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DETERMINANTS OF UPTAKE OF BIOFORTIFIED CROP VARIETIES BY SMALLHOLDER FARMERS IN UGANDA

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ABSTRACT

Hunger and malnutrition can be said to be one of the important global problems that have recently been exacerbated by climate change and environmental degradation. Meanwhile, an estimated two billion people suffer from micronutrient malnutrition, mostly due to low intake of vitamins and minerals such as iron and zinc. Biofortification, an agricultural technology that can increase the micronutrient content of staples, may confer large benefits to rural families and poor children with limited access to expensive high-quality foods. Possible pathways include own-consumption when directly consumed, the income pathway when they are sold and/or the food price pathway when they increase the availability of micronutrient-rich foods in the market place. This research aims to understand the factors associated with the uptake of biofortified crop varieties (BCV) among smallholder farmers in Uganda and derive policy information to support their accelerated uptake. The analysis used two waves of panel data consisting of 6,400 observations collected from 6 districts in Uganda as part of the Feed the Future (FtF) innovation laboratory for nutrition. Descriptive analysis was used to help discern the differences between adopters and non-adopters of BCV. Double hurdle regression analysis was used to understand the factors associated with adoption and the intensity of adoption of biofortified crop varieties. Descriptive results reveal significant differences between adopters and non-adopters of BCV. Double hurdle regression analysis results indicate that the primary determinants of uptake of biofortified crop varieties include geographical location, extension staff visits, household size, and mobile phone ownership. Other important factors associated with the adoption of BCV include the amount of land owned by the household. Results suggest that extension staff visits, and mobile phone ownership were important sources of information for rural households that appear to drive the decision to adopt biofortified crop varieties. Meanwhile, household size, regional location of the household and total land owned were important motivators in adopting BCV technology. From the present analysis, it was not possible to clearly discern the key drivers of the intensity of adoption of biofortified crop varieties among smallholder households in Uganda.

Key words: Biofortification, smallholder farmers, quasi experimental design, double-hurdle regression, Uganda

INTRODUCTION

Malnutrition remains a significant global challenge especially in many developing countries. Although important achievements in food and nutrition security have been recorded over the last few decades, undernutrition remains high, especially in Africa and Asia [1, 2, 3]. Worldwide, more than 790 million people are still classified as chronically hungry, meaning they lack access to adequate calories [4]. Meanwhile, an estimated two billion people suffer from micronutrient malnutrition, mostly due to low intake of vitamins and minerals such as iron and zinc [3]. Globally, undernutrition is estimated to be responsible for the death of 45% of all children [5].

Over the last few decades, Uganda has experienced impressive economic growth and a general decline in poverty levels. Economic growth has averaged 4.5% per year over 2012/13-2016/17 [6]. The percentage of people living below the poverty line declined from 24.3% in 2009/10 to 19.7% in 2012/13 but has recently increased to 22%, according to the most recent 2019/2020 Uganda National Household Survey [7]. There has been an improvement in life expectancy at birth from 51.5 years in 2009/10 to 54.5 years in 2011/12 [8]. However, the country continues to lag behind in reducing child mortality and malnutrition. According to the Uganda Demographic and Health Survey (UDHS) [9], infant mortality in Uganda stands at 54/1000 live births falling short of the Health Sector Strategic and Investment Plan (HSSIP) of 41 deaths per 1000 live births. Meanwhile, 3.6% of children under five years of age are wasted (underweight) and 29% have chronic malnutrition or stunting linked to long-term irreversible consequences affecting the child, community and the nation [9]. Over the last 15 years, there has been a substantial reduction in the prevalence of child stunting, with national prevalence dropping from 45% in 2000 to 29% in 2016, but further improvement is needed to meet the World Health Assembly (WHA) target of reducing the absolute number of stunted children by 40%, by 2025. Applying national population projections to prevalence data shows that there were 1.87 million stunted children under five years of age in 2016. Moreover, there is substantial economic disparity, with the prevalence of stunting in each of the poorest three wealth quintiles nearly double that of the richest quintile. Micronutrient malnutrition is also high among children, with nearly five out of every ten (53%) children being anemic [9]. According to the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) [10], food insecurity and malnutrition are common in Uganda's rural areas. This means that recent public policies that have spurred economic growth do not address household and child malnutrition especially in rural areas yet child nutrition is important for any country's long-term economic and human development.

