yield by 0.47-1.65 percentage points, which translates into a 0.60-0.95 percentage points increase in Household Dietary Diversity Score and a 0.21-0.65 percentage points decrease in Household Food Insecurity Access Scale and Coping Strategy Index. Our results imply that increasing the adoption of Push-Pull Technology might be one of the effective agricultural policy strategies to improve cereal productivity and household food security while preserving biodiversity and the ecosystem.

Keywords: Push-Pull Technology, Adoption Intensity, Food Security, cereal pests.

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1. Introduction

One of the most important puzzles in developing countries is identifying relevant and sustainable mechanisms to increase and sustain agricultural productivity. Agriculture is essential in creating job opportunities, reducing poverty, and improving food security and economic growth in these countries. However, it is documented that unemployment, poverty, and food insecurity risks in developing countries will substantially increase with an increase in the global population estimated at 2.5 percent by 2050. Also, due to this population growth, global food demand is estimated to increase by 60 percent, generally, and global cereal demand to triple, particularly by 2050.

Although different agricultural inputs, such as the use of chemical fertilizers, pesticides, and insecticides, were adopted, agricultural productivity in those countries is still impeded by various biotic and abiotic factors, including high cost of agricultural inputs, reduced soil fertility, resistant pests and crop diseases, and environmental and ecosystem degradation. Fighting insect pests in farms using inorganic inputs is costly for small farmers to afford and seems ineffective in monitoring pests (Misango et al., 2022; Nicolopoulou-Stamati et al., 2016; Sharma & Singhvi, 2017). Thus, farmers still rely on less costly and traditional means like ash, lime, handpicking and burning infected plants, plant extracts, sawdust/pepper mixture, and intercropping to fight pests (Kassie et al., 2018; Kumela et al., 2019; Midega et al., 2015; Misango et al., 2022). In extreme cases, yield loss associated with resistant pests can amount to 88 percent to 100 percent.

The importance of bringing less expensive, climate-resilient, and environmentally friendly agricultural solutions to combat farm disease and pests was made clear by taking all those concerns into account. The Push-Pull Technology (PPT) is one of the recently developed technology to reduce pest occurrence and boost crop productivity (Abdi et al., 2015;

Ntawuruhunga et al., 2016). The factors influencing the adoption of PPT as well as its impact on food security are examined in the literature (Misango et al., 2022; Ntawuruhunga et al., 2016; Nyangau et al., 2017).

This paper is motivated by the implementation of a climate change resilient-innovation "Push-Pull Technology (PPT)" developed by the International Centre of Insect Physiology and Ecology as one of the alternative and nature-based solutions with lower costs for sustainable Integrated Pest Management practices to improve cereal yield and food security in Africa while preserving biodiversity and ecosystem. We examine the impact of adopting PPT, farmers' knowledge about PPT, and attitudes toward PPT on cereal yield and household food security.

The PPT farming is an intercropping system of cereal crops, especially maize, with a fodder legume called *"Desmodium"* that produces a bad smell to "*Push"* away pests and generate bad germination. Then, the field plot is surrounded by perennial fodder grass called "*Napier grass or Brachiaria"* to "*Pull"* pests off the maize plants, thus the name '*Push-Pull.'* Desmodium plant is used as manure and provides soil fertility, while brachiaria grass is used as fodder for livestock and increases milk production.

This study uses the case of Rwanda, where the PPT was implemented in 2016. One District where this technology was implemented was passively selected, and a field survey of 319 small-scale cereal farmers randomly selected was organized. Among them, 175 have adopted the PPT, while 144 have not. From the survey data, we mainly measure farmers' knowledge of PPT, attitude toward PPT, PPT adoption duration, household food security (Household Dietary Diversity Score, Household Food Insecurity Access Scale, and Coping Strategy Index), and cereal yield. We also measure other farm and household variables.

This paper shows that the cereal yield increase significantly with an inceases in the duration of using PPT, farmer's knowledge about PPT, and attitude toward PPT. We also find a positive and statisticall significant direct impact of the duration of using PPT, farmer's knowledge about PPT, and attitude toward PPT on household food security. The estimated spillover effect of the duration of using PPT, farmer's knowledge about PPT, and attitude toward PPT on household food security through cereal yield is positive and statistically significant. We, therefore, conclude that enhancing PPT adoption is apt to improve cereal yield, leading to significantly greater food security. Our results imply that increasing the adoption of PPT should be regarded as a cornerstone of policies designed to improve cereal productivity and household food security.

This paper provides two essential contributions to the literature. First, certain studies document that food security is associated with PPT adoption (Abdi et al., 2015; Ntawuruhunga et al., 2016). We document that the direct impact of PPT adoption on food security estimated in the literature should be bias because the effect of some mediating factors, such as yield, would confound with estimated direct effect. We document that cereal yiled is a robust pathway that enables a greater impact of PPT adoption on improving household food security. Second, we theorize that forwarding-looking agricultural households seeking to increase cereal productivity and then improve their food security level would adopt PPT. Alternatively, the number of households with food insecurity will significantly reduce as the number of households adopting PPT increases. Therefore, the examined pathway predicts a strategic shift from food insecurity to food security for households adpting PPT.

