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Food security gains from the adoption of improved maize varieties among smallholder households in Uganda: A panel analytical framework

Ronald Walusimbi
Department of Environmental Economics, Institute of Environmental Systems Research, Behavioral Economics for the Environment, School of Business Administration and Economics, Osnabrück University, Germany. E-mail: ronald.walusimbi@uni-osnabrueck.de

Fredrick Bagamba
Department of Agribusiness and Natural Resource Economics (DANRE), Makerere University, Kampala, Uganda. E-mail: fbagamba2015@gmail.com

Brian Ogenrwoth
Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences (NMBU), Ås, Norway. E-mail: brian.ogenrwoth@nmbu.no

Racheal Mutiibwa
Department of Agribusiness and Natural Resource Economics (DANRE), Makerere University, Kampala, Uganda. E-mail: mutiibwaraquel@gmail.com

Jackline Bonabana*
Department of Agribusiness and Natural Resource Economics (DANRE), Makerere University, Kampala, Uganda. E-mail: jackline.bonabana@mak.ac.ug

* Corresponding author

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Abstract

This study investigated the food security effect of the adoption of improved maize varieties among farming households in Uganda using four waves of the Uganda National Panel Survey (UNPS) spanning the period 2013 to 2020. The panel data regression analysis using a recursive bivariate probit and a two-stage fixed-effects Poisson regression model that confirmed food security benefits among the adopting farmers, measured as the number of meals taken per day and food availability. Therefore, to widely enjoy the benefits from adoption, awareness of these benefits should be created among farmers by Uganda's Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and NGOs through the various development interventions targeting smallholder farmers.

Key words: fixed-effects Poisson, food availability, household welfare, number of meals, recursive bivariate probit

1. Introduction

The second of the United Nations' 17 Sustainable Development Goals (SDGs) for 2030 is to end hunger, achieve food security and improve nutrition, and to promote sustainable agriculture. However, food security continues to be a pressing global challenge. For instance, in 2022, over 735 million people worldwide were experiencing hunger due to food insecurity, with nearly 38% of these people residing in Africa (FAO *et al*. 2023). The agricultural sector still has a role to play in improving the food security status of farmers (Pawlak & Kołodziejczak 2020), particularly in Africa, where it supports up to 92% of rural households (Davis *et al*. 2017). One way to achieve this is through increased agricultural productivity. However, in most countries in Sub-Saharan Africa (SSA), agricultural productivity is almost half that of other low- and middle-income countries worldwide (Arslan *et al*. 2022). The current discussion points include the low adoption of improved technologies, such as improved maize varieties, despite the documented evidence of the benefits of such (Garbero & Marion 2018; Arslan *et al*. 2022). An improved maize variety refers to one whose performance has been enhanced through formal breeding programmes (Lyimo *et al*. 2014). Because the improved varieties of maize respond more strongly to other inputs like fertilisers, they yield more than the local varieties (Mutyebere *et al*. 2017). The resistance to diseases, high protein content, early maturity, resistance to lodging and other characteristics of improved varieties all contribute to their improved yield performance (CIMMYT 2022).

The food security effects of the adoption of improved maize varieties in terms of increased household consumption expenditure (Biru *et al*. 2020), household caloric acquisition (Muche *et al*. 2014) and maize yields (Wossen *et al*. 2017), among others, are well documented in Africa. However, little is known about the effect of adoption on the number of meals taken per day and food availability, which are important indicators of food security among smallholders. Moreover, the commonly used measures of food security, for example household caloric acquisition, do not take into consideration seasonal variations in food supply, which could have effects on the quantity (Waswa *et al*. 2021) and price of food (Bai *et al*. 2020). Household consumption expenditure as a measure of food security does not take into consideration whether the money spent translates into sufficient quantities of food for a household, and does not capture seasonal variations among producing households (Russell *et al*. 2018).

This study thus contributes to the available literature on the food security effect of the adoption of improved maize varieties (for example Bezu *et al*. 2014; Biru *et al*. 2020) by focusing on the effect of adoption on the number of meals taken per day and food availability. These two indicators of food security are chosen, given the documented positive outcomes of the adoption of improved technologies (such as maize varieties) on specifically two food security dimensions, namely availability and stability (Grote *et al*. 2021). Food availability refers to the ease of access to quality food in adequate quantities obtained through local production or from other countries through trade or donations (FAO 2006). Food stability, incorporating an element of time, is said to be achieved when the population does not risk losing access to food as a consequence of sudden shocks. Understanding the benefits of the adoption of improved maize varieties on food security through these dimensions will assist in shaping efforts geared towards improving livelihoods through productivity enhancement in Uganda, and in Africa as a whole.

The rest of this paper is structured as follows. Section 2 provides a brief literature review. Section 3 discusses the empirical framework used to determine the effect of the adoption of improved maize varieties on household food security, along with a discussion of the data sources and a description of the variables. Section 4 presents the descriptive statistics, empirical results and a discussion of them. The conclusions and policy recommendations are presented in Section 5.

