

# Understanding Drivers of Adoption of Crop Bio-Fortification in Zimbabwe: Implications for Food Policy

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# **Understanding Drivers of Adoption of Crop Bio-Fortification in Zimbabwe: Implications for Food Policy**

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## **Abstract**

The study used secondary data collected from 2,913 households to estimate actual and potential adoption rates of bio-fortified crop varieties in Zimbabwe and determinants of exposure to and adoption of bio-fortification. It found that 88.6% of the households were aware of the technology while 46.3% had accessed at least one variety of the bio-fortified crops. Overall, 47.0% had been fully exposed to at least one bio-fortified crop variety, thereby limiting the actual adoption rate to about 41.0%, when in fact the potential adoption rate could have reached 87.0% had the entire population in the eight districts been exposed. The exposed sample adoption rate of 88.0% implies a substantial population adoption gap of 46.0%, emanating from the incomplete exposure of the target population to the technology. Results of Average Treatment Effects (ATE) adoption estimation using probit regression analysis found age of household head, size of arable land, membership to saving and lending groups, contact with extension, access to market information, agro-ecological potential, farmer perception and irrigation to be significant drivers of adoption. The study recommends increased promotional activities for the bio-fortified crops centred on the provision of well-structured agricultural support services coupled with nutrition-sensitive market information and training.

**Key words:** Awareness, Access, Exposure, ATE estimation, adoption gap

## 1. Introduction

In Zimbabwe, agriculture is key to food security, health and nutrition among other benefits, and several policy interventions have targeted the sector to enhance health and nutritional outcomes of the population. Maize remains the staple and dominant food security crop for the majority of the Zimbabwean population, and government policy in the form of input subsidies, producer price support, strategic grain reserve, pests and disease control, etc., has often targeted the maize crop towards the attainment of national agriculture policy objectives of food and nutritional security (GoZ 2018). The persistently high levels of poverty, particularly in rural areas, consolidate the dominance of maize as the major diet and food security crop with little dietary diversification. Mere access to adequate maize does not necessarily translate to food and nutrition security. The 2014 National Nutrition Survey revealed that while the frequency of meals seemed to be adequate, dietary diversity has remained a big challenge since only 26% of children under five years consumed more than three food groups (WFP 2014). Generally, the diet of most children is composed of maize grain and other cereals, with little of protein-rich foods.

For Zimbabwe to adequately address the issue of food and nutrition security, calls have been made by various stakeholders to promote and prioritize interventions that enhance household nutritional outcomes in food security programmes. Several options have been considered over the years, such as enhancing food diversity, industrial fortification, supplementation and public health measures, but all have not been able to adequately address the malnutrition problem. Emerging on the shopping list of possible interventions is the concept of bio-fortification. In heeding to the call for innovations to maximise nutritional outcomes in agricultural programmes, the Government of Zimbabwe (GoZ)'s Crop Breeding Institute (CBI) in collaboration with the International Maize

and Wheat Improvement Centre (CIMMYT) and the International Centre for Tropical Agriculture (CIAT), has, since 2013, consolidated its research efforts towards the development of nutritionally-superior crop varieties. The idea has been to target staple crops that have far-reaching impacts on society as they are widely consumed by the general population. Breeding programmes by the consortium, under the HarvestPlus banner, have developed bio-fortified maize and bean crop varieties in the form of Pro-Vitamin A (Orange) Maize and iron- and zinc-enriched sugar beans. The basic or foundation seeds for these crop varieties are provided free-of-charge to selected seed companies for multiplication into certified seed for sale as a hybrid seed to farmers.

Notwithstanding Zimbabwe's concerted efforts towards improving food and nutrition security through strategies such as input subsidies, producer price support, strategic grain reserve, land reform, pests and disease control, food diversity, industrial fortification, supplementation and public health measures over the years, the challenge of food and nutrition insecurity is still prevalent. Although the country has registered remarkable progress in reducing malnutrition (both underweight and wasting) in children under the age of five years over the past three decades, the prevalence of these indicators has continued to be significantly high. A common misconception has been to associate maize availability and affordability with food and nutritional security. The nutritional aspect of the commodity (maize grain) is often overlooked in food security policy considerations (WFP 2011). The food utilization component of food security, particularly regarding how the household uses the acquired food and the ability of individual people to absorb and metabolize nutrients, is generally considered to be of less relevance in academic and policy domains. This is despite the fact that maize is the most commonly produced<sup>1</sup>, affordable and

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<sup>1</sup> Maize production account for approximately 80 percent of national arable land allocated to crop production on an annual basis (Ministry of Agriculture, Various Crop Assessment Reports).

widely consumed food source in the country, especially among the low-income households' majority of whom are resident in rural areas. The dominance of maize has limited the country's ability to adequately address the issues of food and nutrition security from its multiple-dimensional perspective of adequate quantity, quality and socio-cultural acceptance. Its richness in energy and fibre with limited content of proteins, vitamins and minerals is a major weakness towards attainment of food and nutrition security in the country.

Bio-fortification was found to have great potential in alleviating the malnutrition problem of poor rural households in a cost-effective manner without necessarily changing their consumption patterns. However, the success of the bio-fortification initiative hinges upon the adoption of the bio-fortified crop varieties by the targeted rural households. Yet, the adoption pattern and its drivers are currently unknown. This study, therefore, seeks to conduct an adoption analysis of the bio-fortified maize and sugar beans to understand what the actual and potential rates of adoption are and factors influencing the adoption process by the rural households. The findings will be instrumental in informing policy on how the technology can be leveraged among farming communities for improved food and nutrition security. The rest of the paper is organized as follows: Section 2 presents the bio-fortification theory and empirical evidence; Section 3 outlines the methodology of the study; Section 4 describes the empirical application and data; Section 5 presents and discusses the results; Section 6 provides policy implications; and Section 7 concludes the study.