The remainder of this paper is organized as follows. Section 2 presents the related literature. In Section 3, we discuss the data, describe the construction of the variables of major interest, and present estimation methods. In Section 4, we present empirical results. Section 5 discusses the results and Section 6 concludes.

2. Literature

Agriculture is essential to developing countries' economic growth, poverty reduction, and food security (Muriithi et al., 2018). The World Bank Annual (2011) reports that the agriculture sector shares 33 percent of the Gross Domestic Product (GDP) and hires 60 percent of the labor force in the SSA. However, the global food demand is estimated to grow by 60 percent by 2050, mainly caused by 2.5 folds population growth which will triple the global cereal demand (Ittersum et al., 2016). Consequently, this global increase in cereal demand is estimated to increase food insecurity risks in Sub-Saharan Africa (SSA) (Ittersum et al., 2016).

Although several studies tried to understand the issues associated with low cereal productivity and a growing food insecurity risks in SSA, the agricultural sector faces challenges that impede productivity and food security and, slow sustainable growth in SSA countries (Kassie et al., 2018). In Eastern Africa, cereal crops are attacked by dangerous pests, including stemborer, Fall Armyworm (FAW), and Striga weed. Stemborer and FAW can induce maize production loss of 37 and 80 percent per year, respectively (Day et al., 2017; Khan et al., 2008; Misango et al., 2022; Kumela et al., 2019; Nyukuri et al., 2014). In extreme cases, yield loss associated with cereal pests can amount to 88 percent to 100 percent (Midega, Bruce, Pickett, Pittchar, et al., 2015; Muriithi et al., 2018).

For the past few years, the emergence of pests and diseases prompted a record increase in the use of fertilizers, pesticides, and insecticides as farming inputs to mitigate those threats and improve crop yield. However, such usage of inputs is associated with high costs, pest-resistant and less friendly to the environment and ecosystem (i.e., harmful to humans, animals, and soil) (Misango et al., 2022; Nicolopoulou-Stamati et al., 2016; Sharma & Singhvi, 2017). As a result, to suppress cereal pests, farmers still depend on less costly and traditional means like ash, lime, handpicking and burning infected plants, plant extracts, sawdust/pepper mixture, and intercropping (Kassie et al., 2018; Kumela et al., 2019; Midega, Bruce, Pickett, & Khan, 2015; Misango et al., 2022).

Despite earlier adopted practices, the resistance of cereal pests intrigued the urgency of finding more effective solutions to those problems. As a response, over 20 years ago, the International Centre of Insect Physiology and Ecology developed a "Push-Pull" Technology (PPT) as one of the sustainable Integrated Pest Management practices to mitigate pests significantly. The PPT farming is an intercropping system of cereal crops, especially maize, with a fodder legume called *"Desmodium"* that produces a bad smell to "*Push"* away pests and generate bad germination (Misango et al., 2022). Then, the field plot is surrounded by perennial fodder grass called "*Napier grass or Brachiaria"* to "*Pull"* pests off the maize plants, thus the name '*Push-Pull'* (Khan et al., 2014; Muriithi et al., 2018). Desmodium plant is used as manure and provides soil fertility, while brachiaria grass is used as fodder for livestock and increases milk production (Chepchirchir et al., 2017; Kassie et al., 2018; Nyangau et al., 2017).

In order to reduce cereal pests, boost agricultural output, and improve food security in Africa, the PPT farming system has been proposed (Muriithi et al., 2018). The experience shows that PPT raises yields, enriched soil fertility, and high-quality fodder, reduced the use of inorganic inputs (Chepchirchir et al., 2017; Kassie et al., 2018, 2018; Kumela et al., 2019). The adoption and perception of the guaranteed advantages by farmers, the empowerment of farmers' knowledge in pest monitoring, and follow-up evaluations are still key factors in the PPT system's performance (Leser, 2013; Misango et al., 2022).

Since the introduction of PPT in Rwanda (in 2017) very few studies have examined the level of adopting PPT and its effect on productivity (Misango et al., 2022; Ntawuruhunga et al., 2016) but, to the best of our knowledge, no study was undertaken to examine it impact on household food security in Rwanda. This apaper relates to works exploring the impact of newly developed agricultural technologies on productivity and food security.

3. Empirical Strategy

We use data obtained from a field survey carried out in 2021 in Nyagihanga Sector of the Gatsibo District, the PPT's benchmark site in Rwanda. This study area was purposively selected based on the existence of previous efforts of PPT implementation and the dominance of pests in maize crops. Gatsibo Districts, located in the eastern province, is a region that grow maize at 77.1 percent (NISR, 2018). The questionnaire used for data collection is structured into 13 modules to produce data regarding household and farm characteristics, cereal production and marketing, knowledge and utilization of PPT, social capital and networks, credit access, and livelihood measures including food security and income. The surey questionnaire was administrated to 319 households growers of Maize, who were systematically selected from the list of households growing maize in Nyagihanga Sector.

3.1. Proxies for PPT Adoption

The empirical analysis in this paper relies on PPT adoption duration, knowledge about PPT, and attitude toward PPT as proxies for PPT adoption.

PPT adoption duration – The number of years a household has been using PPT, that is the difference between the year of the survey (2021) and the year when PPT was adopted.