2. Literature review

Several studies have been conducted to measure welfare gains from technology adoption. These studies have relied on diverse empirical methods. For example, Khonje *et al*. (2015) used propensity score matching (PSM) and endogenous switching regression (ESR) techniques to analyse the impact of the adoption of improved agricultural technologies on rural households' welfare. Other researchers, such as Ouma *et al*. (2014), relied on the generalised propensity score to determine the welfare impacts of technology adoption. However, adoption is endogenous (Lunduka *et al*. 2019) and could potentially suffer from selection bias as a result of the systematic selection of adopters by project implementers, or self-selection into adoption due to observable and unobservable characteristics (Garbero & Marion 2018). Hence, different researchers have employed various methods to control for endogeneity when studying technology adoption. For example, Sserunkuuma (2005) used the instrumental variable in a two-step approach. Other methods used to control for the endogeneity of adoption of improved maize varieties have included the Heckman selection model (Garbero & Marion 2018), the endogenous switching regression model (Khonje *et al*. 2015; Biru *et al*. 2020), the control function approach (Lunduka *et al*. 2019) and correlated random effects (Bezu *et al*. 2014). Mathenge *et al*. (2014) applied a fixed-effects two-stage least squares (FE2SLS) procedure. Empirically, this study deviates from the econometric methods used by the above studies to determine the effect of adopting improved maize varieties on household food security. It does so by using a two-stage fixed-effects Poisson (2SFEP) regression for the number of meals taken per day, and a recursive bivariate probit for food availability, as econometric models while dealing with endogeneity.

The adoption of improved maize varieties has been found to significantly affect farmers in several ways. For example, Biru *et al*. (2020) found a significant positive relationship between adoption and household consumption expenditure. Similarly, Bezu *et al*. (2014) found a significant relationship between the adoption of improved maize varieties and per capita own maize consumption, as well as per capita asset holdings. Other researchers found increased incomes associated with the adoption of improved maize varieties (Bezu *et al*. 2014; Khonje *et al*. 2018). In addition, improved maize seed has been found to increase maize yields, as well as reduce the incidence of poverty and food scarcity (Wossen *et al*. 2017). This study uses two key indicators of food security, viz. the number of meals taken per day, and food availability. Regarding the study area, a few studies have focused on Uganda (e.g. Kinuthia & Mabaya 2017; Garbero & Marion 2018). The study further builds on the earlier studies that focused on Uganda. However, by specifically focusing on maize farmers, this study differs from the one by Kinuthia and Mabaya (2017), who sought to analyse the effect of the adoption of agricultural technology on household welfare and classified adopters as farmers who planted improved seeds of any crop. In addition, the majority of studies, such as those by Kinuthia and Mabaya (2017) and Houeninvo *et al*. (2020), used cross-sectional data. Some of the few that used panel data to study the influence of technology adoption on welfare include Garbero and Marion (2018) and Biru *et al*. (2020). However, these studies relied on a short period to explore the effect of the adoption of improved maize seed on household welfare, which could not cater for the shifts in adoption status and the long-run effect of adoption on the households' welfare (Khonje *et al*. 2018). This study thus resolves this by using eight periods of data, constructed using seasonal data collected from the two agricultural seasons per year.

3. Empirical framework

During the analysis, a dummy variable was created for 'food availability' that took on a value of one if the household reported 'No' to experiencing a food shortage in the 12 months preceding the Uganda National Panel Survey (UNPS), and zero otherwise. The number of meals taken per day was recorded as a count variable during the UNPS, and utilised as such during analysis.

Following other studies, such as Bezu *et al*. (2014), Garbero and Marion (2018) and Biru *et al*. (2020), household food security (FS) was regarded as a function of technology adoption (i.e. improved maize varieties), household and location characteristics and the season of production. Then, let FS refer to the food security status of the household, measured as the number of meals taken per day and food availability:

$$FS = f(Im, H, L, S), \tag{1}$$

where *Im* refers to the adoption of improved maize varieties, *H* is a vector of household characteristics, such as the characteristics of the household head, household size, area under maize, input use and access to extension services, and *L* is a vector of location characteristics that include distance to input markets and region of residence for the maize-producing household. *S* is a vector of seasonal dummies from season 1 to season 8. The food security status of maize-producing households was conceptualised to be determined by the various factors specified in Equation (1).

3.1 Effect of adoption of improved maize varieties on the number of meals taken per day

Number of meals taken per day is a count variable. Therefore, to determine the effect of the adoption of improved maize varieties on the number of meals taken per day, a two-stage fixed-effect Poisson (2SFEP) regression was employed. In the first stage, the treatment variable (improved maize variety) was regressed against other covariates plus selected instruments, and a predicted residual was obtained. In the second stage, the effect of adoption was determined by regressing the number of meals taken per day against the improved maize varieties' adoption variable, plus other covariates. The predicted residual from the first-stage regression was included as a covariate while excluding the instruments. The predicted residual was included in the second-stage tests and controls for the endogeneity of improved maize adoption. Following Cameron and Trivedi (2009), the 2SFEP model is specified as below:

$$\mathrm{Im}_{it} = x_{it}'\delta_1 + Z_{it}'\delta_2 + \mu_{it} \tag{2}$$

$$y_{it} = \exp\left(\mathrm{dSeason}_t + \beta_1 \mathrm{Im}_{it} + x_{it}'\beta_2 + \omega_i + \widehat{u_{it}}\right), \tag{3}$$

where y_{it} is the number of meals taken per day for household i in season t. $\mathrm{dSeason}_t$ is a season dummy equal to one if that was the period of production, and zero otherwise. Im_{it} is a dummy variable indicating the adoption of improved maize varieties; it takes a value of one if a household i reported using improved maize seeds in season t, and zero otherwise. x_{it}' is a vector of explanatory variables, which include age, sex, read, non-farm business, on-farm employment, household size, maize area, inorganic fertilisers, pesticides and labour. Other factors include region dummies and season. β_1, β_2, δ_1 and δ_2 are parameters to be estimated. β_1 measures the effect of adoption on the number of meals taken per day. Z_{it}' are the instrumental variables, i.e. extension services and distance to inputs market in the first-stage regression. The selection of these instruments is based on the understanding that they both affect farmers' decisions to buy improved maize seed, and hence adoption, but with no direct effect on the number of meals taken per day. ω_i denotes the household fixed effects. μ_{it} is the random error term in the first-stage regression (Equation 2), whereas $\widehat{u_{it}}$ is its predicted residual included in the second-stage fixed-effects Poisson regression (Equation 3). The model was estimated following a two-step non-linear IV estimation approach, as detailed by Cameron and Trivedi (2009).