Although several factors contribute to child nutritional outcomes, supportive agri-food policies (or agricultural value chain policies) that are implemented in a timely and effective manner can go a long way in enhancing child nutritional outcomes. In Uganda, key policies intended to synergize agriculture for nutrition include, first and foremost, the Second National Development Plan (NDPII) [8] that has ending hunger, achieving food security and improved nutrition as some of the policy goals; The Uganda Food and Nutrition Policy [11] with the policy goal of ensuring food security and adequate nutrition for all the people of Uganda; The National Agricultural Research Policy [12] that prioritizes research for food security and the MAAIF Agriculture Sector Strategic Plan (ASSP) [10] that among other things highlights food and nutrition security. Under section 3.4 on cross-cutting priorities, one of the key interventions to improve food and nutrition security is the promotion of appropriate technologies.

Biofortification, an agricultural technology that can increase the micronutrient content of staples, may provide large benefits to rural families and poor children with limited access to expensive high-quality foods. These biofortified crops can increase nutrition through the own-consumption pathway when they are directly consumed by the children of producer farmers, through the income pathway when they are sold, or through the food price pathway when they increase the availability of micronutrient-rich foods in the marketplace. Despite the celebrated nutritional importance of bio-fortified crop varieties, there is limited appreciation and understanding of the factors that enable or constrain individual farmers' decision to adopt them. The present study assesses the factors associated with the uptake of biofortified crop varieties (BCV) among smallholder farmers in Uganda and derives policy information to support their accelerated uptake.

The various factors that influence the adoption decisions of smallholder farmers with respect to agricultural technologies have been widely investigated. As elaborated from Figure 1 adopted from Sodjnu [13], these factors include technology characteristics including production, agronomic, processing and consumption attributes; farm, farmer and household characteristics; institutional, economic and agro-ecological factors. Technology-related and consumption aspects of taste, color and texture are important drivers of technology adoption [14, 15, 16, 17]. Meanwhile, farm household and farmer characteristics that have been found to significantly influence agricultural technology adoption include age, sex, education level of the household head, household size and farm size. Important institutional factors that have been empirically established to influence agricultural technology adoption include membership to farmer groups, access to credit,

access to markets, and access to extension services [18, 19, 20]. Agroecological factors have been investigated by, among others, Akankwasa *et al.*, [20] and Nasirumbi *et al.*, [21]. The importance of heterogeneous information in agricultural technology adoption has also been investigated [22].