## **2. Bio-fortification and Technology Adoption Theory**

Bio-fortification refers to the breeding and genetic modification of staple food crops to improve their nutrient content and/or absorption (FAO 2006). According to Bouis and Saltzman (2017),

bio-fortification represents a feasible and cost-effective way of providing micro-nutrients to people who may not have adequate access to diets that are diverse in nutrients. However, the major advantage of bio-fortification is usually associated with once-off investment costs that are only incurred during the breeding process (LFSP 2017). Despite this advantage, much more work still needs to be done before the efficacy and effectiveness of these foods are proven, and current concerns about their safety, costs and impact on the environment are alleviated (Bouis et al. 2013). Bio-fortification helps in combatting hidden hunger through enhanced micronutrient supply in diets of poor households through their most accessible food crops (Zuma et al. 2018). It is a process used in crop breeding to increase the nutritional value of food crops by enhancing their levels of vitamins and minerals. Regular consumption of bio-fortified staple crops has the potential to generate considerable improvements in the nutrition and health status of humans (Bouis and Saltzman 2017). According to Bouis et al. (2013), bio-fortification interventions seek to incorporate micronutrient-dense traits in crop varieties that already have preferred agronomic and consumption traits among the target beneficiaries. If surplus production is encouraged, marketed surpluses of these crops may find their way into retail outlets, eventually reaching other consumers outside of rural areas. For this reason, bio-fortification is mainly targeted at low-income, poor rural farming households, who depend on their own primary production for their daily diets. However, the success of bio-fortification interventions will depend on the level of adoption by farmers (Ayinde et al. 2017).

Nevertheless, the adoption of an innovation can be understood as a decision-making process that an individual farmer goes through from the time of first hearing about the new concept to the time the farmer finally decides to take it up (Feder et al. 1985). Adoption may also refer to the integration of an innovation into the farmers' conventional farming practices over an extended

period (Melisse 2018). It is important to note that adoption may not be a permanent occurrence because an individual can decide to discontinue the use of an innovation for a variety of reasons that may be personal, social, institutional or bio-physical in nature. For instance, the availability of an alternative practice that is deemed superior or better in satisfying the needs of the farmer or household may result in discontinuation of the previously adopted practice. With regards to an agricultural innovation that has been made available, a farmer has two options to choose from: (i) adoption and (ii) non-adoption. Adoption can take place at the individual (farm level) or societal/regional level (aggregate adoption).

## **2.1 Empirical Evidence on Bio-fortification**

However, several empirical studies were conducted on the adoption of bio-fortification. Talsma et al. (2017) noted from a wide review of many empirical studies that bio-fortified crops have not yet been fully disseminated and made available to the target populations, thereby rendering acceptance and adoption findings hypothetical. They discovered that many bio-fortified crops are still in the development phase, with a few like sweet potato and orange maize now moving into the dissemination phase, from where more evidence on adoption and changes in consumer diets can be made available. Low et al. (2017) conducted a study on tackling vitamin A deficiency with bio-fortified sweet potato in selected SSA countries and concluded that bio-fortification needs to be specifically targeted at crops with high per capita consumption among the low-income groups in each country. In Nigeria, Ayinde et al. (2017) conducted a study to evaluate the determinants of adoption of a vitamin A bio-fortified cassava variety among smallholder farmers. Their study investigated both the level of adoption and determinants of adoption by farmers. Using a logit regression model, the authors found the level of adoption of the vitamin A bio-fortified cassava

variety to be around 38%. Factors that were found to have significant influence on adoption of the variety included access to vitamin A bio-fortified cassava planting material, access to media and contact with extension agents. The study recommended for increased awareness campaigns aimed at promoting the new cassava technology to sensitize the farmers and prioritization of accessibility of adequate planting material to farmers.

In Zimbabwe, like in many other SSA countries, bio-fortification is still a new phenomenon and a public health intervention aimed at enhancing the micro-nutrient content of food crops consumed by the majority of low-income farm families residing in rural areas (WFP 2014). There is still a dearth of empirical evidence with regards to extent of bio-fortification and acceptance of bio-fortified crops among the target beneficiaries. In South Africa, Zuma et al. (2018) conducted a study to explore the potential of pro-vitamin A bio-fortified (orange) maize in reducing vitamin A deficiency in rural households. They found one of the advantages of orange maize to be that it is cheaper compared to other vitamin A supplementation options since there is no need for additional fortification or vitamin amendments in people's diets once the maize has been produced at the household level. They note that due to the presence of carotenoids, pro-vitamin A maize is orange in colour, which is an attribute that may lead to negative perceptions about the maize variety by farmers and consumers who prefer white maize. They recommended for more studies to assess farmers' perceptions of and willingness to adopt the orange maize varieties and their potential markets.

Another study conducted on pro-vitamin A maize in Zambia was done by Lividini and Fiedler (2015), who assessed the potential of the orange maize as a public health intervention against

micro-nutrient deficiency in rural areas. Using a logistic regression adoption function, they estimated the proportion of households adopting, producing and consuming the pro-vitamin A maize each year over the next three decades. The authors assumed an adoption ceiling of 20% and concluded that implementation of bio-fortification interventions would result in an average additional intake of 12% of the orange maize if the 20% adoption rate could be achieved and maintained. They recommended increased investment in bio-fortification promotion since it exhibited great potential to become a highly cost-effective addition to public health interventions aimed at combatting hidden hunger. According to Zuma et al. (2018), bio-fortification interventions will work well when targeted at staple foods and women's crops since women often take responsibility for household dietary needs. Maize, as a staple crop for most people in Southern Africa, presents huge potential for cost-effective incorporation of essential vitamins and micronutrients in the diets of many rural households. Together with sugar beans, which is a widely acceptable relish, pro-vitamin A (orange) maize and quality protein maize (QPM) provides a great opportunity for effective bio-fortification of poor people's diets.

Most studies, however, conducted to assess the adoption of new technologies and programmes have tended to simply compute percentages of adopters from survey samples (Nguezet et al. 2012). Diagne and Demont (2007) note that although sampling may be truly random, observed sample adoption rates may not consistently predict the actual adoption rate for the entire target population. The reason cited is that most commonly used predictors of adoption rates suffer from either "selection bias" or what they call "non-awareness" bias, leading to the generation of biased and inconsistent estimates of population adoption rates and effects of their determinants (Nguezet et al. 2012). As such, the use of counterfactual Average Treatment Effects (ATE) in evaluating the adoption of technological innovations is therefore advocated for Dandedjrohoun et al. (2012)) also

argue that there has not been adequate attention devoted to the role that information plays in aiding the adoption process and determining the adoption outcomes. Of particular importance is the fact that although awareness of the existence of technology is a primary condition for its adoption, in principle, some farming households can start using the innovation without really knowing about its characteristics and/or performance (Diagne 2010). Thus, any adoption study that fails to take into consideration the aspect of awareness, when a technological innovation may not be universally known across the entire target population, leads to erroneous results and conclusions regarding its potential adoption. Thus, to consistently estimate the true adoption rate and its determinants, a more appropriate approach entailing the use of the ATE estimation framework can be adopted from the works of Diagne (2010); Diagne (2006); Diagne and Demont (2007); Nguezet et al. (2012).


