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Impact of Improved Maize and Bean Varieties on Household Income and Food Security in Uganda

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Abstract. The National Agricultural Research Organisation (NARO) and development partners have invested substantial resources in breeding maize and bean varieties over the years. However, the impact of the varieties on productivity, household income and food security is not well documented. This paper evaluated the ex-post impact of adopting NARO released bean and maize varieties over the last five years on the productivity, household income and food security in Uganda. Data were collected from 30 districts in Uganda through a cross-sectional household survey of 1445 households, focus group discussions and key informant interviews. Using propensity score matching and endogenous switching regression models, the results showed that adoption of improved bean and maize varieties significantly increased crop productivity, household income and food security. This evidence suggests that there were tangible benefits from funding the development of bean and maize varieties in Uganda. The results indicate that although adoption of the improved bean and maize varieties increased productivity, it was still far below the research production output. This suggests that in addition to developing and disseminating the appropriate varieties, emphasis should be put on training farmers to use the complimentary inputs and practices to get the full benefit of the improved varieties.

Keywords: Maize, Bean, Food Security, Income.

Introduction

Agricultural technology development contributes to agricultural growth and development through enhancing yield and reducing costs of production (Kassie *et al.*, 2011). By increasing productivity, agricultural technology development can also contribute to increased household income, food security and poverty reduction (Becerril and Abdulai, 2010; Minten and Barrett, 2007). Given the rapidly increasing population in many African countries, it is projected that more food will be needed to feed the increasing number of people. Expanding the area under agricultural production is increasingly becoming unfeasible, leaving increasing productivity as the only realistic option. For this reason, governments in Africa have supported agricultural research and development (R&D) leading to the development of crop varieties that have the potential to improve agricultural productivity.

In Uganda, the National Agricultural Research Organisation (NARO) and development partners have invested substantial resources in breeding maize and bean varieties yet the impact of these crops on livelihoods and overall economic development in the country is not well documented. Maize and beans are prioritized as strategic commodities to drive improved food and nutritional security and contribute to household income in Uganda.

Several studies on the impact of improved maize varieties on household welfare in Africa showed that adoption of the improved varieties is likely to have substantially greater positive impacts on aggregate real incomes in high potential regions than in marginal regions (Karanja *et al.*, 2003; Kijima *et al.*, 2008). Karanja *et al.*, (2003). Gebre *et al.* (2021) showed that there are substantial variations in the productivity, income, and food security effects, depending on the scale of adoption while Darnhofer and Cungura (2011) revealed that using improved maize seeds and tractors, significantly increased the income of those households who had better market access. Similarly, studies on the impact of bean varieties on household income have been conducted in Africa (Letaa *et al.*, 2020; Kotu *et al.*, 2019; Zeng *et al.*, 2015; Larochelle and Alwang, 2022).

The above literature indicates that the magnitude and heterogeneous distribution of the impacts of improved bean and maize varieties is always an empirical question. Whereas a number of studies have been conducted on the impact of maize and bean varieties in Africa, no such studies have been conducted in Uganda. There is still a paucity of information on the impact of the bean and maize varieties on household incomes, food security and nutrition in Uganda. Given the structural differences among countries, even within Africa, it is important that the Ugandan situation is understood. Assessing the impact of the improved bean and maize varieties will enable policy makers to make informed decisions on investing in the development of the varieties, provide feedback to researchers and guide priority setting. Therefore, this study sought to assess the impact of improved bean and maize varieties developed by NARO on the productivity, household income and food security in Uganda.

Methods

The study was conducted in six out of nine agricultural research zones, namely, Abi and Ngetta, Buginyanya, Bulindi, Kachwekano and Mukono zone (Fig. 1). These zones were purposely selected to respectively represent the Northern, Eastern, Western and Central regions of Uganda.