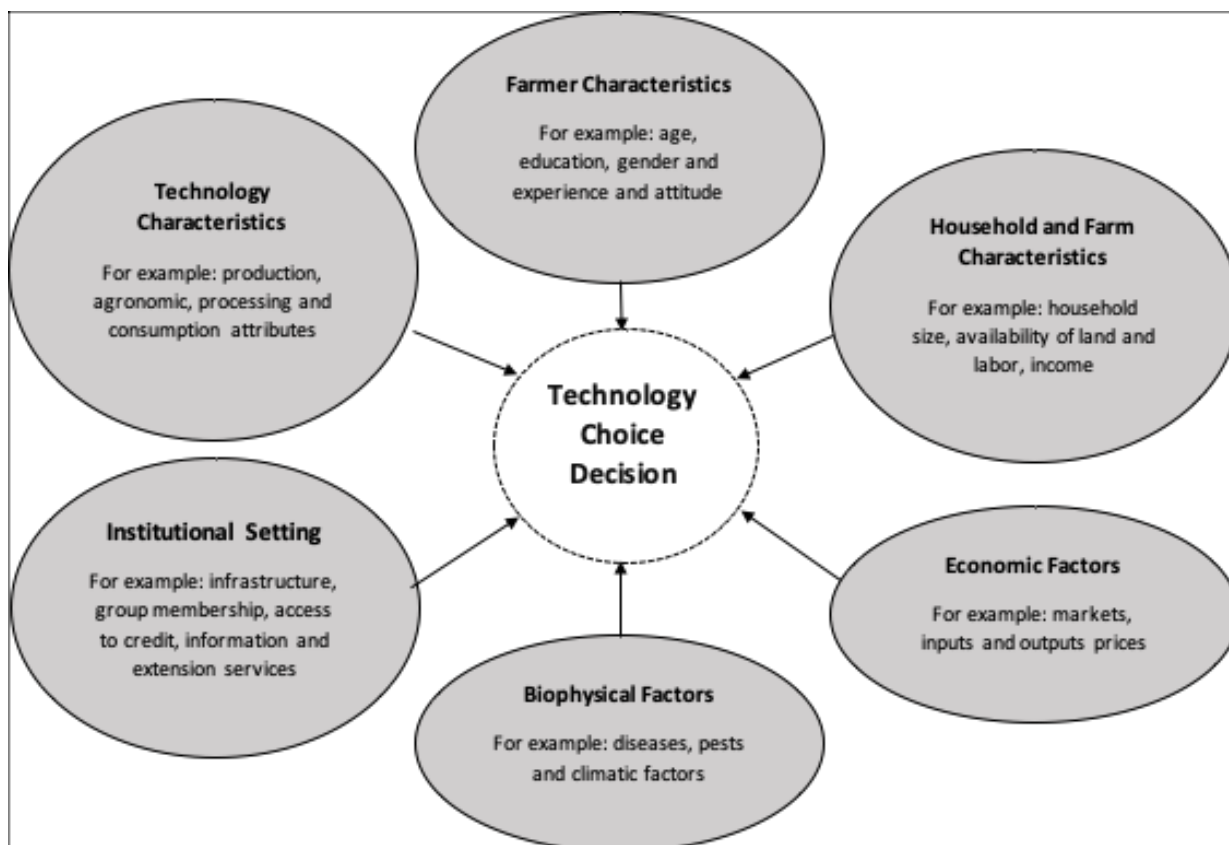


Figure 1: Factors that influence adoption and intensity of adoption of agricultural technology

Source: Adapted from Sodjinou [13]

Although many studies have investigated determinants of technology adoption, only a few have examined determinants of adoption of agricultural biotechnology and even fewer have examined determinants of adopting biofortification [23, 24, 25]. In addition to traditional plant breeding methods such as evaluation of accessions, conventional breeding and transgenic breeding, researchers are increasingly using biotechnology as a tool to meet the ever-changing end-user needs and the challenges imposed by climate change with the attendant increased disease and pest pressure. Biofortification contributes to addressing nutrition. Hence, inadequate empirical evidence exists on the role and relative importance of technology attributes alongside farmer, household, institutional and agro-ecological

factors in the uptake of biofortified crop varieties among smallholder farmers. In the present analysis we examine both the adoption and intensity of adoption of the three currently promoted biofortified crops in Uganda namely, Orange Fleshed Sweet Potato (OFSP), Quality Protein Maize (QPM), and High Iron Beans.

Objectives

The general objective of this study is to understand the factors that influence the uptake of biofortified crop varieties (BCVs) among smallholder farmers in Uganda. The specific objectives are to:

- (i) Characterize adopters and non-adopters of biofortified crop varieties across important socioeconomic and demographic characteristics.
- (ii) Establish and empirically examine determinants of uptake (adoption and intensity) of biofortified crop varieties by smallholder farmers and their relative importance.