The justification for the use of this ATE framework instead of the other classical techniques, such as Logit, Probit and Tobit models, is that the latter are liable to generate biased and inconsistent estimates even when based on truly randomly selected samples (Nguezet et al. 2012). Within the context of this study, “treatment” entails exposure to the technology (bio-fortified crops) and the ATE becomes the population mean adoption outcome when all farmers in the target population have been exposed (are aware and have access) to the technology. The ATE estimate, therefore, measures the intrinsic value of the technology as it relates to revealed preference (potential demand) by the target population (Simtowe et al. 2011). Thus, the population mean adoption outcome as measured by the ATE parameter becomes the mean potential adoption outcome for the entire target population. The adoption gap, which in essence measures the unmet aggregate demand for the technology, signifies the population exposure bias, which is the difference between

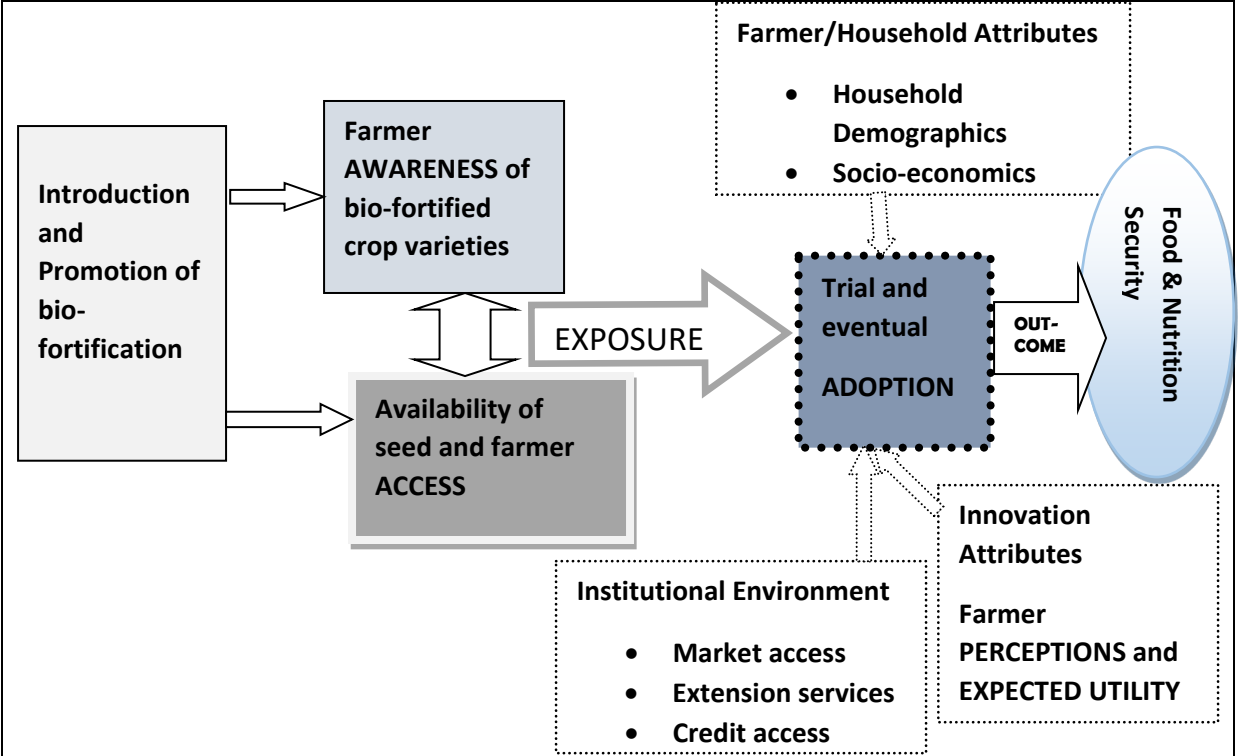
the population mean potential adoption outcome and the mean of the actual observed adoption outcome (Diagne and Demont 2007). The gap is said to exist because of incomplete diffusion of the technology (Simtowe et al. 2011). Similarly, the average adoption outcome within the segment of the population that is fully exposed to the technology corresponds to the average treatment effect on the treated (ATT) (Nguezet et al. 2012) while the average treatment effect on the untreated (ATU) corresponds to the adoption rate in the non-exposed subpopulation (Dandedjrohoun et al. 2012). The observed proportion of adopters in the population corresponds to a measure of joint exposure and adoption (JEA), which is the proportion of individuals who have been exposed to the technology and go on to adopt it. Diagne and Demont (2007) contend that the JEA alone does not truly inform about adoption since it contains two types of conceptually different information: (i) awareness or knowledge of the technology among the target population (*diffusion*); and (ii) utilization of the technology by the target population (*adoption*). Dandedjrohoun et al. (2012) refer to this difference between the observed population JEA and the population potential adoption rate (ATE) as the population adoption gap (GAP), also known as the population non-exposure bias (NEB). Finally, the difference between the ATE and the ATT constitutes what is known as the population selection bias (PSB) (Simtowe et al. 2011).

### **3. The Methodology of the study**

The approach adopted for the study is outlined in this section, including the conceptual framework, analytical framework, research design and description of explanatory variables used in the study.

### 3.2 Conceptual framework

The adoption of bio-fortified crops at the household level can be conceptualized within the lens of innovation systems in agriculture and rural development. The way farming households make decisions on whether to adopt a technological innovation can be understood from the expected utility theory (Joao et al. 2015). The expected utility theory (EUT) postulates that after comparing the innovation with the conventional technology, a farmer decides to adopt if the expected utility derived from adopting is greater than that of continuing with the traditional technology. Although the utility function is unobservable, it is assumed to be a function of a vector of observed variables and an error term.  Figure 1 presents a schematic framework of how a technological innovation, such as bio-fortified crops, gets introduced and promoted for farmers to know, gain access to seeds and exposure in order to be able to make necessary decisions on whether to adopt or not. The introduction and promotion of bio-fortification bring about the availability of and access to seeds and awareness about their existence and benefits to farmers. These two aspects (awareness and access) combine to constitute exposure of the farmers to the bio-fortification technology, which is key for a variety trial and adoption to take place. In that decision-making process, there are several households, bio-physical, technological and institutional factors that are hypothesized to come into play, in terms of influencing the final decision regarding whether to adopt or not. It is the eventual decision by the farmers to adopt the bio-fortified crop varieties that ensures attainment of the ultimate food and nutrition security outcome at the household level that is desired by policy.