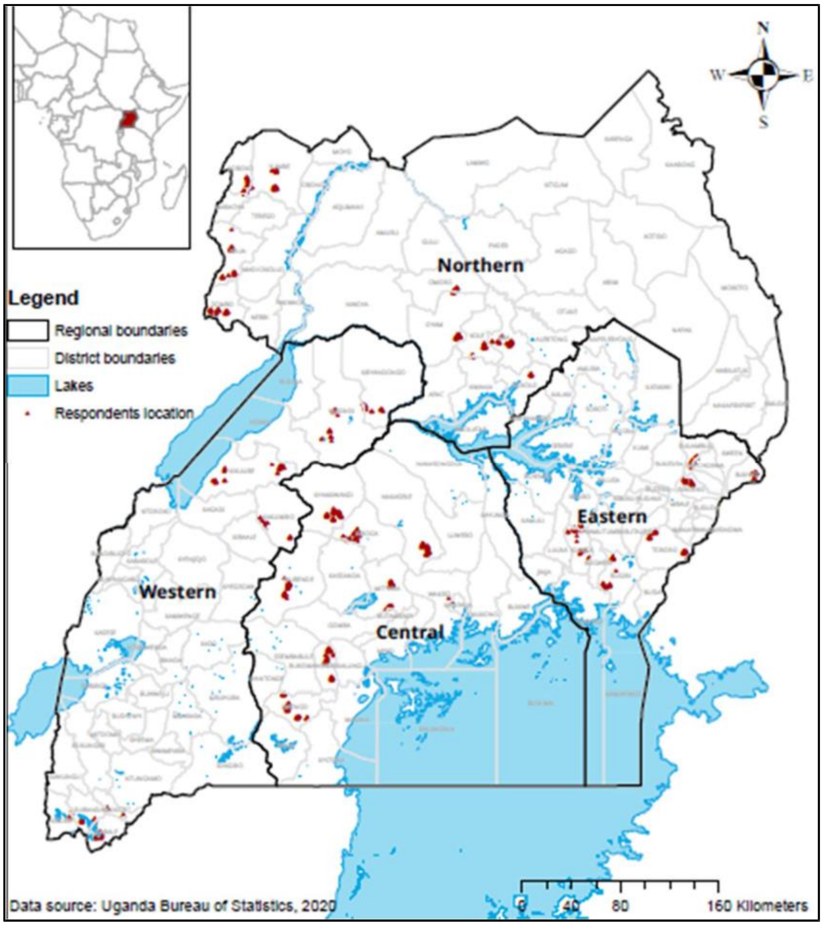


Figure 1: Study Sites

Data were collected following a mixed methods approach. Quantitative data were collected through a cross-sectional questionnaire survey while qualitative data collection employed a combination of Focus Group Discussions (FGDs) and key informant interviews (KIIs). Focus Group Discussions (FGDs) and key Informant interviews were used to gather collective and expert views, respectively, on the impact of the varieties on farmer's income and food security. The key informants included agricultural officers at the District and Sub-county levels, produce dealers and local leaders.

Thirty districts, from six agricultural research zones, were selected for the study (located in all the four regions of Uganda). The sample size in each zone was in proportion to the estimated number of maize and bean farmers in the zone. For each selected district, one treatment and one control sub-county were selected. The treatment sub-county was where NARO and her implementing partners actively conducted bean and or maize variety dissemination activities while a control sub-county was where such interventions did not take place. The adopters of the improved bean and maize varieties were randomly selected from lists provided by the agricultural officers of the treatment sub-counties while the non-adopters were sampled from the control sub-counties. Using Cochran's (1977) formula, a sample size of approximately 2,294 households was obtained.

Table 1. Distribution of Sample

	Number of districts	Observations			Proportion
		Non-adopters	*Adopters*	*Overall*	
Abizardi	4	99	100	199	0.137
Bugizardi	6	51	283	334	0.231
Buzardi	4	25	80	105	0.073
Karzardi	4	73	29	102	0.071
Muzardi	7	134	362	496	0.343
Ngetta	5	56	153	209	0.145
Total	**30**	**438**	**1007**	**1445**	**1.000**

This study measured impact of improved NARO bean and maize varieties adoption on five outcome variables, namely; bean/maize productivity/yield, bean/maize income, total farm income, total household income and household food security. Total farm income comprised income from beans and/or maize, other crops, livestock products and sales of live animals. Thus, total household income comprised total farm income and non-farm income (salaries, business, informal labour employment, among others) earned by household members. Household food security was measured using the food consumption score (FCS) for a seven- day short run recall and household food insecurity access scale scores for a 30-day period. Farm yield was measured by the bean/maize harvested per acre of land and is an indicator of productivity and profitability.

In this study, the treatment group comprised of farmers who planted NARO improved maize and bean varieties in the past five years (2016-2020). Farmers who did not plant an improved beans or maize variety in the said period were placed in the control group category.