Knowledge of PPT – This study uses Abdi et al. (2015a)'s nine knowledge score questions as in Table 1 to measure the smallholder farmers' knowledge of PPT. The knowledge score is obtained by computing the arithmetic average for the knowledge score questions for each observation in our sample.

Attitude toward PPT – The farmer's attitudes toward PPT is measured based on the Likert scale (1932)'s approach. This approach is built on fifteen statements with 5 choice options as in Table 2. Following the literature (Abdi et al., 2015a; Chege et al., 2013a; Nyangau et al., 2017; Zumbo & Ochieng, 2002). Those options are transformed into a 2-scales format with 1 combining 1 & 2 and 0 taking 3 & 4 & 5 so that 1 and 0 represent positive and negative attitudes, respectively. The attitude score is then obtained by computing the arthimetic average for the attitude score questions for each observation in our sample.

3.2. Proxies for Outcome Variables

Cereal Yield – The cereal yield is measured as the ratio of cereal production per hectare.

Household Dietary Diversity Score (HDDS) – The HDDS is a food security indicator that measures dietary diversity in terms of food access and availability at the household and community level (Kennedy et al., 2010). The HDDS is a sum of food groups or food types consumed and counts the number of days a household consumed such types during a certain reference period for a week ago. For this study, there are 17 food groups consumed seven days ago. Those groups include cereals (maize, wheat, and sorghum); vitamin-A-rich vegetables and tubers; white tubers and roots; dark green leafy vegetables; other vegetables (tomato, onion, eggplant, and wild vegetables); vitamin-A-rich fruits; other fruits; organ meat /(iron-rich); flesh meats; eggs; fish; legumes, nuts, and seeds; milk and milk products; oils and fats; red palm products; sweets and spices, condiments, and beverages. Following the three phases outlined by Kennedy et al. (2010), we constructed the HDDS. By grouping foods with comparable qualities, we first construct food groupings, reducing the original 17 to just 12. Second, by adding together the 12 groups that families consume (with values ranging from 0 to 12), we produce the HDDS variables with 0 or 1 values. The average HDDS, which is the total HDDS divided by the number of households, can then be calculated.

Household Food Insecurity Access Scale (HFIAS) – HFIAS is defined as a measure of the degree to which a household experienced food insecurity for a period of the past 30 days or months ago (Coates et al., 2007). HFIAS is a scale that measures the frequency of incidents of food insecurit; it is used to assess the state of household food security (Swindale & Bilinsky, 2006). To compute HFIAS, this study uses the method suggested by Coates et al. (2007).

Coping Strategy Index (CSI) – The CSI counts the frequency or number of days (0–30) when a household used a strategy or action because there wasn't enough food. CSI is used to track how sensitive or responsive families are to food shocks in terms of the quick answers or strategies they employ to deal with food insecurity scenarios. A lack of access to enough food or a food shortage are both examples of a food shock (Maxwell & Caldwell, 2008). The CSI is a count variable that measures the frequency of times a household has felt food insecure. The steps of (Maxwell & Caldwell, 2008) are followed in this study to calculate the CSI. Prior to doing anything further, we create severity weights for coping strategies based on the frequency score out of 30 (i.e., assign 1 for all less severe, 2 for least, and 4 for most severe methods). The frequency scores are then multiplied by the severity weights that have been applied to each question and added up to the results for each technique.

3.3. Candidate exogenous instruments

Training on PPT and the number PPT training attended ─ We assume that training on PPT and the number of training offered is independent of the household's decision to improve cereal productivity and food security. Perhaps, household members are more likely to attend trainings offered close to their homes or trainings with insentives to attend it. Each attended training would improve the household's awareness about the PPT which can subsequently affect cereal yield toward food security. Moreover, households who attend many trainings on PPT are perhaps more likely to receive belief-changing information about about the use of PPT relative to households who attend few trainings on PPT. Consequently, the selected candidate instruments have the potential for improving the household's level of using PPT, cereal yield, and household food security concurrently.

3.4. Estimation Methods

To investigate the impact of PPT adoption on cereal, we estimate the following cross-sectional regression model using ordinary least squared (OLS):

$$CY_i = \alpha + \beta^{PPT \rightarrow CY} PPT_i + \gamma_j \sum X_{ij} + u_i, \quad (1)$$

where CY_i denotes the outcome variable for household i's cereal yield, PPT_i represents the PPT adoption measured by PPT adoption duration, knowledge about PPT, and attitude toward PPT for household i, $\beta^{PPT \rightarrow CY}$ indicates the impact of PPT adoption on cereal yield by the household i, X_j is a vector of j control regressors included in the regression to reduce the impact of omitted variable bias on our estimates (controls are described in Table 1, Panel B), γ_j represents the influence of each control regressor on the outcome variable, and u_i denotes the error term. Results obtained with Eq. 1 are reported in Table 2.