METHODOLOGY

Analytical model

Several factors influence farmers' decision to adopt or reject new technologies, including biofortified crop varieties meant to increase productivity and nutrition. The factors include differing resource endowments, education level, aims and objectives, and utility preferences. Qualitative response models such as Probit, Logit and Linear Probability Models are the gold standard when analyzing such a dichotomous dependent variable [26, 27]. The biggest drawback with these models is that they do not measure the intensity of technology adoption [28]. Thus, the Tobit model [29] is usually used to analyze the intensity of technology adoption. The Tobit model, however, also imposes restrictions that the variables and coefficients determining whether and how much to adopt decisions are identical, which may not always be true [30]. The alternative is to use a Double-hurdle model such as the Heckman model and the two-step combination of the Probit and Truncated regression models. In estimating the Double-hurdle model, a Probit regression (using all observations) is followed by a truncated regression on the non-zero observations (adopters only) [30].

Empirical model

The double-hurdle model was thus used to analyze the drivers of both adoption and the intensity of adoption of biofortified crop varieties (BCVs). The model was preferred because it addresses the fact that a farmer makes two sequential decisions with regard to adopting biofortified crop varieties. The model analyzes instances where a farmer may or may not adopt the BCVs and then the intensity

by which the technology is applied. Each hurdle (decision) is conditioned by the farmer's socio-economic characteristics and technology-specific attributes, among other factors that may include household, community, institutional and agro-ecological factors. In the present research, adoption intensity was measured in terms of the proportion of total output, which is biofortified crop production. Following Greene [31], the panel probit model can be specified as follows (equation 1):

$$y_{it}^* = x'_{it}\beta^0 + \epsilon_{it}, \quad t=1, \dots, T, \quad i = 1, \dots, N \quad (1)$$

Where y_{it}^* is a latent variable describing the farmer's decision to adopt biofortified crop varieties (BCVs) and $y_{it} = 1 (y_{it}^* > 0)$; β are the coefficients to be estimated.

The data consist of N observations on $Z_i = (y_i X_i)$ where $y_i = (y_{i1}, y_{i2}, \dots, y_{iT})$ and the T rows of the $T \times K$ matrix X_i and x'_{it} , $t = 1, \dots, T$.

The disturbances T -variate are normally distributed with $T \times T$ positive definite covariance matrix Σ . The typical element of Σ is denoted σ_{ts} . The standard deviations, $\sqrt{\sigma_{tt}}$ are denoted σ_t . The data on x_{it} are assumed to be strictly exogenous, implying that $\text{cov}[x_{it}, \epsilon_{js}] = 0$ across all individuals i and j and all periods t and s . Hence, the empirical Panel Probit model to be estimated is the following, based on the latent regression (Equation 2).

$$y_{it}^* = \beta_1 + \sum_{k=2}^{15} x_{k,it} \beta_k + \epsilon_{it}, \quad y_{it} = 1 (y_{it}^* > 0). \quad i = 1, \dots, 3200; \quad t = 2012 \text{ and } 2014 \quad (2)$$

$Y_{it} = 1$ if a household grew at least 1 biofortified crop variety (BCV) in year t

$x_{2,it}$ = Sex of household head (1 = male and 0 = female)

$x_{3,it}$ = Formal schooling of household head (number of years)

$x_{4,it}$ = Household size (number of persons in the household)

$x_{5,it}$ = Total size of land (acres)

$x_{6,it}$ = Number of extension visits over the last year (number of visits)

$x_{7,it}$ = Household membership to a farmer group (1 = Yes and 0 = No)

$x_{8,it}$ = Household owns a radio (1 = Yes and 0 = No)

$x_{9,it}$ = Household owns a mobile phone (1 = Yes and 0 = No)

$x_{10,it}$ = Regional location (1 = Southwest and 0 = North)

In the second hurdle, the dependent variable is the proportion of total crop harvest that is comprised of biofortified crop varieties. The estimated truncated regression model to determine the intensity of adoption of biofortified crop varieties is presented in equation (3). This equation is estimated using only non-zero observations [30].

$$Z_{it} = \omega'_{it}\beta^0\mu_{it} \quad (3)$$

where z_{it} is the observed dependent variable or the fraction of total land cultivated that is devoted to cultivation of biofortified crop varieties (observed only for $Z_{it} > 0$), β are the coefficients to be estimated.