The difficulty in estimation of impact of any programme is the attribution problem, where a change may be wrongly attributed to a given intervention. Propensity score matching (PSM) procedure was used to create two comparison groups, matched based on a set of same characteristics other than the outcome variables of interest such that the treated and untreated farmers do not differ on e(X). Using PSM, impact of varieties adoption is the average treatment effect on the treated (ATT) (Rosenbaum and Rubin, 1983). This is the difference between outcome of the adopters and the counterfactual position. Impact can be represented as:

$$ATT = E(Y_1 - Y_0 | J = 1, \mathrm{X}) = E(Y_1 \ | J = 1, \mathrm{X}) - E(Y_0 \ | J = 1, \mathrm{X})$$

Where participation is denoted by J, and $J = 1$ for adopters and $J = 0$ for non-adopters. X denotes a set of observable household characteristics that explain adoption of improved bean and maize varieties. Y_1 represents outcomes for adopters and Y_0 outcomes for non-adopters. Since the counterfactual, $E(Y_0 | J = 1, \mathrm{X})$, is not observable in the data, the average outcome in the control group, $E(Y_0 | J = 0, \mathrm{X})$, is used to estimate it – then considered a counterfactual. Matching was done using nearest neighbour (NN), Kernel, and the Radius matching approaches.

PSM is a useful tool for impact evaluation when only observed characteristics affect adoption of maize and bean varieties. However, the effect of unobservable factors may confound the effect (Rosenbaum, 2002). The study therefore checked robustness of the results, using an endogenous switching regression.

Results

The household characteristics, some of which are used in the estimated models, are shown in Table 2.

Table 2. Household Characteristics

	Maize			Beans		
	Adopters	*Non-adopters*	*χ^2 or t-test*	*Adopters (N=425)*	*Non-adopters (N= 281)*	*χ^2 or t-test*
Bean/ maize income (UGX)	1,494,322 (2,367,235)	870,282 (1,491,646)	-3.1***	1,408,949 (2,861,306)	822,635 (1,208,290)	-3.24***
Farm income (UGX)	4,301,269 (6,439,143)	2,719,774 (3,197,925)	-2.97***	3,963,218 (5,395,208)	3,065,172 (5,909,438)	-2.08**
Total household income (UGX)	6,250,843 (8,157,673)	4,082,074 (5,071,641)	-3.16***	5,867,748 (7,218,560)	4,817,051 (9,751,689)	-1.64
Food consumption score	58.7(23.8)	54.0(24.5)	-2.18**	58.1 (22.7)	51.9 (22.5)	-3.54***
Sex of household (1= male; 0= female)	85%	73%	11.1***	75%	72%	0.82
Age of household head (years)	46 (12.3)	49 (15.1)	2.6	46 (12.4)	47 (13.6)	0.93
Marital status (1=married; 0= otherwise)	76%	87%	14.3***	82%	80%	8.20**
Household head education (years)	8.4 (4.6)	7.1 (4.9)	-3.2***	7.9 (4.4)	7.5 (4.7)	-1.28
Main occupation of household head (1=farming; 0= otherwise)	93%	94%	2.4	92%	93%	5.00
Group member (1= Yes; 0= No)	74%	70%	1.1	73%	72%	0.11
Household size	7.6 (3.8)	7.3 (4.6)	-0.69	7.4 (3.7)	6.9 (4.5)	-1.53
Number of working household members	4.1 (2.5)	3.7 (3.0)	-1.63	4.0 (2.6)	3.88 (3.3)	-0.90
Access to credit (1= Yes; 0=otherwise)	63%	55%	3.8***	68%	57%	8.38**
Farming experience (years)	11.1 (9.4)	10.4 (9.1)	-0.79	13.3 (8.8)	11.0 (11.3)	-2.72**
Accessed information (1= Yes; 0=No)	74%	47%	41.4***	73%	50%	37.9***
Abizardi(1= Abizardi; 0= otherwise)	53%	47%	44.7***	47%	53%	8.35**
Bugizardi(1=Bugizardi; 0= otherwise)	88%	12%	14.9***	79%	21%	25.9***
Buzardi(1= Buzardi; 0= otherwise)	89%	11%	4.6**	55%	45%	0.47
Kazardi(1= Kazardi; 0= otherwise)	0%	100%	-	28%	72%	50.2***
Muzardi(1= Muzardi; 0= otherwise)	76%	24%	1.9	70%	30%	15.83***
Ngeta zardi(1= Ngeta zardi; 0= otherwise)	84%	16%	2.7*	56%	44%	0.65

χ^2 for categorical variables and t-test for continuous variables. ** = p < .05, *** = p < .001. Standard deviations appear in parentheses.