Moreover, we estimate the direct impact of cereal yield and PPT adoption on household food security using the econometric specification in Eq. 2. Equation 2 is estimated using the Poisson regression estimator. HFS_i denotes the outcome variable for household i's food security, (which is assessed by Household Dietary Diversity Score, Household Food Insecurity Access Scale, and Coping Strategy Index), CY_i represents cereal yield for household i, PPT_i represents the PPT adoption measured by PPT adoption duration, knowledge about PPT, and attitude toward PPT for household i. $\beta^{CY \rightarrow HFS}$ indicates the impact of cereal yield on food security for household i, $\beta^{PPT \rightarrow HFS}$ indicates the impact of PPT adoption on food security for household i, X_j is a vector of j control regressors to reduce the impact of omitted variable bias on our estimates (controls are described in Table 1, Panel B), γ_j represents the influence of each control regressor on the outcome variable, and u_i denotes the error term. Results obtained with Eq. 2 are reported in Table 3, Panel A.

$$HFS_i = \alpha + \beta^{CY \rightarrow HFS} CY_i + \beta^{PPT \rightarrow HFS} PPT_i + \gamma_j \sum X_{ij} + u_i, \qquad (2)$$

As the estimated direct impact of PPT adoption on household food security is more likely to be biased, due to other counfounding factors, we implement a two-stage linear regression analysis to investigate the spillover effects of PPT adoption on household food security through cereal yield. First, by using coefficients in Table 2, Panel A, estimated from Eq. 1 using OLS, we predict cereal yield as function of PPT adoption. Second, we use the predicted cereal yield , CY_i^*, to obtain the impact of PPT adoption on the household food security mediated by cereal yield. The following cross-sectional regression model, Eq. 3, applied to evaluate the effect of proposed spillover effect is estimated using Poisson regression estimator. HFS_i denotes the outcome variable for household i's food security, X_j is a vector of j control covariates described in Table 1, Panel B, and the coefficient $\beta^{CY^* \rightarrow HFS}$ measures the spillover effect of PPT adoption on household food security via cereal yield.

$$HFS_i = \alpha + \beta^{CY^* \rightarrow HFS} CY_i^* + \gamma_j \sum X_{ij} + u_i, \qquad (3)$$

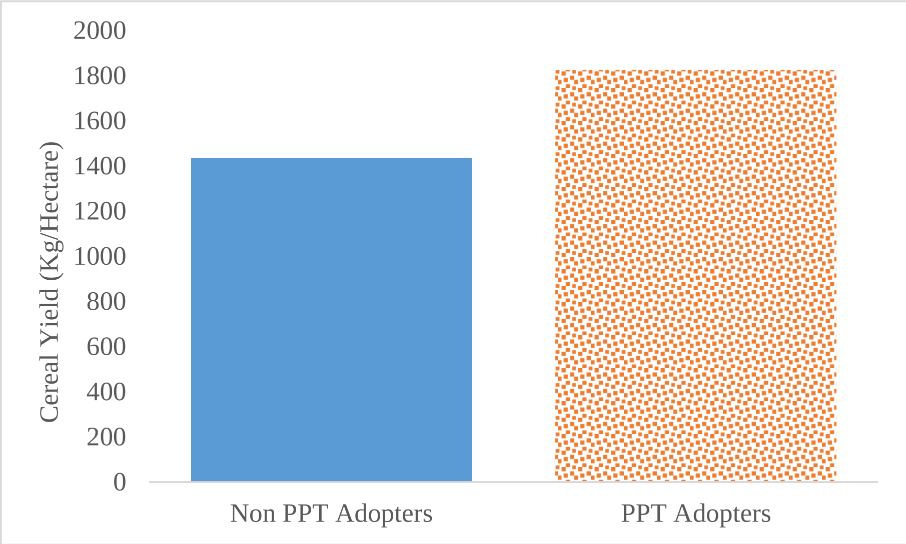
4. Results

Table 1 presents descriptive statistics – mean, standard deviation, minimum and maximum values – for the major variables. Figure 1 shows the mean difference of cereal yield between PPT adopter households and non-PPT adopter households. Although, Figure 1 predicts a higher cereal yield among PPT adopter households when compared to non-PPT adopter households but the mean difference is not statistically significant. Figure 2 shows the mean difference of proxies of household food security between PPT adopter households and non-PPT adopter households. This figure predicts a higher food security among PPT adopter households when compared to non-PPT adopter households and the mean difference is statistically significant. Notably, figures 1 and 2 shows that adopting PPT typically would relate to household food security.