Source: Compiled by Author

**Figure 1: Schematic presentation of bio-fortified crops adoption at household level**

### 3.3 Analytical framework

To consistently estimate the adoption rate of bio-fortified crops and determine factors that influence it, this study has followed the Average Treatment Effect (ATE) approach proposed by Diagne and Demont (2007) and Diagne (2006; 2010). The ATE estimation framework has since been used widely in adoption studies in Africa (see Dandedjrohoun et al. 2012; Nguezet et al. 2012; Simtowe et al. 2011). As highlighted by Diagne and Demont (2007) the ATE approach becomes necessary since classical techniques such as Logit, Probit and Tobit models are liable to yield biased and inconsistent estimates even when the sample is randomly selected. According to Nguezet et al. (2012), in addition to the non-exposure bias that renders the observed sample adoption rate to systematically underestimate the potential adoption rate for the target population, there is also the selection bias, which may result in under- or over-estimation of the sample

adoption rate. Combined, both types of biases render the estimation parameters of classical adoption models to be inconsistent. The true population adoption rate can be consistently estimated using the ATE framework, which estimates the effect of a “treatment” (bio-fortified crops, in this case) on a randomly selected farming household from the target population (Diagne, 2006). The adoption rate among the farming households exposed to the technology is given by the average treatment effect on the treated (ATT), and the potential adoption rate among the non-exposed households becomes the average treatment effect on the untreated (ATU) (Nguezet et al. 2012, Simtowe et al. 2011). As argued by Nguezet et al. (2012), there can still be another constraint to adoption in the form of a lack of access to the technology, even though the farmers may have been made aware of the technology. A farming household may fail to be classified as an adopter merely because of a lack of access to the bio-fortified crop varieties. Thus, full exposure, in terms of unconstrained awareness and access to the bio-fortified varieties, becomes a necessary condition for adoption. In this study, the ATE adoption framework for estimation of potential adoption rates when the farmers either have unrestricted awareness and/or unrestricted access to the bio-fortified crop varieties is adopted. Furthermore, the determinants of bio-fortification awareness, access and adoption are estimated, including the related adoption gaps.

#### **4 Empirical application**

To accomplish the study objectives, we adopt the potential outcome framework proposed by Nguezet et al. (2012) in which every farming household in the target population has four potential adoption outcomes: an outcome with awareness and access to bio-fortified crop seed say  $y_{11}$  ( $w = 1$  and  $s = 1$ ), an outcome when aware but do not have access  $y_{10}$  ( $w = 1$  and  $s = 0$ ), an outcome with no awareness but access  $y_{01}$  ( $w = 0$  and  $s = 1$ ), and an outcome with no awareness and no

access  $y_{00}$  ( $w = 0$  and  $s = 0$ ). Hence, the observed adoption outcome  $y$  can be expressed relative to the four potential adoption outcomes as:

$$y = wsy_{11} + (1 - s) w y_{10} + (1 - w) s y_{01} + (1 - w) (1 - s) y_{00} \quad (1)$$

where  $y$  is the adoption outcome,  $w$  stands for awareness and  $s$  for access to seed for bio-fortified crops

Since joint awareness and access are a necessary condition for adoption, it implies that  $y_{10} = y_{01} = y_{00} = 0$  and equation (1) simplifies to:

$$y = wsy_{11} \quad (2)$$

As noted by Awotide and Olawale (2014) as well as Nguezet et al (2012), since the potential adoption outcome is always 0 when the household is not aware and/or does not have access to the technology, the potential outcome  $y_{11}$  is the treatment effect for a given household when it has both awareness and access. The ATE estimate, which encompasses both awareness and access, is then derived from the expected value  $E(y_{11})$ .

Given a random sample of observations  $(y_i, w_i, s_i, x_i)$ , where  $i=1, \dots, n$ , the ATE parameters outlined above can be estimated using different estimation procedures. For this study, the parametric estimation procedure described in detail by Diagne and Demont (2007) is employed. The estimation specifies a parametric model for the conditional expectation of the observed adoption status  $y$  given the vector of covariates  $x$ , which is restricted to the sub-population sample of individual farming households that are aware ( $w = 1$ ) of the technology:

$$E(y | x, d = 1) = g(x, \beta) \quad (3)$$

where  $g$  is a known (and possibly non-linear) function of the vector of covariates  $x$  and the unknown parameter vector  $\beta$ , which is to be estimated using standard Least Squares (LS) or Maximum Likelihood Estimation (MLE) procedures using the observations  $(y_i, x_i)$  from the subsample of farming households with awareness ( $w = 1$ ) and access ( $s = 1$ ) only, with  $y$  as the dependent variable and  $x$  the vector of explanatory variables. The variables  $w$  and  $s$  are indicators for exposure to the bio-fortification technology, denoted by  $d$ , where  $d = ws_i = 1$  denotes exposure of an individual farming household  $i$  and  $d = ws_i = 0$  corresponds to otherwise. With an estimated parameter  $\hat{\beta}$ , the predicted values are calculated for all the observations  $i$  in the sample (including the observations in the non-exposed sub-population sample). The ATE, ATT and ATU are then estimated by taking the average of the predicted estimates across the full sample (for ATE) and respective subsamples (for ATT and ATU), such that:

$$\hat{ATE} = \frac{1}{n} \sum_{i=1}^n g(x_i, \hat{\beta}) \quad (4)$$

$$\hat{ATT} = \frac{1}{n_1} \sum_{i=1}^n d_i g(x_i, \hat{\beta}) \quad (5)$$

$$\hat{ATU} = \frac{1}{n - n_1} \sum_{i=1}^n (1 - d_i) g(x_i, \hat{\beta}) \quad (6)$$

where  $n$  is the sample size and  $n_1 = \sum_{i=1}^n d_i$  is the size of the treated sample.

The effects of the determinants of adoption as measured by the  $K$  marginal effects of the  $K$ -dimensional vector of covariates  $x$  at a given point  $\bar{x}$  are estimated as:

$$\frac{\partial E(y_i | \bar{x})}{\partial x_k} = \frac{\partial g(\bar{x}, \hat{\beta})}{\partial x_k} \quad k = 1, \dots, K$$

(7)

where  $k$  is the  $k^{\text{th}}$  component of  $x$ .