The results (Table 2) show that 85% of households adopting improved maize varieties were male headed compared to 73% for non-adopting households. The average age of household heads for adopting households was 46 years, each having 7.6 members. In contrast, the average age of household heads for non-adopting households was 49 years, with 7.3 members per household. The results (Table 2) also showed that the percentage of male headed households was 75% and 72% for adopters and non-adopters of improved NARO bean varieties, respectively. The average age of household heads was 46 and 47 years for adopters and non- adopters of improved NARO bean varieties. Crop farming was a major source of livelihood in both maize and bean farming households (92% – 94%). These results concur with the national report that shows that 80 percent of households are engaged in agriculture (UBOS, 2019). The households that adopted improved NARO maize and bean varieties had a significantly higher maize/bean income, farm income and food consumption score than the non-adopters. There was also a significant association between adoption status of both crops and access to credit and information.

Technology Yield Gap

In Table 3, the yield gap between adopters and non-adopters of improved NARO varieties was assessed and the evidence shows a significant gap in yield ($P < 0.01$), indicating the benefit of adopting NARO technologies. The results show that on all parameters (area planted, output, and yield), the adopters have an edge over non-adopters. The gap in yield between adopters and non-adopters is estimated to be about 11 percent among bean farmers and 12 percent among the maize farmers. Considering adopters also planted bigger area, results also suggest that there could be an incentive of increased allocation of area under the crop if one is an adopter of an improved variety.

Table 3. Technology Yield Gap

	Non-adopters		**Adopters**		**Gap**	**P**
	Mean	*Std. Dev.*	*Mean*	*Std. Dev.*		
Beans						
Area planted under beans (ha)	0.395	0.378	0.605	0.666	34.7%	0.0000
Quantity of bean harvested (kgs)	317.914	393.214	622.292	1171.823	48.9%	0.0000
Bean yield (kgha^{-1})	860.947	591.847	962.619	677.038	10.6%	0.0000
Maize						
Area planted under maize (ha)	0.659	0.595	1.043	1.012	36.8%	0.0000
Quantity of maize harvested (Kgs)	1447.33	2238.972	2432.776	3314.137	40.5%	0.0000
Maize yield (kgha^{-1})	1963.382	1679.293	2232.687	1524.033	12.1%	0.0002

Contribution of Beans and Maize to Total Farm and Household Income

Results (Table 4) show that the share of bean and maize income to farm income ranged between 36 percent and 41 percent for non-adopters and about 42 percent for adopters of either bean or maize varieties. Additionally, the contribution of bean and maize income to household income ranged between 27 and 34 percent. These results indicate that most households were highly dependent on bean and maize farming for household income.

Table 4. Share of Bean and Maize in Income

	Bean farmers		Maize farmers	
	Non-Adopters	*Adopters*	*Non-Adopters*	*Adopters*
Share of farm income to household income	0.792	0.777	.824	.778
Share of bean/maize income to farm income	0.407	0.418	.357	.417
Share of bean/maize income to HH income	0.328	0.338	.296	.332

Propensity Score Matching

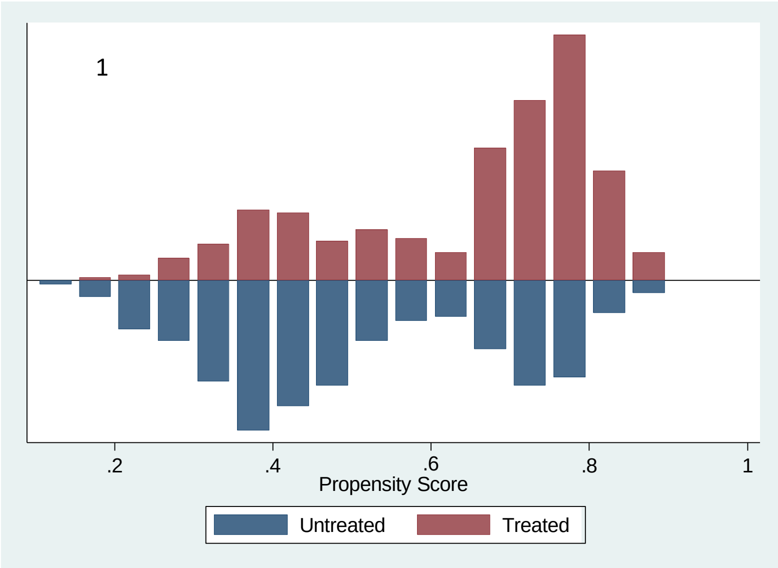
A visual inspection of the distributions of estimated propensity scores (Figure 2) and the treatment assignment tables indicated that there was considerable overlap in common support meaning that the conditions of common support were satisfied. This implies that there are adequate observations in the treatment and comparison groups with similar or comparable propensity scores.