Table 1. Descriptive Statistics

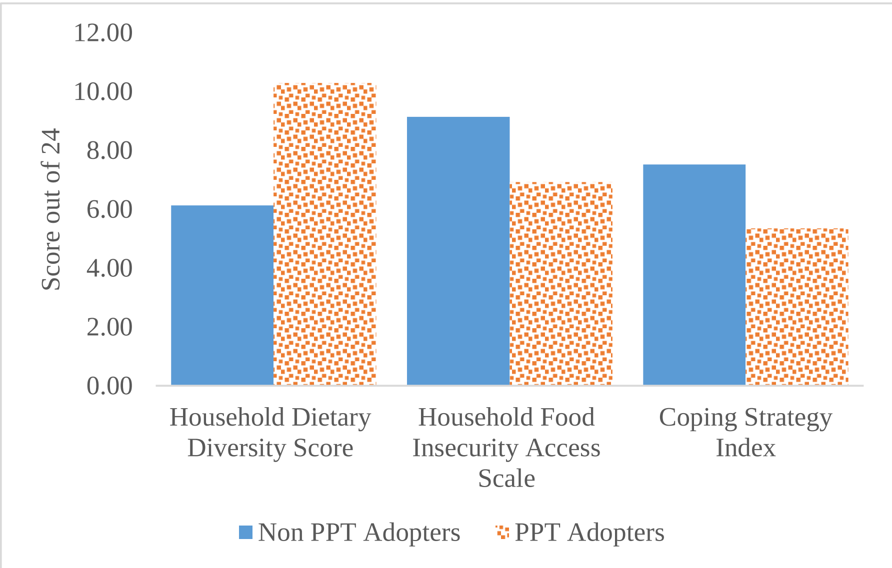
	Mean (1)	Std. Dev. (2)	Minimum (3)	Maximum (4)
Panel A. Major variables				
Cereal yield	1649.62	2725.18	0.00	27922.22
PPT adoption duration	1.81	2.16	0.00	5.00
Knowledge about PPT	0.72	0.35	0.00	1.69
Attitude towards PPT	0.28	0.28	0.00	1.10
Household Dietary Diversity Score	8.41	4.30	0.00	24.00
Household Food Insecurity Access Scale	8.92	6.07	0.00	27.00
Coping Strategy Index	32.27	31.72	0.00	122.40
Panel B. Control Covariates				
Gender of the household head	0.81	0.40	0.00	1.00
Credit Access	0.25	0.44	0.00	1.00
Age of the household head	48.31	12.01	22.00	84.00
Distance extension services	5.21	9.48	0.10	120.00
Capacity of extension officers	0.46	0.50	0.00	1.00
Years lived in village	27.27	17.93	1.00	84.00
No education level	0.17	0.38	0.00	1.00
Primary education level	0.60	0.49	0.00	1.00
Secondary edducation level	0.06	0.24	0.00	1.00
Communication items	0.60	0.66	0.00	4.00
Livestock of the household head	1.13	1.51	0.00	20.00
Land size	49.82	87.92	1.00	500.00
Off farm income	33,883.08	89,959.82	0.00	500000.00
Farm income	44,536.22	110,465.80	1.00	1,100,000.00

Figure 1. Cereal Yield by PPT Adoption



Notes: The figure compares cereal yield among PPT adopter households and non-PPT adopter households. The t-statistic for mean difference between PPT adopters and non-PPT adopters is -1.27. With these t-statistic, the null hypotheis that the mean difference between the two groups is not statistically significant is accepted.

Figure 2. Household Food Security by PPT Adoption



Notes: The figure compares household food security among PPT adopter households and non-PPT adopter households. The t-statistic for mean difference between PPT adopters and non-PPT adopters is -10.490, 3.610, and 3.070 for Household Dietary Diversity Score, Household Food Insecurity Access Scale, and Coping Strategy Index, respectively. With these t-statistic, the alternative hypotheis that the mean difference between the two groups is statistically significant is accepted.

4.1. Impact of PPT Adoption on Cereal Yield

Table 2 evaluates the impact of adopting PPT on cereal yield. Column 1, presents results for ordinary least squares (OLS). From the preliminary results in Column, we generally observe that the impact of all three measures of PPT adoption (PPT adoption duration, knowledge about PPT, and attitude towards PPT) on cereal yield is positive and statistically significant. Columns 1.1 and 1.3 show that PPT adoption duration and positive attitude towards PPT adoption significantly ($\alpha = 1\%$) improve cereal yield among adopter households. Columns 1.2 show that knowledge about PPT significantly ($\alpha = 5\%$) improve cereal yield among adopter households. An increase of a one-year in using PPT is likely to increase cereal yield by 4.71 percentage points. Also, an increase of a one-unit score (out of 24) in the household's knowledge about PPT and attitude towards PPT is likely to increase cereal yield by 1.37 and 1.65 percentage points, respectively.

Although these results in Column 1 are interesting, they need to be interpreted with caution due to bias arising from potential endogeneity and thus may not isolate the causal impact of PPT adoption on cereal yiled. The literature documents several factors, not controlled in this parer, which significantly predict cereal yiled. Theoretically, an increase in cereal yield caused by other factors not controlled in this paper may also explain the households' decision to adopt PPT.

To check whether these estimates are robust to potential endogeneity, we use instrumental variable (IV) estimation techniques using the candidate instruments proposed earlier and test the sensitivity of the preliminary results to different assumptions about endogeneity. Moreover, the variables used to construct a proxy for PPT adoption do not capture a household's risk preferences and management. Consequently, the household's PPT adoption may depend on other endogenous factors, such as time preferences and belief-changing information to manage pests and cereal diseases for better yield. Thus, using IV estimation techniques not only allows us to manage the issue of potential reverse causality but also helps us to address possible omitted variable bias.

The estimated IV results in Table 4, Column 2, are consistent with the preliminary results in Column 1. We also observe that the endogeneity assessment increases the magnitude of the impact of the PPT adoption effect on cereal yield. More specifically, we observe that an increase of a one-year in using PPT is likely to increase cereal yield by 6.34 percentage points. Also, an increase of a one-unit score (out of 10) in the household's knowledge about PPT and attitude towards PPT is likely to increase cereal yield by 3.77 and 1.70 percentage points, respectively.