3.2 Effect of adoption of improved maize varieties on food availability

For the binary outcome of food availability in the presence of an endogenous binary variable of improved maize seed adoption, the study followed the econometric framework proposed by Carrasco (2001). According to Carrasco (2001), using a two-stage least squares (2SLS) regression approach would result in inconsistency with the statistical assumptions of the nonlinear discrete models, yet the alternative linear probability model is incompatible with the data. Thus, the recursive bivariate probit model for panel data was adopted as an empirical method for the dummy endogenous adoption variable with a binary outcome variable (food availability). The Wald chi-square test for correlation between the error terms of the treatment (Equation 4) and outcome equations (Equation 5) served as a formal test for endogeneity. Following Greene (2005), the model is specified as follows;

$$\mathrm{Im}_{it}^{*} = \alpha_{i2} + V_{it}^{\prime}\beta + Z_{it}^{\prime}\delta + \mu_{it}, \tag{4}$$

$$\mathrm{Avail}_{it} = \alpha_{i1} + \delta_1 \mathrm{dSeason}_t + V_{it}^{\prime}\partial + \gamma \mathrm{Im}_{it} + \varepsilon_{it}, \tag{5}$$

$$\text{where, } \mathrm{Im}_{it} = 1[\mathrm{Im}_{it}^{*} > 0], \tag{6}$$

$$\begin{pmatrix}\mu_{it}\\ \varepsilon_{it}\end{pmatrix} \sim N\left[\begin{pmatrix}0\\0\end{pmatrix}, \begin{pmatrix}1 & \rho\\ \rho & 1\end{pmatrix}\right].$$

Avail_{it} is an outcome indicator measuring food availability for household i in season t, which is equal to one if the household reported no food shortage in the last 12 months, and zero otherwise. $\mathrm{dSeason}_t$ and Im_{it} are as defined in Equation 3. $V_{it}^{\prime}$ is a vector of covariates that include sex, age, education, household size, maize area, region and season. $Z_{it}^{\prime}$ is a vector of instrumental variables, which are extension services and distance to inputs market. ε_{it} is the random error term in the outcome equation, whereas μ_{it} is the random error term in the treatment equation, which is normally distributed with a zero mean and a constant variance. α_{i1} and α_{i2} are the respective individual fixed effects in the outcome and treatment equations respectively. ∂, γ, β, δ_1 and δ are the vectors of the respective parameters to be estimated, with γ being the effect of the adoption of improved maize varieties on food availability for maize-producing households.

3.3 Data sources

Data for this study was collected using the household, agriculture and community modules administered to the selected households during the Uganda National Panel Survey (UNPS) (Uganda Bureau of Statistics [UBOS] 2020). The datasets comprised annual data collected over a period of 12 months for each wave. To collect accurate information for each of the two agricultural seasons, two visits to the same household were undertaken by the UNPS enumerators in the course of 12 months, with each visit covering six months. During the visits, respondents were asked for information on the last completed agricultural season and, where possible, some data on the ongoing agricultural season, such as seasonal input purchases and crops planted. For this study, data collected during the 2013/2014, 2015/2016, 2018/2019 and 2019/2020 UNPS waves was used to generate an eight-season unbalanced panel dataset with 8 003 household-season observations. The time dimension was a planting season and the observational unit was a household. In this particular study, farmers were classified as adopters if they reported having planted any improved maize variety in a particular planting season. Table 1 presents a description of the explanatory variables considered.

Table 1: Description of explanatory variables

Variable	Description	Type	Measurement
Age	Age of household head	Continuous	Completed years
Sex	Male-headed household	Dummy	1 if yes, 0 otherwise
Read	Household head can read and write	Dummy	1 if yes, 0 otherwise
Education	Household head educational attainment	Continuous	Number of years completed in school
Non-farm business	Household head owns a non-farm business	Dummy	1 if yes, 0 otherwise
On-farm employment	Household head has on-farm employment	Dummy	1 if yes, 0 otherwise
Household size	Number of household members	Count	Number of persons
Maize area	Total area under maize	Continuous	Acres
Inorganic fertilisers	Quantity of inorganic fertilisers used by the household in a season	Continuous	Kilograms
Pesticides	Quantity of pesticides used in a season	Continuous	Litres
Labour	Total labour used by the household in a season	Continuous	Total person-days
Extension services	Household access to extension services	Dummy	1 if yes, 0 otherwise
Distance to inputs market	Distance to the nearest inputs market in the parish	Continuous	Kilometres
Region	Region of residence for the household (Central, Eastern, Northern and Western)	Dummy	For each region, 1 if yes, 0 otherwise
Season	Season of production (1 to 8)	Dummy	For each season, 1 if yes, 0 otherwise

Source: UNPS 2013 to 2020 datasets

4. Results and discussion

4.1 Descriptive statistics

Figure 1 presents the distribution of surveyed households by region. According to the data, more maize producers were surveyed in the central region than in the other regions.