Results of the balancing test showed that the covariates $e(X)$ were not statistically different after matching and the standardized bias of all covariates was less than 20 percent (Table 5). This indicates that the matching procedure balanced the covariates in the treated and control groups. Therefore, the following results have passed the balancing test and the common support condition.

Table 5. Kernel and Radius matching

	Standardized bias after matching			
	Maize		Beans	
	Radius matching	*NN matching*	*Radius matching*	*NN matching*
Sex of household	19.9	5.2	3.6	-1.8
Age of household head	6.4	-	-3.3	8.8
Household head marital status	-19.1	-6.6	9.8	-
Household head education, years	8.7	19.0	8.4	-4.4
Main occupation of household head	4.4	1.4	13.1	-
Group membership	6.5	-	7.4	0.4
Household size	9.0	17.5	11.8	12.9
Members contributing	20	-	8.8	9.1
Access to credit	20.9	-5.1	24.3	-0.2
Who makes decisions	-21.1	-13.9	-5.4	-
Farming experience (years)	8.6	3.8	-18.1	8.0
Narozone1	-	2.5	-	4.8
Narozone2	-	0.5	-	2.4
Narozone3	-	18.3	-	5.2
Narozone4	-	0.8	-	-2.2
Narozone5	-	-3.7	-	-3.5
Narozone6	-	-	-	-4.4

Note: NN denotes nearest neighbour matching method.



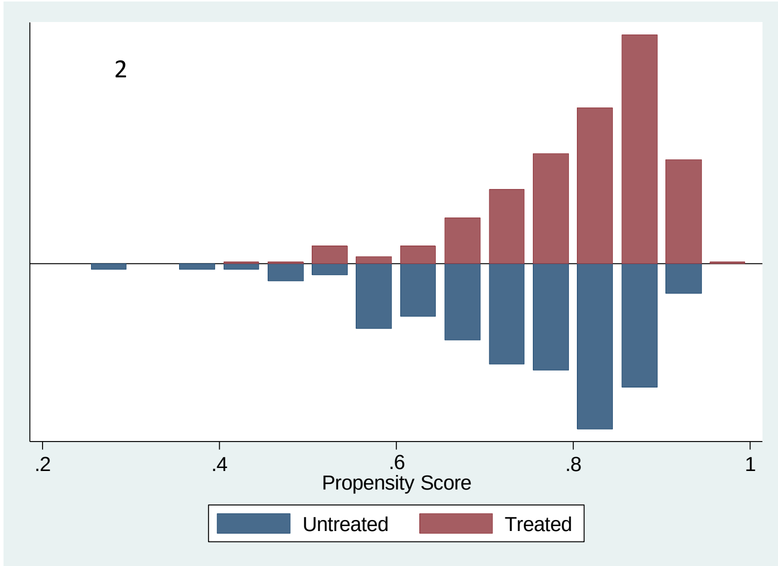


Figure 2. Common support using nearest neighbour matching method for beans (1) and maize (2) farmers

Estimated Impact of Technology Adoption using PSM

Table 6 shows results on effects of Average Treatment on Treated (ATT) of adopting varieties (ATT) using the nearest neighbour and radius-matching estimators. The two matching estimators were used to check robustness of the PSM results. However, interpretation of ATT results is based on the radius-matching estimator.

The results show that adoption of NARO bean and maize varieties increased bean and maize yield by 141kgha^{-1} (19%) and 414 kgha^{-1} (22%), respectively. Adoption of NARO bean varieties increased bean income, farm income and household income by UGX 709000, UGX 1143000, and UGX 1650000, respectively which represents an average increase of 80 percent, 37 percent, and 36 percent, respectively (Table 6). Additionally, the results show that adoption of NARO maize varieties increased maize income, farm income and household income by UGX. 661000; UGX 1560000; and UGX 2083000, respectively which represents an average increase of 65 percent, 54 percent, and 48 percent, respectively.