Using the parametric regression-based estimators outlined above and assuming a binary Probit model, the empirical analysis based on the adoption command in STATA generates estimates of the ATE, ATT, ATU, the joint exposure and adoption (JEA), the population adoption gap (GAP) and the population selection bias (PSB) parameters. The equations for calculating the JEA, GAP and PSB are as follows:

$$\hat{JEA} = \frac{1}{n} \sum_{i=1}^n y_i \quad (8)$$

$$\hat{GAP} = \hat{JEA} - \hat{ATE} \quad (9)$$

$$\hat{PSB} = \hat{ATT} - \hat{ATE} \quad (10)$$

The parametric estimation of ATE reduces, in this case, to a standard binary Probit estimation, which is restricted to the fully exposed sub-population sample. The binary Probit regression analysis of the determinants of awareness and access (also called the propensity scores) is further conducted. The estimation of the determinants of awareness and access is important because it provides valuable information regarding the diffusion of innovation and factors that influence farmers' adoption decisions (Awotide and Olawale 2014).

The estimates presented in the results have been generated using the statistical package STATA, with the STATA add-on “*adoption*” command developed by Diagne and Demont (2007) to

automate the estimation of ATE adoption models. The *adoption* command is a STATA add-on command that works just like standard STATA regression commands. It internally makes use of various STATA standard estimation commands to execute the estimation procedures described above. Depending on the option chosen, it can also provide the inverse probability weighting (IPW) or parametric regression estimates of ATE, ATT, ATU, JEA, GAP and PSB.

## 4.2 Study Area and Data Collection

This study was conducted in Zimbabwe, where the focus was put on the production of two bio-fortified crops (maize and beans) by rural households across the country. We combined the two bio-fortified crops in the analysis of this study and assumed that if a farmer planted just one bio-fortified crop, either maize or beans, the farmer was considered as having adopted bio-fortification. Secondary data obtained from the HarvestPlus’ Livelihoods and Food Security Programme (LFSP) survey were used. The data were collected in early 2018, in which the sampling design for the survey was guided by the need to report with 95% statistical confidence the rural livelihoods and food security prevalence at the district level, which is the country’s third lowest administrative tier. The assessment survey covered eight districts<sup>2</sup> in three rural provinces<sup>3</sup> targeted with bio-fortification interventions since 2015. The primary sampling unit for the survey was the household, which was selected using the systematic random sampling method. After extracting the eight districts, the distribution of sampled households by province and district is presented in Table 1.

Table 1: *Sample size distribution by district and province*

<b>Province</b>	<b>District</b>	<b>Sample size</b>	<b>%</b>
	Makoni	402	13.8

<sup>2</sup> Gokwe, Guruve, Kwekwe, Makoni, Mount Darwin, Mutare, Mutasa and Shurugwi

<sup>3</sup> Manicaland, Mashonaland Central and Midlands

Manicaland	Mutare	369	12.7
	Mutasa	395	13.6
Mashonaland Central	Guruve	350	12.0
	Mount Darwin	349	12.0
Midlands	Gokwe South	350	12.0
	Kwekwe	347	12.6
	Shurugwi	351	12.0
<b>Total</b>	<b>8</b>	<b>2,913</b>	<b>100</b>

**Source:** HarvestPlus LFSP Bio-fortification Survey (2018)

Table 1 indicates that a total of 2,913 households were sampled across the eight districts by the assessment survey. The sample size averaged 364 households per district, with a minimum of 349 households in Mount Darwin (12.0%) and a maximum of 402 households in Makoni district (13.8%).

#### 4.2.1 Description of variables used in the estimation model

The variables used in the analysis of factors influencing the adoption of bio-fortified crops are outlined as follows:

**Table 2: Variable Description**

<b>Dependent variables:</b>	
AWARENESS	= 1 if the farmer is aware of at least one bio-fortified crop
ACCESS	= 1 if the farmer has had access to at least one bio-fortified crop variety
EXPOSURE	= 1 if the farmer is aware and has had access to at least one bio-fortified crop
ADOPTION	= 1 if the farmer adopted at least one bio-fortified crop for production
<b>Independent variables:</b>	
EDUCATION	= 1 if the household head is educated
GENDER	= 1 if the household head is male

AGE	= age of head of household in years
AGEsquared	= the square of the household head's age <sup>4</sup>
MARITALstatus	= 1 if household head is married
LANDsize	= agricultural land owned in hectares
ISALmembership	= 1 if the farmer is a member of an internal savings and lending group
LFSPtraining	= 1 if the farmer received training from LFSP
MARKETINFOACCESS	= 1 if the farmer has access to the market information for inputs and outputs
EXTENSION	= 1 if the household has access to agricultural extension
DRAFTPOWER	= 1 if the household has draft power
AEZ	= 1 if the district is in high potential agro-ecological zone
CREDIT	= 1 if the farmer has access to credit
PERCEPTION	= 1 if nutrition information is perceived as being useful
IRRIGATION	= 1 if the household has some irrigated land

A detailed description of the theoretical expectations about the marginal probabilities of selected variables on the adoption decision of production of bio-fortified crops by farming households is presented in Table 6 in Appendix 1.A. The marginal probabilities measure the expected change in the probability of a choice being selected with respect to a unit change in an independent variable (Munyungu et al. 2020).

## 5 Results and discussion

Descriptive and summary statistics of variables used in the analytical models are presented in Table 3 disaggregated by farmers' adoption status. Household demographic and socio-economic characteristics show that a typical rural household in the LFSP districts has a majority of household heads (88.5%) who are older (i.e. above 35 years), with only 26.0% of them headed by females.

<sup>4</sup> Introduced in the model to test for the linearity of age with adoption and access to bio-fortified crops varieties

With regard to educational achievements, more than half of the household heads (61.0%) can be classified as educated, having attained at least secondary level education. However, there are more educated household heads in adopting households (56.0%) than those in non-adopting households (44.0%), thereby supporting the widely held assertion that formal education positively influences technology adoption (Kassie et al. 2009; Mudombi 2013; Mwangu et al. 2020; Simtowe et al. 2011).