ω_{it} are variables explaining the intensity of adoption of BCVs (including sex of household head, formal schooling of household head, household size, extension visits, household membership to a farmer group, ownership of radio, ownership of mobile phone and household membership to a Savings and Credit Cooperative Organization (SACCO)), μ_{it} is the error term assumed to be independent and normally distributed as $\mu_{it} \sim N(0, \delta^2)$.

Since the double-hurdle model allows for the possibility that the same factors may impact each decision differently, a similar (but not exactly the same) set of independent variables were used to estimate the adoption and intensity models. To deal with possible heteroscedasticity, the regressions were estimated using robust standard errors. The values of variance inflation factors (VIF) for both models indicated no multicollinearity.

Data and Sources

As part of USAID Feed the Future (FtF) Innovation Laboratory for Nutrition, a cross-sectional quasi experimental design with a carefully selected counterfactual study was implemented in six districts selected in Western and Northern Uganda in three time periods 2012, 2014 and 2016 constituting three waves of panel data. A validated questionnaire was used to collect data from selected households in each district. Eligible households were chosen on the basis of having at least one of the following; one child aged less than 24 months and adult woman of child-bearing age. The present study uses only the 2012 and 2014 data. The study had a sample of 6,400 households.

Data collected included household identification information, demographics of respondents, health and sanitation, including anemia and malaria parasite assessment in children six months or older, and women of child-bearing age,

nutritional status, gender issues, general household information on: socio-economic status, agriculture and income generation, food security and hunger, diet-food consumption patterns among others. The data were then analyzed using Stata 16 statistical software.

RESULTS AND DISCUSSION

Socioeconomic and demographic characteristics of households

Table 1 summarizes the descriptive statistics of some of the variables used in the model for the two survey waves utilized for the analysis. The summary results show that on average the changes in the variables between the two survey waves for most of the variables were relatively small. For example, the mean acreage in 2012 was 7.46 acres while in 2014 it was 7.63 acres. The proportion of male-headed households decreased from about 91.02% in the 2012 survey wave to 86.67% in the 2014 survey wave. There were more male headed families in the 2012 survey wave compared to the 2014 survey wave.

As can be discerned from Table 2, adopters and non-adopters of biofortified food crops differ in significant ways across important household characteristics, including sex of household head, membership in farmer groups and visits by extension agents, which are very critical for access to agricultural and nutrition information. There are no significant differences above 5% among the two groups regarding the level of access to the other important sources of information (radio, mobile phone) and membership to a savings and credit cooperative organization (main source of rural credit). However, the two groups differ significantly in terms of levels of annual agricultural income and usage of other improved agricultural technology. The importance of these household characteristics is later manifested quantitatively in the regression results.

Factors that affect adoption of biofortified crop varieties

The regression results presented in Table 3 shows that, nearly all the hypothesized variables significantly influence the household decision to adopt bio-fortified crop varieties at varying power (see marginal effects). The exception being sex and education of household head. The regional variable of a household located in Northern Uganda strongly suggests that a household located in Northern Uganda has a high probability of deciding to adopt bio-fortified crop varieties. A closer look at the descriptive statistics revealed that of all the farmers who adopted at least one BCV, 89.2% were residing in Northern Uganda with only 10.8% residing in Southwestern Uganda. The proportions for 2012 were 90.4 % for Northern Uganda and 9.6% for Southwestern Uganda. The proportions for 2014 were still consistent

at 86.4% for Northern Uganda and 13.6% for Southwestern Uganda confirming the high probability noted from regression results. This of course may have much to do with the fact that four out of the six districts studied were in Northern Uganda, with only two in Southwestern Uganda.

All other variables held constant, households regularly visited by extension staff also have a high probability of 5.6% of adopting bio-fortified crop varieties, followed by ownership of a mobile phone with a probability of 3.3%, followed by household size with a probability of 0.6%.

The amount of land owned by a household increases the probability of adopting bio-fortified crop varieties by just 0.003%. Extension staff visits and mobile phone ownership combine to create a very powerful force as a source of information for rural households and that appears to drive the decision to adopt bio-fortified food crops in our analysis.