From the preliminary results and results after addressing the issue of potential endogeneity in Table 2, we generally observe that the impact of all three measures of PPT adoption (PPT adoption duration, knowledge about PPT, and attitude towards PPT) on cereal yield is positive and statistically significant.

4.2. Mechanism for Improving Household Food Security

So far, we have tested whether adopting PPT has a nontrivial impact on cereal yield. In this section, we evaluate whether PPT adoption's spillover effect on household food security through improvement in cereal yield is positive and statistically significant. Our theoretical intuition is based on three viewpoints. First, estimating the direct effect of PPT adoption on household food security may be misleading because household food security among agricultural households is more related to crop yield than the technology used to get the yield. Second, the adoption of agriculture technology with the potential of improving crop yield, that technology would impact household food security through yield. Third, it is well documented that yield is one of the major determinants of food security. Indeed, we expect that adopting PPT increases cereal yield, thereby improving the household's food security.

In Table 3, Panel A, we start by examining the direct impact of adopting PPT on household food security. Our initial results in Column 1 show that PPT adoption duration, knowledge about PPT, and positive attitude towards PPT adoption significantly ($\alpha = 1\%$) improve Household Dietary Diversity Score. Results in Column 2 show that PPT adoption duration significantly ($\alpha = 1\%$) reduce Household Food Insecurity Access Scale. Results in Column 3 show that PPT adoption duration and knowledge about PPT significantly ($\alpha = 1\%$) reduce the household Coping Strategy Index. However, the established direct effect can bear several criticisms because other factors may confound this documented direct impact.

To test the proposed mechanism, we implement a two-stage Poisson regression analysis. The first stage results (Table 2, Panel A) estimate the marginal effects of adopting PPT on cereal yield. We observe that a cross-section total marginal effect of a 1 percentage point increase in PPT adoption duration, knowledge about PPT, and attitude about PPT leads to an increase of 0.44, 1.39, and 1.50 percentage points in cereal yield. We then test whether the estimated marginal effects translate into economically meaningful outcomes regarding the household's food security.

The second-stage results are presented in Table 3, Panel 2. Results show that the estimated spillover effects for Household Dietary Diversity Score are positive and robust while they are negative and robust for Household Food Insecurity Access and Coping Strategy Index. These findings confirm our theoretical intuition that adopting PPT increases cereal yield, which in turn improves the household food security. More specifically, our findings document that the total effect of the assessed mechanism is larger for improving Household Dietary Diversity Score.

Table 2. Impact of PPT on Cereal Yield

Dependent Variable: Cereal Yield (log)	Linear Regression Estimates (1)			Instrumental Variable Estimates (2)		
	(1.1)	(1.2)	(1.3)	(2.1)	(2.2)	(2.3)
Panel A. Less Complete Model						
PPT adoption duration	0.439**			0.497*		
	(0.173)			(0.276)		
Knowledge about PPT		1.385**			3.080**	
		(0.584)			(1.526)	
Attitude towards PPT			1.502**			3.512**
			(0.690)			(1.704)
Constant	5.722***	5.321***	5.705***	5.679***	4.440***	5.257***
	(0.228)	(0.374)	(0.235)	(0.242)	(0.804)	(0.404)
Observations	319	319	319	319	319	319
Prob> chi2	0.011	0.018	0.029	0.079	0.044	0.039
R-squared	0.020	0.013	0.017	0.019	.	.
Root MSE	2.418	2.425	2.421	2.411	2.442	2.451
Anderson-Rubin chi2(10) [p-value]				8.804	7.841	0.651
				[0.551]	[0.644]	[0.420]
Basmann F(10, 307) [p-value]				0.847	0.755	0.645
				[0.583]	[0.673]	[0.423]
Control covariates	No	No	No	No	No	No
Panel A. More Complete Model						
PPT adoption duration	0.471***			0.634**		
	(0.160)			(0.287)		
Knowledge about PPT		1.369*			3.769**	
		(0.723)			(1.640)	
Attitude towards PPT			1.654***			1.699*
			(0.577)			(0.919)
Constant	6.818***	6.537***	6.856***	6.673***	5.311***	6.846***
	(0.875)	(0.715)	(0.666)	(0.768)	(1.119)	(0.754)
Observations	319	319	319	319	319	319
Prob> chi2	0.002	0.224	0.002	0.107	0.114	0.154
R-squared	0.064	0.055	0.062	0.061	0.018	0.062
Root MSE	2.409	2.42	2.41	2.359	2.412	2.358
Anderson-Rubin chi2(10) [p-value]				7.093	6.445	8.592
				[0.717]	[0.777]	[0.573]
Basmann F(10, 307) [p-value]				0.656	0.596	0.795
				[0.765]	[0.817]	[0.634]
Control covariates	Yes	Yes	Yes	Yes	Yes	Yes

Notes. In panels A to B, the dependent variable is cereal yield in log. Column 1 reports ordinary least squares estimates. Column 2 reports limited-information maximum likelihood estimator results. Robust standard errors are in parentheses. Significant at ***1%, **5%, and *10%. The table also reports Anderson-Rubin and Basmann tests. Both tests accept the null hypothesis that the used instruments are valid. All regressions in Panel B (for more complete model) control for covariates as described in Table 1, Panel B.