While the number of dependents per household is modestly low at around two among both adopting and non-adopting households, there is a statistically significant difference between their dependency ratios. Results displayed in Table 3 further show that access to essential agricultural support services is well pronounced among the farmers, with 93.4%, 88.0% and 79.1% respectively having access to agricultural extension, LFSP training and market information (input and output markets). The adopting households exhibit greater affinity for these services compared to non-adopters. A moderately high proportion of the households (55.4%) belong to community-based internal savings and lending (ISAL) groups, but membership to these groups is even higher among adopting (61.3%) than non-adopting households. According to Simtowe et al. (2011), participation in community-based groups or associations is a proxy for social capital. This result is consistent with the notion that group membership provides easier access to relevant information (Mwangu et al. 2020) and social capital positively influences technology adoption (Simtowe et al. 2011). Access to credit is exceptionally low (17.1%) but differs significantly between the two groups in favour of the adopters (65.3%). Over three-quarters (88.6%) of the farming households indicated they were aware of bio-fortified crop varieties (55.0% among adopters and 45.0% non-adopters), while the majority of them (89.2%) perceived the information they received on nutrition and bio-fortification to be useful. However, in terms of actual access to the bio-fortified crop

varieties, only 46.3% managed to access seed for planting. These figures indicate that not all the farming households (88.6%) that were aware of the bio-fortified varieties had access to the seeds. Indications are that the adopters were more exposed to essential information and institutional support, as evidenced by their having better access to agricultural support services (extension and markets) than non-adopters. Due to the awareness campaign and supply of seeds for bio-fortified crops under the LFSP programme, 45.2% and 40.1% of the households produced and consumed respectively at least one of the bio-fortified crop varieties.

**Table 3: Descriptive and summary statistics of household characteristics**

<b>Variables</b>	<b>Description</b>	<b>Total (N=2,913)</b>	<b>Adopters (N=1,566)</b>	<b>Non- Adopters (N=1,347)</b>	<b>Chi- Square/T- Test</b>
<b>Dependent</b>					
<b>AWARENESS</b>	Aware about bio-fortification (%)	88.60	54.98	45.02	50.1***
<b>ACCESS</b>	Access to at least one bio-fortified crop variety (%)	46.30	99.78	0.22	2143.4***
<b>Independent</b>					
<b>Perception</b>	Nutrition information useful (%)	89.20	55.97	44.03	47.1***
<b>Consumption</b>	Consumed at least one bio-fortified crop variety (%)	40.10	99.74	0.26	1656.2***
<b>Production</b>	Produced at least one bio-fortified crop variety (%)	45.20	99.77	0.23	2044.***
<b>Agro-ecological potential</b>	High potential district (%)	25.60	66.89	33.11	69.6***
<b>IRRIGATION</b>	Irrigated land dummy (%)	13.70	51.13	48.87	1.3
<b>EXTENSION</b>	Access to agricultural extension (%)	93.40	55.11	44.89	30.2***
<b>MARKETINFORMATION ACCESS</b>	Access to inputs and outputs market information (%)	79.10	57.23	42.77	45.4***
<b>CREDIT</b>	Access to credit (%)	17.10	65.33	34.67	32.4***
<b>LFSP Training</b>	Household received training from LFSP (%)	88.00	56.05	43.95	44.9***

<b>ISAL Membership</b>	ISAL Membership (%)	55.40	61.25	38.75	81.6***
<b>Draft Power</b>	Availability of draft power (%)	63.70	54.87	45.13	2.6
<b>Marital Status</b>	Marital status of household head (Married) (%)	75.00	54.65	45.35	2.8*
<b>GENDER</b>	Gender of household head (Female) (%)	26.10	51.45	48.55	2.2
<b>EDUCATION</b>	Educational Status of household head (Educated; > primary school) (%)	60.80	55.88	44.12	8.1***
<b>Age category</b>	Older experienced farmer; > 35 years (%)	88.50	55.18	44.82	18.2***
<b>Labour</b>	Number of agriculturally active household members (n)	3.89 (1.86)	4.01 (1.86)	3.74 (1.85)	3.998***
<b>Dependency Ratio</b>	Dependency ratio	0.27 (0.23)	0.26 (0.22)	0.28 (0.23)	-2.28**

Note: \* = significant at 10%, \*\* = significant at 5% and \*\*\* = significant at 1% level; Numbers in parenthesis represent standard deviation

**Source:** HarvestPlus LFSP Bio-fortification Survey (2018)

The test for independence between adopters and non-adopters using Chi-square and T-tests reveals that there is a significant difference for almost all the variables. This suggests that the variables have a high likelihood of influencing the exposure to and adoption of bio-fortification. It is important to note that exposure, in terms of awareness of and access to bio-fortified crop varieties, is generally high among the target population, implying that the diffusion of the technology is extensive among the target population.

## **5.2 ATE estimation of adoption rates of bio-fortified crops**

Results of the ATE estimation of adoption rates and gaps in the adoption of the bio-fortified crop varieties in the LFSP districts are presented in Table 4. All the parameters estimated are significant at the 1% level. The results are for the actual and the potential adoption rates (represented by the JEA and ATE, respectively) of the bio-fortified crop varieties. Also presented are the adoption gap as a result of incomplete diffusion of the technology, potential adoption rates among the “treated” (exposed) and “untreated” (unexposed) farming households (ATT and ATU) and the population

selection bias (PSB). The ATE represents the effect of a “treatment” on a farming household randomly selected from the population. It corresponds to exposure in terms of both awareness and access to the bio-fortified crop varieties. The ATE corresponds to the (potential) population adoption rate, that is, the adoption rate when the technology has been fully diffused, and all the farming households have been fully exposed to the technology.

**Table 4: ATE Estimates of Population Bio-fortification Adoption Rates**

<b>VARIABLE</b>	<b>AVERAGE TREATMENT EFFECTS</b>	<b>PARAMETER</b>
Population Potential Adoption Rate	ATE	0.87***
Adoption Rate among Farmers Exposed to Bio-Fortification	ATT	0.88***
Adoption Among Non-Exposed Farmers	ATU	0.86***
Actual Adoption Rate	JEA	0.41***
Adoption Gap	GAP	-0.46***
Population Selection Bias	PSB	0.10***
Observed Adoption Rates		
Adoption Rate of the Exposed within the Target Population	Ne/N	0.47***
Adoption Rate among the Adopting within the Entire Population	Na/N	0.42***
Adoption Rate among the Exposed	Na/Ne	0.89***
Number of Observations	N = 2,729	
Number of Exposed Farmers	Ne = 1,280	
Number of Adopters	Na = 1,131	

Note: \*\* = significant at 5% and \*\*\* = significant at 1% level

The observed adoption results presented in Table 4 show that only 47.0% of the farming households had been fully exposed to at least one bio-fortified crop variety in 2018. This incomplete diffusion of (or exposure to) the technological innovation limited the actual adoption rate (JEA estimate from Equation 8) to about 41.0%, when the potential adoption rate (ATE estimate from Equation 4) of 87.0% could have been realised. These results imply that the adoption

rate of bio-fortified maize and bean varieties could have been 87.0% in 2018 had the entire population of farming households in the target districts been exposed to bio-fortification instead of the actually realised (JEA) rate of 41.0%. When compared with the sample adoption rate (ATT estimate from Equation 5) of 88.0%, there is a substantial population adoption gap (GAP estimated from Equation 9) of 46.0% emanating from the incomplete exposure of the target population to the bio-fortified varieties. This GAP implies that there is great scope for enhancing the adoption rate by 46.0% through improved exposure. From the results presented in Table 3, it seems the ‘awareness’ aspect of the exposure is not really the major constraint, but the ‘access’ part, as indicated by 88.6% of farmers who were aware compared to only 46.3% that had access to bio-fortified crop varieties. The adoption gap can be significantly closed if more effort is channelled towards improving access to the seeds of the bio-fortified maize and bean varieties.