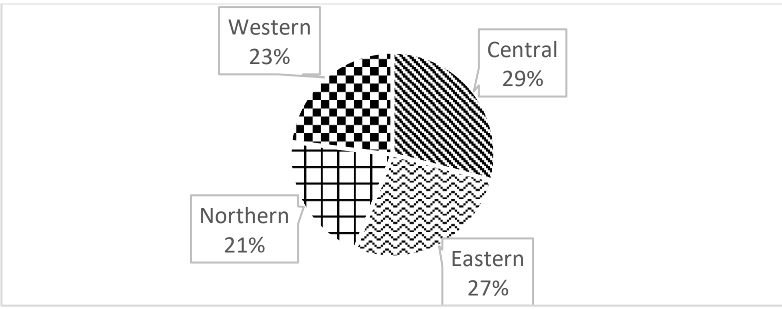

Figure 1: Surveyed maize-producing households
Source: Authors' computations based on UNPS 2013 to 2020 datasets

Figure 2 presents the adoption status by region. According to the data, the eastern region was leading, followed by the northern region, whereas the western region had the lowest percentage of adopters of improved maize.

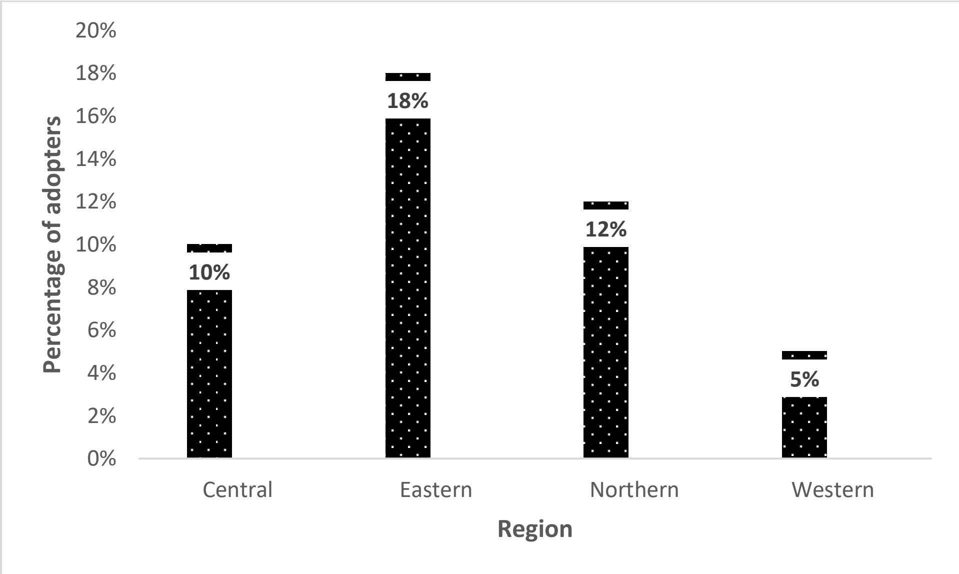

Figure 2: Adoption status by region
Source: Authors' computations based on UNPS 2013 to 2020 datasets

Figure 3 presents the distribution of adopters by season. According to the data, adoption status varied by season. In addition, season 1 had the highest percentage of adopters, whereas season 2 had the lowest across the eight seasons under consideration. Similar patterns in adoption status were identified by Garbero and Marion (2018), who noted that adoption is non-static but changes over time. They attribute this to the challenges farmers face in accessing improved maize seeds.

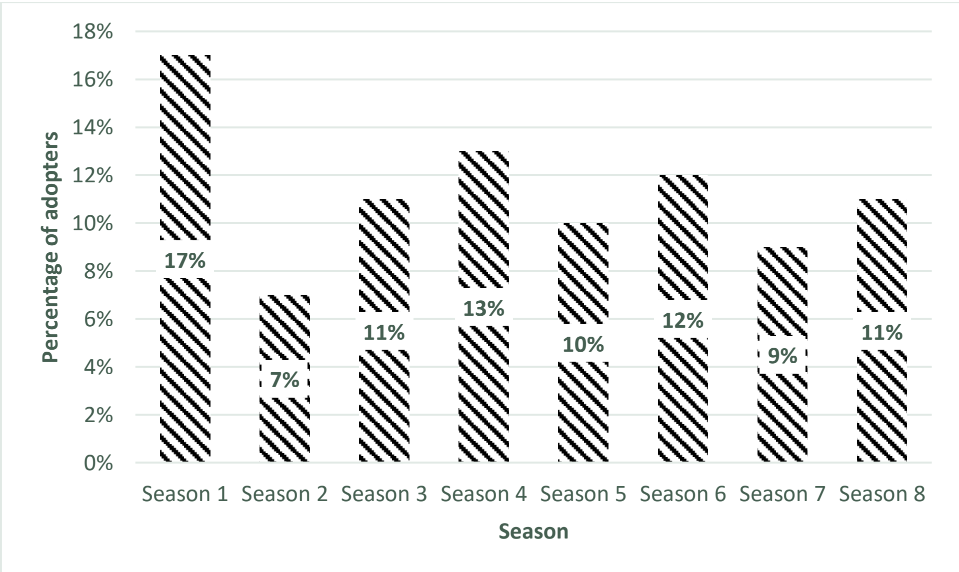

Figure 3: Adoption status by season
Source: Authors' computations based on UNPS 2013 to 2020 datasets

Table 2 presents summary statistics for selected variables of the study sample. According to the data, adopters of improved maize seed consumed more meals per day, had more male-headed households, more household heads who could read and write, and with more years of education. In addition, adopters of improved maize varieties had a higher proportion of heads employed on the farm as compared to non-adopters. Furthermore, adopting households had bigger household sizes, a bigger area under maize, and used a higher quantity of inorganic fertilisers compared to their counterparts.