Table 6. Estimates of average effects of NARO technology adoption

Output variable	Radius matching			Nearest neighbour matching		
	ATT		LCV (Γ)	ATT		LCV (Γ)
Bean technologies						
Yield (Kg/ha)	141**	(52.16)	1.6	96.4*	(33.13)	1.5
Bean income	709,399***	(154,664)	1.2	424,650*	(218,577)	1.3
Total farm income	1,143,493***	(294,495)	1.2	1,144,509**	(434,293)	1.6
Household income	1,650,486***	(396,201)	1.3	1,979,914***	(607,466)	1.5
Food security (FCS)	5.39***	(1.19)	1.9	6.94**	(2.84)	1.3
Maize technologies						
Yield (Kg/ha)	414.4**	(266)	1.5	440**	(207)	1.6
Maize income	661,963***	(108,542)	1.2	762,086***	(265,944)	1.5
Total farm income	1,559,881***	(289,564)	1.3	1,651,449***	(604,007)	1.2
Household income	2,083,231***	(366,070)	1.5	1,734,828*	(974,410)	1.3
Food security (FCS)	4.65***	(1.08)	1.6	-0.87	(3.87)	1.4

Note. Significant at the 99% (***), 95% (**) and 90% (*) levels. Values in parenthesis are standard errors. ATT = average treatment effects on the treated; LCV = lowest critical value. Income is captured in Uganda Shillings.

Whereas there was evidence of increased income and productivity due to technology adoption, the increases were not maximised due to limited use of complimentary inputs. However, most farmers used improved seed.

Regarding food security, adoption of NARO bean varieties increased the FCS by 5.4 points, representing a 10 percent increase, which means adoption improved food security by 10 percent in relation to non-adoption. A comparable increase in FCS (4.7) was observed for adopters of improved NARO maize varieties (Table 6). The increased food security is not only attributed to consumption but also increased yield and household income associated with bean and maize technology adoption.

Findings of this study indicate that bean and maize farming households were highly dependent on the two crops for their food security. A large percentage of the bean and maize farmers consumed beans and maize on at least 3 days in a week thus contributing about 53 percent and 43 percent of the required energy intake for the active women and men, respectively. The study revealed that an average sized household (6 members) consumed at least 10 kg of maize and about 8 kg of beans per week.

Rosenbaum Sensitivity Analysis

The Rosenbaum bounds sensitivity analysis was used to assess if our ATT estimates based on PSM are sensitive to the possible presence of hidden bias (Rosenbaum, 2002). Table 6 presents results of the Rosenbaum bounds sensitivity analysis for the ATT estimates. Overall, the critical values of Γ ranged from 1.2 to 1.9 and did not vary significantly between matching estimators and outcome measures. These are relatively low critical values, implying that these estimates are sensitive to hidden bias. Since some results are sensitive to hidden bias, robustness of the results was counter checked by estimating the ATTs using an endogenous switching regression.

Effects of Technology Adoption based on Endogenous Switching Regression

The summary of results from the endogenous switching regression (ESR) models are shown in Table 7. Based on the full information maximum likelihood endogenous switching regression model (Table 7), the evidence indicates that adoption of improved NARO bean and maize varieties had a positive and significant impact on food security and income (bean or maize income, total farm income, and total household income). Using the ESR model which controls for hidden selection bias, the results further confirm that adoption of NARO bean varieties increased bean income, farm income and household income by about 55 percent, 31 percent, and 31 percent, respectively. Adoption of improved NARO bean varieties also improved the food security. A similar pattern was observed for adoption of improved NARO maize varieties. Their adoption increased the maize income, farm income and household income by 64, 27 and 70 percent, respectively. Adoption of the varieties also increased household food security.