Table 4. Impact of PPT on Household Food Security

	Household Dietary Diversity Score			Household Food Insecurity Access Scale			Coping Strategy Index		
	(1)			(2)			(3)		
Panel A. Direct Impact of PPT Adoption on Household Food Security									
logyield_Cereal_w	0.013	0.026*	0.019**	-0.016	-0.020	-0.019	-0.022	-0.022	-0.025
	(0.009)	(0.014)	(0.009)	(0.016)	(0.018)	(0.017)	(0.020)	(0.019)	(0.019)
logPPT_adoption_duration_new2_1	0.404***			-0.146***			-0.162***		
	(0.025)			(0.038)			(0.062)		
logKnowledge_score_w		0.790***			-0.298			-0.874***	
		(0.125)			(0.210)			(0.285)	
logAttitude_score_w			1.098***			-0.283			-0.276
			(0.123)			(0.174)			(0.306)
Constant	1.720***	1.624***	1.820***	2.078***	2.128***	2.037***	4.103***	4.389***	4.058***
	(0.127)	(0.159)	(0.152)	(0.217)	(0.265)	(0.181)	(0.303)	(0.329)	(0.300))
Observations	319.000	319.000	319.000	319.000	319.000	319.000	319	319	319
Prob>chi-2	0.000	0.000	0.000	0.002	0.000	0.043	0.000	0.000	0.000
Pseudo R-squared	0.161	0.066	0.103	0.036	0.028	0.028	0.119	0.133	0.110
Control covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel B. Spillover effect of PPT Adoption on Household Food Security through Cereal Yield									
Creal yield predicted with duration	0.936***			-0.351***			-0.392**		
	(0.056)			(0.103)			(0.163)		
Creal yield predicted with knowledge about PPT		0.600***			-0.235*			-0.648***	
		(0.101)			(0.136)			(0.203)	
Creal yield predicted with attitude towards PPT			0.754***			-0.209**			-0.215
			(0.083)			(0.103)			(0.169)
Constant	-3.547***	-1.410**	-2.352***	3.977***	3.250***	3.098***	6.197***	7.683***	5.110***
	(0.313)	(0.655)	(0.485)	(0.662)	(0.859)	(0.672)	(1.042)	(1.190)	(1.058)
Observations	319	319	319	319	319	319	319	319	319
Prob>chi-2	0.000	0.000	0.000	0.033	0.019	0.149	0.000	0.000	0.002
Pseudo R-squared	0.160	0.062	0.101	0.034	0.025	0.025	0.116	0.131	0.106
Control covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: In panels A to B, each column (columns 1 to 3) represents an outcome variable for household food security, Household Dietary Diversity Score, Household Food Insecurity Access Scale, Coping Strategy Index, respectvely. Both panels report Poission regression estimates. In Panel B, the independent variable of interest is the household's predicted cereal yield. This variable is predicted separately using the household's PPT adoption duration, knowledge about PPT, and attitude towards PPT without other controls (the predictor estimates are reported in Table 3, Panel A for less complete model). Panel B reports the results of the second stage of two-stage Poision regression. Robust standard errors are in parentheses. Significant at ***1%, **5%, and *10%. All regressions in Panel B (for more complete model) control for covariates as described in Table 1, Panel B.

5. Discussion

The adoption of new agricultural technologies offers opportunities of improving agricultural productivity and food security. In agrarian economies, food security differences among households are often associated with the adoption of new agricultural technologies heterogeneity (some households are extremely less willing to adopt new agricultural technologies while others are more willing to adopt them). In this paper, we evaluate the impact of adopting PPT on cereal yield and household food security. We also examine whether yield is a robust mediating factor in achieving a greater impact of adopting PPT on household food security. Our key finding is that adopting PPT significantly improve cereal yiled, which in turn improve the household food security. This finding is consistent with the theory behind developimng new agricultural technologies and implies that adopting PPT is an important avenue for reducing hunger and food insecurity.

Our findings suggest that the adoption of PPT is a robust pathway to achieving a higher impact of cereal yiled on household food security. This finding implies that the number of households with food insecurity will reduce as the number households adopting PPT increases. Given that food insecurity is a cause of great concern in the modern economy, this implication is very important from a policy perspective. It shows that cereal yield mediated by PPT adoption is among the important factors with the potential of reducing food insecurity among households. Some other reasons can also explain the economic significance of the assessed pathway. Perhaps, PPT adoption and cereal yield concurrently improve with trainings on the use of new agricultural technologies.

Notably, one of the most difficult challenges that households face is balancing income with expenses. Households in developing countries are mostly inclined to rely on farm-income than off-farm income. This may explain why household with low agricultural productivity are the most exposed to povery and then food insecurity. Our findings suggest that households can reduce the likelihood of becoming poor, and thereby exposed to food insecurity, by taking advantage of adopting PPT. These findings also reiterate the importance of developing and offering PPT education and training programs to improve the average level of cereal yield and hence household income.

5.1. Limitations and Directions for Future Research

This study uses crossectional data for the 2021 year and applies crosssection analysis thechniques to address our research questions. However, this study would have conducted an impact evaluation if annual data would have been collected regularly for the last five years since PPT was exercised to get robust impact of drivers of the adoption of PPT and its robust effect on cereal yield and food security. For such evaluation, we would be able to apply scientific methods (i.e., Randomization Control Trials, Instrument Variables, Difference in Differences, Regression Discontinuity Design and Propensity Score Matching). Also, the used estimation of the effect of PPT adoption might suffer from issues rooted in the measurement of some explanatory variables which, in turn, might lead to less efficiency of the estimated relationship between the duration of PPT adoption and food security.