The average treatment effect on the treated (ATT) value of 0.88 indicates that 88.0% of farming households in the sample population adopted at least one of the bio-fortified varieties they were exposed to. On the other hand, the average treatment effect on the untreated (non-exposed) sub-population (ATU estimate from Equation 6) value of 0.86 implies that 86.0% of the farming households that were not exposed could have adopted had they been fully exposed to the bio-fortified crop varieties. The population selection bias (PSB estimate from Equation 10) of 0.10 as measured by the difference between the potential adoption rate among the exposed sub-population (ATT) and the potential population adoption rate (ATE), suggests that there is a 10.0% bias. This selection bias suggests that the probability of a farming household belonging to the sub-population of exposed farmers is significantly different from the adoption outcome for any other farming household selected randomly from the entire population.

### **5.3 Estimation of the determinants of adoption restricted to the awareness-access sub-sample**

Table 5 presents the results of the ATE probit model regression analyses of the determinants of exposure to and adoption of the bio-fortification technology restricted to the awareness-access (exposed) sub-sample. The models for the two dependent variables (exposure and adoption) are globally significant at the 1% threshold. These results from estimation of the effects of factors hypothesized to have influence on the probability of exposure to at least one bio-fortified crop variety indicate that there are several variables that are statistically significant. As shown in Table 5, age of the household head, size of arable land, membership to an ISAL group, contact with agricultural extension, and access to inputs and output market information all have a significant and positive influence on the probability of exposure to bio-fortified crop varieties. Older farmers exhibited a higher tendency of exposure to and a greater probability of adopting the bio-fortified varieties than younger farmers. Although this finding may seem to be in contradiction to findings by other researchers ((Siziba et al. 2013; Simtowe et al. 2011; Diagne and Demont 2007) who found age to be negatively correlated with potential for adoption, the sign of the age square variable is negative, implying that the influence of age is positive only to a certain extent. According to the Life Cycle Hypothesis, as the farmers get older, they become risk-averse and reluctant to try new things; thus, they would not adopt the technology at a very old age.

With regards to the actual adoption of bio-fortified crop varieties by households that have been exposed to the bio-fortification technology, age of household head, size of arable land, membership to an ISAL group, agro-ecological potential (AEZ) of the area, and irrigation stood out as the factors with significant influence on adoption, as shown in Table 5. Of these significant

factors, only agro-ecological potential (AEZ) has a negative influence on adoption, indicating that the probability of adoption increases as the agro-ecological potential decreases. This is in line with findings by Diagne and Demont (2007), who found agro-ecological conditions to negatively influence household adoption decisions for a certain rice variety in the Ivory Coast. The negative influence of the conditions of the agro-ecological zone on the uptake of the bio-fortification technology seems to imply that as the conditions get poorer, the likelihood of adoption tends to increase. This might be explained by the way the LFSP programme was designed, where the emphasis of bio-fortification has deliberately been on targeting poorer farming households located in marginal areas characterized by semi-arid climatic conditions.

**Table 5: ATE Estimates of Determinants of Exposure and Adoption of Crop Bio-fortification**

VARIABLE	EXPOSURE MODEL		ADOPTION MODEL.	
	Coef.	Std Err	Coef.	Std Err
EDUCATION	0.0289	0.0592	0.2470**	0.1128
GENDER	0.0200	0.0910	-0.0181	0.1772
AGE	0.0270*	0.0126	0.0497**	0.0239
AGESQUARED	-0.0003***	0.0001	-0.0004**	0.0002
MARITAL STATUS	0.0457	0.0928	0.0677	0.1787
DRAFTPOWER	0.0890	0.0570	-0.1135	0.1081
LANDSIZE	0.1354***	0.0250	0.1046**	0.0479
ISALMEMBERSHIP	0.3805***	0.0534	0.2709**	0.1014
LFSPTRAINING	0.3887***	0.0945	0.1789	0.1909
AEZ	0.4793***	0.0608	-0.2665**	0.1023
CREDIT	0.2183***	0.0690	-0.0299	0.1238
MARKETINFOACCESS	0.1194*	0.0699	0.0649	0.1417
EXTENSION	0.2380*	0.1265	-0.1334	0.2818
DEPENDENCY RATIO	-0.1200	0.1127	0.0919	0.2170
PERCEPTION	0.1509	0.0896	0.1002	0.1800
IRRIGATION	-0.0419	0.0731	0.3670**	0.1604
CONSTANT	-2.23***	0.3989	-0.8624	0.7612
N	2,792		1,280	
PSEUDO-R <sup>2</sup>	0.07		0.05	
CHI-SQUARE	256.85		47.43	

Note: \* = significant at 10%, \*\* = significant at 5% and \*\*\* = significant at 1% level

Membership to an internal savings and lending (ISAL) group has also proven to have a positive and significant influence on the households' awareness and adoption decisions. This finding resonates with adoption theory and studies, which suggest that farmer group membership fosters social networks and capital, which are enablers for adoption (Feder et al. 1985; Rogers, 2003; Bouis and Saltzman 2017). Belonging to an ISAL group by a member of the household has proven to have a significant and positive influence on exposure to and adoption of bio-fortified crops in tandem with prior expectations. Farmer groups promote the building of social capital, which gives rise to strong social networks that in turn facilitate quicker diffusion of innovations (Mudombi 2013; Tey et al. 2011). The ISAL groups also present an easy target for extension and other development agents when introducing and promoting innovation.