Concerning accessing extension services, a larger proportion of adopting households accessed extension compared to non-adopters.

Table 2: Summary of descriptive statistics for selected variables used in the estimations

Variable	Pooled	Improved maize seed		
		Adopters	Non-adopters	
	Mean (SD)	Mean (SD)	Mean (SD)	p-value
Number of meals	2.55 (0.59)	2.63 (0.55)	2.53 (0.59)	0.000
Food availability (yes = 1)	0.82 (0.39)	0.82 (0.39)	0.82 (0.39)	0.988
Age (years)	47.22 (15.37)	46.44 (14.60)	47.32 (15.46)	0.116
Sex (male = 1)	0.69 (0.46)	0.73 (0.44)	0.68 (0.47)	0.002
Read (yes = 1)	0.75(0.43)	0.79 (0.41)	0.75 (0.44)	0.010
Education (years)	5.78 (4.05)	6.48 (3.99)	5.69 (4.04)	0.000
Non-farm business (yes = 1)	0.25 (0.44)	0.28 (0.45)	0.25 (0.43)	0.126
On-farm employment (yes = 1)	0.76 (0.43)	0.79 (0.41)	0.76 (0.43)	0.021
Household size (number)	6.02 (3.07)	6.34 (3.12)	5.98 (3.07)	0.002
Maize area (acres)	0.41 (1.35)	0.70 (2.90)	0.37 (0.98)	0.001
Inorganic fertilisers (kg)	2.54 (36.16)	5.47 (33.62)	2.16 (36.46)	0.007
Pesticides (litres)	0.83 (16.30)	1.95 (33.43)	0.68 (12.51)	0.191
Labour (total person-days)	96.58 (134.27)	100.31 (138.38)	96.10 (133.74)	0.457
Extension services (yes = 1)	0.16 (0.37)	0.26 (0.44)	0.15 (0.36)	0.000
Distance to inputs market (km)	5.86 (7.01)	5.55 (6.42)	5.90 (7.08)	0.146
N	8 003	910	7 093	

Note: SD means standard deviation
Source: Authors' computations based on UNPS 2013 to 2020 datasets

4.2 Empirical results

4.2.1 Effect of adoption of improved maize varieties on the number of meals taken per day

The results of a second stage for the 2SFEP regression are presented in Table 3. The Wald chi-squared statistic was significant at the 1% level, indicating the joint significance of the selected variables. In addition, the coefficient for the included residual predicted from the first-stage regression was significant at the 10% level, confirming the endogeneity of improved maize seed adoption, and thus justifying the use of instrumental variables to control for endogeneity. The relevance and overidentification of selected instruments were checked using Equations 2 and 3, where access to extension services was found to meet the relevance condition (Appendix 1).

According to the results in Table 3, the adoption of improved maize seed has a significant positive effect on the number of meals taken per day, at a 10% level of significance, with an increase of approximately 34% in the number of meals taken per day among adopters compared to non-adopters, all other factors kept constant. Other covariates with a significant effect on the number of meals taken per day include household size, maize area, labour (total person-days), and residence in the north. A log-transformed household size significantly increased the number of meals taken per day, by about 2% among maize-producing households at a 1% level of significance, all other factors held constant. On the other hand, a log-transformed area under maize reduces the number of meals taken per day among maize-producing households by approximately 4% at a 1% level of significance, keeping all other factors constant. Similarly, the log-transformed number of person-days for labour reduces the number of meals taken per day by approximately 1% at a 5% level of significance, ceteris paribus. Residing in the northern region significantly reduced the number of meals taken per day – by approximately 3% at a 5% level of significance – when compared to residing in the central region.

Table 3: Panel Poisson regression results for the number of meals taken per day

Variable	Coefficient (SE)	IRR (SE)
Adoption of improved maize seed (yes = 1)	0.294* (0.157)	1.342* (0.211)
Age (years)	-0.000 (0.000)	0.999 (0.000)
Sex (male = 1)	0.001 (0.008)	1.001 (0.008)
Read (yes = 1)	0.001 (0.010)	1.001 (0.010)
Non-farm business (yes = 1)	0.006 (0.008)	1.007 (0.008)
On-farm employment (yes = 1)	-0.014 (0.008)	0.986 (0.008)
Log Household size (number)	0.015* (0.008)	1.015* (0.008)
Log area maize (acres)	-0.040*** (0.015)	0.961*** (0.014)
Log inorganic fertilisers (kg)	-0.004 (0.005)	0.996 (0.005)
Log pesticides (kg)	0.000 (0.004)	1.000 (0.004)
Log labour (total person-days)	-0.005** (0.002)	0.995** (0.002)
Eastern region (yes = 1)	-0.018 (0.014)	0.982 (0.014)
Northern region (yes = 1)	-0.027** (0.011)	0.973** (0.011)
Western region (yes = 1)	0.011 (0.013)	1.011 (0.013)
Season 2 (yes = 1)	-0.016*** (0.006)	0.984*** (0.006)
Season 3 (yes = 1)	-0.025*** (0.009)	0.976*** (0.009)
Season 4 (yes = 1)	-0.017** (0.008)	0.983** (0.008)
Season 5 (yes = 1)	-0.005 (0.010)	0.995 (0.010)
Season 6 (yes = 1)	-0.003 (0.011)	0.997 (0.011)
Season 7 (yes = 1)	-0.030** (0.013)	0.970** (0.013)
Season 8 (yes = 1)	-0.032** (0.014)	0.969** (0.014)
Residual	-0.291* (0.157)	0.747* (0.117)
Observations	7 375	
Wald chi^2 (22)	115.26	P-value = 0.000

Note: Significance: *** = p < 0.01, ** = p < 0.05, * = p < 0.1. Robust standard errors are in parentheses, and SE means standard errors.
Source: Authors' computations based on the UNPS 2013 to 2020 datasets

4.2.2 Effect of adoption of improved maize varieties on food availability

The results of a recursive bivariate probit model are presented in Table 4. The Wald chi-square statistic is significant at a 1% level, indicating the joint significance of the selected variables. Furthermore, the correlation between the error terms of the treatment and outcome equations is statistically significant at a 5% level of significance, indicating that the adoption of improved maize varieties is endogenous and justifying the use of exclusion restrictions.