The results underscore the power of information above formal education and other household resources like land in as far as the decision to adopt bio-fortified crop varieties is concerned. The strong association (at 1% significance level) between adoption and ownership of a mobile phone suggest that access to information may be more important than other resources such as education of household head in as far as adoption decisions are concerned. Similar or close results have been observed by other authors in connection with other commodities. These include studies such as Nkonya *et al.* [18], Doss [19] and Akankwasa *et al.* [20] whose research show that membership to farmer groups, access to credit, access to markets, and access to extension services significantly influence agricultural technology adoption.

In as far as information is concerned, our results are consistent with Kabunga [22] who, focusing on tissue culture banana technology among a sample of Kenyan farmers, separately examined awareness exposure (having heard of the technology) and knowledge exposure (understanding the attributes of the technology). Their results show that the parameters differ considerably from those from a classical adoption model when accounting for heterogeneous knowledge exposure. The authors underscore the importance of their results for other technologies that are knowledge-intensive and require considerable adjustment in traditional practices. Whereas bio-fortified crop varieties may not require significant adjustments in farming practices, they can be said to be knowledge-intensive as a farmer would need to be educated about and appreciate the nutritional benefits of BCVs. The results suggest that the information transmitted through agricultural

extension staff, and telephone goes beyond awareness creation to include knowledge exposure. Moreover, the type of BCVs involved in this study were, to a large extent, visually discernable from the traditional varieties. The Orange Fleshed Sweet Potato (OFSP) are clearly orange colored, the Quality Protein (QPM) Maize or Longe V locally called Nnalongo is known by farmers to have two cobs on each plant, while the iron-rich beans varieties that red in colour.

The present study found a positive and significant influence on the adoption of BCVs by the key variables hypothesised. However, literature on adoption presents mixed and largely inconclusive results concerning the association between these variables and the adoption decision. Some studies report a positive and significant association between the education level of the farmer and the adoption of agricultural technologies [15, 32]. In contrast, other studies have found a negative and significant association between education level and adoption of agricultural technology [20, 33]. Similarly, while some studies found a positive and significant association between farm size and adoption of agricultural technology [19, 34], other studies found a negative and significant relationship between farm size and technology adoption [35]. The negative relationship between farm size and the adoption decision has been explained based on risk aversion on the part of the farmer.

Factors that affect the intensity of adoption of biofortified varieties

As earlier noted, in the second regression, we estimated a truncated regression on the adopters only to investigate factors that determine the intensity of adoption of bio-fortified crop varieties. The results, also presented in Table 3, suggest that the size of land owned by a farmer negatively influences the intensity of adoption of bio-fortified crop varieties. The location variable (region) was positive and significant in the adoption intensity decision, again underscoring the high probability to adopt and use biofortified crop varieties by farmers living in Northern Uganda compared to those living in Southwestern Uganda.

CONCLUSION

The combination of factors, including visits by extension staff, household size, total land acres, and ownership of mobile phone underscore the importance of information as a critical driver of the decision to adopt biofortified crop varieties (BCVs) among smallholder households in Uganda.

The present analysis is unable to conclusively predict the key drivers of the intensity of adoption of biofortified crop varieties among smallholder households in

Uganda. This may be probably because since biofortified crop varieties are relatively new (2012-2016) in the agriculture system of Uganda the intensity of their adoption is still too low to be captured by quantitative regression analysis models. Authors' Contributions: BB, PW, NK, SG, and EA had a significant role in the design and implementation of the panel study and/or panel data cleaning and processing. RIE analyzed the data under the guidance of BB and contributed to manuscript revision. BB wrote the paper and had primary responsibility for the final content. All authors have read and approved the final manuscript.