Table 7. Summary of ATT from switching regressions

Variable	Improved NARO bean technologies	Improved NARO maize technologies
ATT, food consumption score	6.17(0.36) ***	4.72(0.71) ***
σ_0	22.95(1.23)	24.07(1.59)
σ_1	23.17(1.94)	28.13(4.8)
ρ_0	0.345(0.22)	-0.51(0.28)
ρ_1	-0.399(0.26)	-0.76(0.16) **
ATT, log beans or maize income	0.547(0.077) *	0.64(0.10) ***
σ_0	4.3(0.14)	4.81(0.14)
σ_1	3.2(0.15)	5.8(0.36)
ρ_0	0.04(0.19)	0.14(0.14)
ρ_1	0.12(0.25)	-0.17(0.23)
ATT, log farm income	0.307(0.048) ***	0.26(0.05) ***
σ_0	1.88(0.06)	2.56(0.08)
σ_1	1.61(0.06)	2.46(0.14)
ρ_0	0.15(0.12)	-0.98(0.005)
ρ_1	-0.06(0.16)	-0.001(0.88)
ATT, log total household income	0.311(0.04) ***	0.709(0.06) ***
σ_0	1.79(0.62)	2.08(0.06)
σ_1	1.69(0.72)	2.52(0.14)
ρ_0	0.08(0.14)	0.04(0.16)
ρ_1	-0.063(0.16)	-0.015(0.42)

Note. Significant at the 99% (***), 95% (**) and 90% (*) levels. Figures in parentheses are standard errors. ρ_i = correlation coefficient between the outcome and selection equations and σ = the standard deviation of the error term of the equation.

Discussion

Overall, the findings reveal that there are significant positive effects on income and food security due to adoption of both bean and maize varieties. Thus, results from endogenous switching regression are consistent with PSM results, which indicated that adoption of improved NARO bean and maize varieties increased maize and bean income, farm income and total household income. Key attributes of improved NARO bean and maize varieties that were reported by the farmers to contribute to increase household income include higher yields, drought tolerance, pest and disease resistance, better taste, and early maturity.

The increase in food security is attributed to the increased maize and bean yield and increased household income of technology adopters. This is in agreement with a similar study in South-Central Uganda which showed that higher maize and beans yields were associated with food security (Apanovich and Mazur, 2018). Other studies have also shown that total monthly income is positively correlated with HFIAS, implying that the higher the monthly income, the greater the likelihood of being food secure (Nord *et al.*, 2014). This is likely because households with higher monthly income have raised disposable income to purchase larger quantities and more diverse food types.

The results suggest that adoption of improved bean and maize varieties has the potential to significantly increase farm and household income and food security. The evidence reinforces the dire need for increased support to agricultural research and dissemination of improved varieties. These improved varieties have potential to improve rural household welfare and contribute to agricultural transformation for long-term national economic development, especially for countries like Uganda, where about 70 percent of households depend on agriculture for their livelihood and where agricultural products contribute about 22 percent to national GDP. Therefore, increasing funding to research and the agricultural extension apparatus is likely to increase farmer livelihoods and national economic development. The evidence suggests that the improved varieties can significantly contribute to the development objectives in the National Development Plan III and the current Parish Development Model frameworks for medium term transformation of Uganda.

The results indicate that although adoption of the improved varieties increased productivity, it was still far below the research production output. According to FGDs, the use of inorganic fertilizers and pesticides among users and non-users of NARO varieties remains low, estimated at below 45 percent. This concurs with (UBOS, 2018) that indicates that 23 percent of farmers in Uganda were using fertilizers and 21 percent were using agro-chemicals by 2018. Information from the survey and FGDs indeed confirmed that farmers were resource constrained to access agro-inputs such as fertilizers and pesticides. The few farmers who afforded herbicides, applied them only during initial land clearing prior to planting. The remaining majority who were entirely dependent on hoe-weeding, only did it once instead of the recommended three times due to the drudgery associated with hoe-weeding. These findings suggests that in addition to developing and disseminating the appropriate varieties, emphasis should be put on enhancing farmers' access to complimentary inputs and practices to get the full benefit of the improved varieties.

Conclusion

This study set out to estimate the impact of improved NARO maize and bean varieties on productivity, household income and food security. The findings demonstrate that adoption of improved varieties has significant benefits to households in the farming communities. Farmers who adopted improved bean and maize varieties released by NARO were found to have better outcomes from agricultural activity compared to the non-adopters. Adopters had higher productivity, incomes, and food security. Although adoption of the varieties increased productivity, it was still far below the research production output. This was mainly attributed to low use of complementary inputs by both adopters and non-adopters of the improved technologies. These findings suggests that in addition to developing and disseminating the appropriate technologies, emphasis should be put on enhancing farmers' access to complimentary inputs and practices to get the full benefit of the improved varieties.

Conflict of Interest

The authors declare that they have no conflicts of interest in relation to this article.

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