According to the results in Table 4, the adoption of improved maize varieties significantly increases the probability of food availability for maize-producing households, at a 1% level of significance when keeping other factors constant. Other explanatory variables with a significant effect on food availability include education, household size, and residence in the Eastern and Northern regions – all at a 1% level of significance, ceteris paribus.

Table 4: Estimates of a recursive bivariate probit model for food availability

Variable	Outcome model	Treatment model
	Food availability	Improved seed adoption
	Coefficient (SE)	**Coefficient (SE)**
Adoption of improved maize seed (yes = 1)	0.926*** (0.274)	
Sex (male = 1)	0.056 (0.038)	0.063 (0.044)
Age (years)	0.000 (0.001)	
Education (years)	0.027*** (0.005)	0.013*** (0.005)
Log household size	-0.173*** (0.032)	-0.013 (0.035)
Log area maize (acre)	-0.004 (0.058)	0.358*** (0.043)
Extension services (yes = 1)		0.334*** (0.048)
Log distance to inputs market (km)		-0.080*** (0.021)
Eastern region (yes = 1)	-0.239*** (0.049)	0.347*** (0.050)
Northern (yes = 1)	-0.284*** (0.047)	0.135** (0.057)
Western (yes = 1)	0.195*** (0.052)	-0.328*** (0.063)
Season 2 (yes = 1)	0.088 (0.060)	
Season 3 (yes = 1)	0.229*** (0.060)	
Season 4 (yes = 1)	0.137** (0.057)	
Season 5 (yes = 1)	0.360*** (0.069)	
Season 6 (yes = 1)	0.384*** (0.068)	
Season 7 (yes = 1)	0.293*** (0.066)	
Season 8 (yes = 1)	0.335*** (0.063)	
Constant	0.867*** (0.108)	-1.420*** (0.101)
N	7 634	
Wald chi-square (25)	611.220	P-value = 0.000
Wald test of rho = 0: Chi-square (1)	6.062	P-value = 0.014

Note: Significance: *** = p < 0.01, ** = p < 0.05, * = p < 0.1; Standard errors in parentheses.

4.3 Discussion of results

The results show a significant positive effect of the adoption of improved maize varieties on the number of meals taken per day and food availability. The positive effect could be an outcome of increased maize yields registered from the adoption of improved maize seed, as suggested previously by Garbero and Marion (2018) and Grote *et al*. (2021). This leads to improved food security for maize-producing households. The finding for the effect of adoption on the number of meals taken per day is comparable with an earlier finding by Bezu *et al*. (2014), who found a positive and significant relationship between improved maize seed and per capita own maize consumption. Similarly, the study finding of the effect of adoption of improved maize varieties on food availability is consistent with an earlier study by Wossen *et al*. (2017). The study findings emphasise the role of improved seed in enhancing the food security of maize-producing households through increasing yields.

The finding regarding the effect of household size on the number of meals taken per day suggests that households with more members consume more meals per day, and thus are more food secure. This could be attributed to the age composition of such households, with many members that often include children, teenagers and adults with varying activity levels and nutritional needs. This can contribute to an increase in the number of meals taken per day within these households to meet the energy and nutritional requirements of the different age groups. This finding of the study contradicts that of an earlier study by Bezu *et al*. (2014), who found a negative relationship between household size and own maize consumption. On the other hand, the negative effect of household size on food availability implies that an increase in household size reduces food availability among maize-producing households. This implies that, as household size increases, there will be more members to feed, which reduces the probability of food availability. The study result for household size and food availability agrees with an earlier finding by Bezu *et al*. (2014), but contradicts the finding by Biru *et al*. (2020).

The diverse effects of household size imply that, with more dependants, the number of meals consumed per day will increase, consequently reducing food availability within such households.

The negative effect of area under maize on the number of meals taken per day seems to suggest that, as farmland allocated to maize increases, the food security status of maize-producing households in terms of number of meals taken per day decreases. This could be due to reduced output from the increased maize area for a household (Noack & Larsen 2019). This finding contradicts an earlier one by Geffersa *et al*. (2022), who found a positive relationship between area allocated to improved maize varieties and household maize consumption. The result emphasises the role of an intensification strategy over extensification in increasing food security among farmers.

The negative effect of the total person-days on the number of meals taken per day suggests that, as the person-days for labour increase, the household will not be able to consume many meals on a given day. This could be due to the many mouths to feed as a result of the numerous persons, including hired individuals, who stay longer on the farm to provide labour for farm activities. In addition, the negative effect of total person-days points to reduced labour productivity, and thus inefficiencies among such households. With more labour than required, yet with low yields, the number of meals taken per day will be greatly reduced. This finding contrasts with that of Lunduka *et al*. (2019), who found a significant positive effect of total hired labour on total maize production as a food security indicator.