While this paper investigates the effect of adopting PPT on cereal yield and household food security, the adoptoption decision could be constrained by other social dimensions, which can inhibit households' willingness to adopt PPT. Given the limitations of this study it is not possible to explore the actual impact of adopting PPT on cereal yield and food security. Nevertheless, conducting a Randomization Control Trials would improve our knowledge on the impact of adopting PPT on cereal yield and household food security.

6. Concluding Remarks

The adoption of agricultural innovations or practices is one of the major factors improving agriculture productivity and livelihood of famers (Misango et al., 2022; Nyangau et al., 2017). However, the effectiveness of adopted agricultural innovations on productivity and the welfare of famers significantly varies depending on the technology to adopt and the society adopting it. Though there are several studies in the literature that explore the impact of agricultural innovations adoption on the socio-economic welfare of famers but the literature exploring the effect of adopting PPT is scant. Therefore, this study assesses the impact of adopting PPT on cereal yield and household food security.

This paper shows that adpting PPT has an economically significant impact on improving cereal yield and household food security. We found that cereal yiled is a robust pathway that enables a greater impact of PPT adoption on improving household food security. The examined pathway predicts a strategic shift from food insecurity to food security for households adpting PPT. Our results suggest that PPT might be one of the effective agricultural innovative technology to improve the welfare of cereal farmers, increase cereal availability at marketplaces, and household food security while preserve biodiversity and the ecosystem.

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Appendices

Table A1. Knowledge Score Questions

Knowledge Score Questions		Point Scales
1	Do you know the Stem/stalk borer?	(1 = Yes or 0 =No)
2	Have you seen a Stem/stalk borer on your farm?	(1 = Yes or 0 =No)
3	Do you know the Striga weed?	(1 = Yes or 0 =No)
4	Do you have Striga weed on your farm?	(1 = Yes or 0 =No)
5	Is Striga weed a constraint to crop production on your farm?	(1 = Yes or 0 =No)
6	Do you know the Fall armyworm (FAW)?	(1 = Yes or 0 =No)
7	Do you have a Fall armyworm (FAWon your farm?	(1 = Yes or 0 =No)
8	Is Fall armyworm (FAW) a constraint to crop production on your farm?	(1 = Yes or 0 =No)
9	Have you received training on PPT in the past 3 years	(1 = Yes or 0 =No)

Source: Author's construct following Abdi et al., (2015)

Table A2. Likert Scale Questions

	Likert scale questions	Point Scales
1	How effective is the PPT in control of Stem/stalk borer?	1 = Very effective; 2 = Somewhat effective; 3 = Less effective; 4 = Not effective; 5 = Do not know
2	How effective is the PPT in control Striga weed?	1 = Very effective; 2 = Somewhat effective; 3 = Less effective; 4 = Not effective; 5 = Do not know
3	How effective is the PPT in controlling Fall armyworm, (FAW)?	1 = Very effective; 2 = Somewhat effective; 3 = Less effective; 4 = Not effective; 5 = Do not know
4	How would you rate the stability of cereal production in PPT farming?	1 = Very unstable; 2 = Little unstable; 3 = Same; 4 = A little stable; 5 = Much stable.
5	How has the number of labor required in plowing changed with PPT farming?	1 = More labour; 2 = Same labour; 3 = Less labour; 4 = Do not know
6	How has the number of labor required in planting changed with PPT farming?	1 = More labour; 2 = Same labour; 3 = Less labour; 4 = Do not know
7	How has the number of labor required in weeding changed with PPT farming?	1 = More labour; 2 = Same labour; 3 = Less labour; 4 = Do not know
8	How has the number of required herbicides or insecticides changed with PPT farming?	1 = More labour; 2 = Same labour; 3 = Less labour; 4 = Do not know.
9	How has the quantity of insecticides changed with the PPT application?	1 = Increased; 2 = remained the same (no change); 3 = Decreased; 4 = Do not know
10	How has the quantity of Maize production changed with the PPT application?	1 = Increased;; 2 = remained the same (no change); 3= Decreased; 4 = Do not know
11	How has the quantity of Herbicide changed with the PPT application?	1 = Increased; 2 = remained the same (no change); 3 = Decreased; 4 = Do not know
12	How has the quantity of sorghum production changed with the PPT application?	1 = Increased; 2 = remained the same (no change); 3 = Decreased; 4 = Do not know
13	How has the quantity of fodder production changed with the PPT application?	1 = Increased; 2 = Remained the same (no change); 3 = Decreased; 4 = Do not know.
14	How has the fodder availability (no of months fodder is available) changed with the PPT application?	1 = Increased; 2 = Remained the same (no change); 3 = Decreased; 4 = Do not know.
15	How has the quantity of milk production changed with the PPT application?	1 = Increased; 2 = remained the same (no change); 3 = Decreased; 4 = Do not know

Source: Author's construct following Abdi et al., (2015) and Chege et al., (2013)