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Table 1: Summary Statistics of the variables by BCV adoption and Survey wave

Variable	2012 Survey Wave			2014 Survey Wave		
	Pooled	Adopters of BCVs	non- adopters of BCVs	Pooled	Adopters of BCVs	non- adopters of BCVs
Total land (acres)	7.46 (5.85)	8.74 (5.91)	7.00 (5.76)	7.63 (6.48)	10.40 (7.06)	7.21 (6.25)
Education of household head (years)	6.33 (3.40)	6.98 (3.32)	6.08 (3.40)	6.13 (3.39)	6.66 (3.37)	6.06 (3.38)
Household size	6.00 (2.58)	6.29 (2.57)	5.90 (2.57)	6.74 (2.31)	7.17 (2.31)	6.69 (2.30)
Proportion (percent)						
Sex of household (1=male, 0=female)	91.02	93.66	90.07	86.67	89.01	86.29
Membership to farmer group	31.69	39.88	28.71	22.80	27.91	22.10
Visited by extension agent	32.08	38.37	29.75	15.96	17.58	15.84
Membership to SACCO	55.55	59.32	54.21	60.84	69.01	59.75
Own radio	62.97	65.86	61.90	58.48	63.74	57.98
Own Phone	51.29	58.11	48.76	56.97	63.96	56.06
Number of observations (n)	3,597	993	2,588	3,302	455	2,815

Table 2: Characteristics of adopters and non- adopters of biofortified food crop varieties

Variable	Pooled	Adopters of BCVs (n=1,395)	non-adopters of BCVs (n =4,979)	Test
	Mean			T-statistic
Education of household head (years)	6.25 (3.40)	6.89 (3.33)	6.07 (3.39)	-8.06
Total land (acres)	7. 58 (6.13)	9.23 (6.29)	7.12 (6.00)	-11.47
Household size	6.34 (2.49)	6.53 (2.52)	6.29 (2.47)	-3.27
Value of agric. Income (UGX)	1,379,858 (1,705,898)	1,551,828 (1,619,519)	1,340,043 (1,722,931)	-4.86***
	Proportion (percent)			P-Value
Sex of household	90.6	93.2	89.9	0.0002
Membership to farmer group	28.3	37.0	25.9	0.000
Visited by extension agent	25.5	32.9	23.4	0.000
Membership to SACCO	57.5	62.2	56.2	0.297
Own radio	61.3	65.1	60.2	0.227
Own Phone	53.7	59.8	52.0	0.391
Other improved agric. Technology	42.8	71.7	36.4	0.000

Note: *** means significant at 1 percent level; Standard Deviation in parentheses;
UGX = Uganda Shillings

Table 3: Factors that affect adoption and intensity of adoption of biofortified crop varieties

Variables	Panel Probit model results (adoption model)	Marginal effects	Truncated regression model (Intensity of adoption model)
	Coefficients	Marginal effects	Coefficients
Sex of household head (1=male,0=otherwise)	0.031 (0.121)	0.006	0.119 (4.359)
Education of household head (years of schooling)	0.012 (0.011)	0.003	0.541 (0.349)
Household size (number)	0.0273** (0.014)	0.006	-0.489 (0.453)
Total land (acres)	-0.000903** (0.000447)	0	-
Extension visits (1=yes, 0 otherwise)	0.270*** (0.088)	0.056	3.211 (3.197)
Farmer group membership (1=yes, 0 otherwise)	0.0434 (0.073)	0.009	1.612 (2.174)
Own radio (1=yes, 0 otherwise)	0.110 (0.069)	0.023	1.599 (2.484)
Own mobile phone (1=yes, 0 otherwise)	0.160** (0.072)	0.033	3.322 (2.431)
Region (1=northern, 0=southwestern)	0.690*** (0.087)	0.142	14.572*** (5.557)
Member of SACCO (1=yes, 0 otherwise)	-	-	-1.412 (2.652)
Constant	-2.154*** (0.159)		33.816*** (7.280)
Sigma			15.918*** (0.759)
Insig2u	-2.254 (0)		
Observations	2,804		235

Notes:

1. Robust standard errors in parentheses
2. ***, **, * means significant at 1%, 5% and 10% significance level, respectively
3. Dependent variable for panel probit model is whether household grew at least one BCV while the dependent variable for the truncated regression model is proportion of total crop harvest that is comprised of biofortified crop varieties

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