The finding regarding the effect of the education of a household head on food availability suggests that households with more educated heads will have improved food availability. This could be due to enhanced use of opportunities that may come up, for example making optimal use of resources such as improved maize varieties, hence the difference in food security level in terms of food availability for more educated household heads. This result is consistent with an earlier study by Sserunkuuma (2005).

Compared to residence in the Central region, the negative effects of residence in the Eastern and Northern regions on the number of meals taken per day and the probability of food availability, respectively, could be attributed to challenges experienced by farmers in these specific regions in accessing agricultural inputs, such as improved maize seeds required for production. This would curtail their yields, and thus their food security. This finding agrees with a study by Wichern *et al.* (2017). The varying effects of seasons on number of meals taken per day underscores the seasonal effect on production, and thus the food security of farming households.

5. Conclusions and policy recommendations

The findings of the study shed light on the role of the adoption of improved maize varieties in the food security of maize-producing households. According to the findings, the adoption of improved maize seeds has significant food security gains for maize-producing households in terms of the number of meals taken per day and food availability. This emphasises the role of improved maize varieties as a technology in enhancing the food security status of maize-producing households. However, the study finds heterogenous effects regarding the food security effect of household size. This study thus recommends that Uganda's Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and NGOs in the country should promote adoption by creating awareness of these benefits among farmers. Furthermore, the effect of household size on the food security of farming households needs to be explored more in future research by paying special attention to the age-dependency ratio.

Our research has some limitations regarding the indicators of food security chosen, which may suggest future research dimensions. For example, the dietary diversity of number of meals taken per day, and food utilisation such as intra-household distribution among children and adults are not taken into consideration. Future research could attempt to explore the effect of technology adoption on the number of nutritious meals taken per day and intra-household food distribution among children and adults.

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References

Arslan A, Floress K, Lamanna C, Lipper L & Rosenstock TS, 2022. A meta-analysis of the adoption of agricultural technology in Sub-Saharan Africa. PLOS Sustain Transform 1(7): e0000018. https://doi.org/10.1371/journal.pstr.0000018

Bai Y, Naumova EN & Masters WA, 2020. Seasonality of diet costs reveals food system performance in East Africa. Science Advances 6: eabc2162. https://doi.org/10.1126/sciadv.abc2162

Bezu S, Kassie GT, Shiferaw B & Ricker-Gilbert J, 2014. Impact of improved maize adoption on the welfare of farm households in Malawi: A panel data analysis. World Development 59: 120–31. https://doi.org/10.1016/j.worlddev.2014.01.023

Biru WD, Zeller M & Loos TK, 2020. The impact of agricultural technologies on poverty and vulnerability of smallholders in Ethiopia: A panel data analysis. Social Indicators Research 147(2): 517–44. https://doi.org/10.1007/s11205-019-02166-0

Cameron CA & Trivedi PK, 2009. Microeconometrics using STATA. Lakeway Drive, TX: Stata Press Books.

Carrasco R, 2001. Binary choice with binary endogenous regressors in panel data: Estimating the effect of fertility on female labour participation. Journal of Business & Economic Statistics 19(4): 385–94.

CIMMYT, 2022. Maize research. https://www.cimmyt.org/work/maize-research/

Davis B, Di Giuseppe S & Zezza A, 2017. Are African households (not) leaving agriculture? Patterns of households' income sources in rural Sub-Saharan Africa. Food Policy 67: 153–74. https://doi.org/10.1016/j.foodpol.2016.09.018

FAO, 2006. Food security. Policy Brief No. 2, Food and Agriculture Organization, Rome, Italy. https://www.fao.org/fileadmin/templates/faoitaly/documents/pdf/pdf_Food_Security_Cocept_Note.pdf

FAO, IFAD, UNICEF, WFP & WHO, 2023. The state of food security and nutrition in the world 2023. Urbanization, agrifood systems transformation and healthy diets across the rural–urban continuum. Rome: FAO. https://doi.org/10.4060/cc3017en

Garbero A & Marion P, 2018. Understanding the dynamics of adoption decisions and their poverty impacts: The case of improved maize seeds in Uganda. IFAD Research Series 28. https://www.ifad.org/documents/d/new-ifad.org/28_research-pdf

Geffersa AG, Agbola FW & Mahmood A, 2022. Improved maize adoption and impacts on farm household welfare: Evidence from rural Ethiopia. Australian Journal of Agricultural and Resource Economics 66(4), 860–86. https://doi.org/10.1111/1467-8489.12489

Greene WH, 2005. Econometric analysis. Eighth edition. Upper Saddle River NJ: Pearson Education.

Grote U, Fasse A, Nguyen TT & Erenstein O, 2021. Food security and the dynamics of wheat and maize value chains in Africa and Asia. Frontieres in Sustainable Food Systems 4: 617009. https://doi.org/10.3389/fsufs.2020.617009
Houeninvo GH, Célestin Quenum CV & Nonvide GMA, 2020. Impact of improved maize variety adoption on smallholder farmers' welfare in Benin. Economics of Innovation and New Technology 29(8): 831–46. https://doi.org/10.1080/10438599.2019.1669331
Khonje M, Manda J, Alene AD & Kassie M, 2015. Analysis of adoption and impacts of improved maize varieties in Eastern Zambia. World Development 66: 695–706. https://doi.org/10.1016/j.worlddev.2014.09.008
Khonje MG, Manda J, Mkandawire P, Tufa AH & Alene AD, 2018. Adoption and welfare impacts of multiple agricultural technologies: Evidence from eastern Zambia. Agricultural Economics 49(5): 599–609. https://doi.org/10.1111/agec.12445
Kinuthia BK & Mabaya E, 2017. The impact of agricultural technology adoption on farmer welfare in Uganda and Tanzania. PEP Brief No. 163, Partnership for Economic Policy. https://www.academia.edu/65610217/The_Impact_of_Agricultural_Technology_Adoption_on_Farmer_Welfare_in_Uganda_and_Tanzania
Lunduka RW, Mateva KI, Magorokosho C & Manjeru P, 2019. Impact of adoption of drought-tolerant maize varieties on total maize production in south Eastern Zimbabwe. Climate and Development 11(1): 35–46. https://doi.org/10.1080/17565529.2017.1372269
Lyimo S, Mdurum Z & De Groote H, 2014. The use of improved maize varieties in Tanzania. African Journal of Agricultural Research 9(7): 643–57. https://doi.org/10.5897/AJAR11.065
Mathenge MK, Smale M & Olwande J, 2014. The impacts of hybrid maize seed on the welfare of farming households in Kenya. Food Policy 44: 262–71. https://doi.org/10.1016/j.foodpol.2013.09.013
Muche M, Endalew B & Koricho T, 2014. Determinants of household food security among Southwest Ethiopia rural households. Food Science and Technology 2(7): 93–100. https://doi.org/10.13189/fst.2014.020701
Mutyebere R, Nanyanzi SA, Bonabana-Wabbi J & Basamba TA, 2017. Adoption of improved varieties and input elasticities among smallholder maize farmers in Kabarole district – Western Uganda. International Journal of Agricultural Sciences and Natural Resources 4(6): 50–7.
Noack F & Larsen A, 2019. The contrasting effects of farm size on farm incomes and food production. Environmental Research Letters 14(8): 084024. https://doi.org/10.1088/1748-9326/ab2dbf
Ouma J, Bett E & Mbataru P, 2014. Does adoption of improved maize varieties enhance household food security in maize growing zones of Eastern Kenya? Developing Country Studies 4(23), 157–65.
Pawlak K & Kołodziejczak M, 2020. The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. Sustainability 12(13): 5488.
Russell J, Lechner A, Hanich Q, Delisle A, Campbell B & Charlton K, 2018. Assessing food security using household consumption expenditure surveys (HCES): A scoping literature review. Public Health Nutrition 21(12): 2200–10. https://doi.org/10.1017/s136898001800068x
Sserunkuuma D, 2005. The adoption and impact of improved maize and land management technologies in Uganda. Electronic Journal of Agricultural and Development Economics 2(1): 67–84.
Uganda Bureau of Statistics (UBOS), 2020. Uganda National Panel Survey (UNPS) 2019-2020. Ref: UGA_2019_UNPS_v03_M. Dataset downloaded on 8 June 2021 from https://microdata.worldbank.org/index.php/catalog/3902/get-microdata
Waswa LM, Jordan I, Krawinkel MB & Keding GB, 2021. Seasonal variations in dietary diversity and nutrient intakes of women and their children (6–23 months) in western Kenya. Frontiers in Nutrition 8: 636872. https://doi.org/10.3389/fnut.2021.636872

Wichern J, Van Wijk MT, Descheemaeker K, Frelat R, Van Asten PJ & Giller KE, 2017. Food availability and livelihood strategies among rural households across Uganda. Food Security 9: 1385–403.

Wossen T, Abdoulaye T, Alene A, Feleke S, Menkir A & Manyong V, 2017. Measuring the impacts of adaptation strategies to drought stress: The case of drought tolerant maize varieties. Journal of Environmental Management 203: 106–13. https://doi.org/10.1016/j.jenvman.2017.06.058

Appendix 1: Test for overidentification and relevance of selected instruments

Variable	Treatment	Outcome
Read (yes = 1)	0.024** (0.012)	0.010 (0.009)
Non-farm business (yes = 1)	0.004 (0.012)	0.010 (0.008)
On-farm employment (yes = 1)	0.021* (0.012)	-0.006 (0.008)
Household size (number)	-0.002 (0.002)	0.001 (0.001)
Log area maize (acres)	0.081*** (0.014)	-0.014** (0.006)
Extension services (yes = 1)	0.046*** (0.014)	0.004 (0.008)
Log inorganic fertilisers (kg)	0.020*** (0.007)	0.002 (0.003)
Log pesticides (kg)	0.014* (0.008)	0.004 (0.004)
Log labour (total person-days)	-0.001 (0.004)	-0.004** (0.002)
Log distance to inputs market (km)	-0.013** (0.006)	-0.008** (0.004)
Eastern region (yes = 1)	0.066*** (0.017)	0.005 (0.010)
Northern region (yes = 1)	0.041** (0.016)	-0.012 (0.011)
Western region (yes = 1)	-0.017 (0.015)	-0.001 (0.010)
Season 2 (yes = 1)	-0.046*** (0.013)	-0.016*** (0.006)
Season 3 (yes = 1)	-0.017 (0.014)	-0.026*** (0.009)
Season 4 (yes = 1)	-0.017 (0.015)	-0.018** (0.008)
Season 5 (yes = 1)	-0.045** (0.023)	-0.005 (0.010)
Season 6 (yes = 1)	-0.056** (0.024)	-0.001 (0.011)
Season 7 (yes = 1)	-0.049*** (0.019)	-0.033** (0.013)
Season 8 (yes = 1)	-0.033 (0.022)	-0.034** (0.015)
Adoption of improved maize seed (yes = 1)		0.002 (0.007)
Constant	0.093*** (0.031)	
Observations	7 976	7 375

Notes: Robust standard errors are in parentheses; significance levels: *** = $p < .01$, ** = $p < .05$, * = $p < .1$
Source: Authors' computations based on UNPS datasets 2013 to 2020