## **6 Policy Implications**

As a promising intervention and strategy for fighting hidden hunger among rural communities through enhancement of the nutrient density of their diets, the success of bio-fortification depends on the willingness of producers and consumers to embrace this new technology being promoted by the Government of Zimbabwe and its partners. However, adoption of bio-fortification is dependent on awareness of the technology and benefits of the crops and access to seeds of the bio-fortified crop varieties. As noted in the findings of this study, the gap of 46.0% between the actual and potential adoption rates is too wide. This huge divergence is emanating from a lack of exposure (awareness and access) to the technology. It is mainly the accessibility component of the exposure that is hindering adoption. Since a farming household may have full knowledge and information (awareness) about a bio-fortified crop variety, without having access to its seed, it cannot adopt the technology. This study has tackled the issue of this gap in adoption with respect to two bio-fortified crop varieties (Pro-Vitamin A maize and Zinc and Iron-enriched beans) being promoted in the country. The policy should therefore aim to achieve widespread accessibility of seeds for the bio-fortified crop varieties to narrow down the gap between actual and potential adoption rates. Bio-fortification as a concept is still in its infancy stage in Zimbabwe, having only been introduced to farmers in 2015. As such, this study on adoption is only indicative of uptake and trial thereof by farmers during the piloting phase of the technology.

In addition to improving accessibility of seeds, the policy should also ensure increased promotional activities for the bio-fortified crops, centred on the provision of well-structured agricultural support services such as extension, coupled with well-crafted and targeted nutrition-sensitive market information delivery and training programmes. There is great scope for scaling up their production and uptake of their consumption, as informed by the results of this study. The bio-fortified crop varieties should be carefully targeted at vulnerable households located in marginal areas (semi-

arid regions) characterised by poor agro-ecological conditions to ensure the effectiveness of the technology. Evidence generated from this study suggests that the technology also needs to be augmented with access to credit as well as market development and linkages to enable the rural farming households to generate income in addition to improving their food and nutrition security

## **7 Conclusions**

The main objective of the study was to estimate actual and potential adoption rates of bio-fortified crop varieties among rural households in eight districts of Zimbabwe and determine factors that influence exposure to and adoption of bio-fortification. The analysis revealed that 45.2% and 40.1% of the households had produced and consumed the bio-fortified crops, respectively. Overall, 47.0% of the farming households had been fully exposed to at least one bio-fortified crop variety, thereby limiting the actual adoption rate to about 41.0%, when in fact the potential adoption rate could have reached 87.0% had the entire population of farming households in the target districts been exposed to the bio-fortified crop varieties. When this actual adoption rate (41.0%) of the entire population is compared with the exposed sample adoption rate of 88.0%, there remains a substantial population adoption gap of 46.0%, which emanates from the incomplete exposure of the target population to the bio-fortified varieties. This gap in adoption implies that there is great scope for improving the adoption rate for bio-fortified crop varieties by up to 46.0% if efforts are made to enhance exposure, particularly with regard to the “access” component. The adoption gap can be significantly reduced by improving access to the seeds of the bio-fortified maize and bean varieties. About 88.0% of farming households in the sample population adopted at least one of the bio-fortified varieties they were exposed to. However, 86.0% of the farming households that were not exposed to the technology could have adopted had they been fully exposed. The ATE adoption

estimation obtained using probit regression analysis has underscored the importance of socio-economic characteristics, bio-physical conditions and institutional factors in the determination of adoption of bio-fortification at the household level. Factors that were found to have a significant influence on the exposure of farming households to bio-fortified crops include the age of household head, size of arable land, membership to an ISAL group, LFSP training, agro-ecological potential (AEZ), credit access, access to inputs and output market information and contact with agricultural extension. With regards to the actual adoption of the bio-fortified crop varieties, age of household head, size of arable land owned, membership to an ISAL group, the agro-ecological potential of the area, and irrigation proved to be the significant drivers. However, the influence of agro-ecological potential was negative, implying that the adoption of the bio-fortified crop varieties improves as the agro-ecological conditions decline in terms of potential for agriculture.

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## 9 Appendices 1.A

**Table 6:** *Description of Variables used in the ATE Adoption Estimation Model*

Variable	Nature of variable	Expected sign	Expected effects
<b>Dependent variables (Y<sub>i</sub>)</b>			
ADOPTION	A dummy variable 1 if household adopted at least one variety, 0 otherwise		
EXPOSURE	A dummy variable 1 if household is both aware and has access, 0 otherwise		
<b>Independent Variables (X<sub>i</sub>)</b>			
AWARENESS	A dummy variable 1 if farmer is aware and 0 otherwise	+	Knowledge about the technology is a prerequisite for adoption (Diagne and Demont, 2007)
ACCESS	A dummy variable 1 if household has access and 0 otherwise	+	Availability and accessibility of the technology enhances adoption (Nguezet et al., 2012)
<b>Socio-economic characteristics</b>			
Gender of household head (GENDER)	A dummy variable 1 if gender of the household head is male and 0 otherwise	-	Female-headed households would have better opportunity to adopt bio-fortified crops. This is because they normally have the prerogative to make household diet-related choices (Talsma et al., 2017). Expected sign is negative.
Age of household head (AGE)	Continuous variable measured in years	-	As age increases households' probability of adopting nutrition-enhancing crop varieties decreases. Younger farmers, of child-bearing age, are expected to adopt unlike older farmers. The coefficient hypothesized is negative (Talsma et al., 2017).

Marital status of household head	Dummy variable 1= married 0= otherwise	-	Due to their vulnerability, unmarried household heads, particularly widows, are mostly targeted with such innovations and are expected to adopt more than married heads. The expected sign is negative (Kassie et al., 2009).
Educational attainment of household head (EDUCATION)	Dummy variable 1= educated (secondary education and above) 0= otherwise	+	Educated farmers are believed to acquire, analyse and evaluate information on new concepts and phenomena. The expected sign is a positive one (Mudombi, 2013).
Dependency ratio <sup>5</sup> (DEPENDENCY)	Number of dependants in the household per agriculturally active	+	The greater the number of dependants, the greater the probability of adoption (Kassie et al., 2009).
Perception about nutritional information (PERCEPTION)	Dummy 1= if nutritional information perceived to be useful	+	If household perceives nutritional information to be useful, it is highly likely that it will adopt bio-fortification (Mwungu et al. (2018)
<b>Bio-physical characteristics</b>			
Land Size (LANDSize)	Size of arable land owned by the household	+	The larger the landholding, the less likelihood of adoption. The sign is expected to be negative (Mellesse, 2018).
Agro-ecological zone (AEZ)	Dummy 1= high potential 0= otherwise	-	Low potential agro-ecological conditions are expected to enhance the likelihood of adoption. A negative sign is expected (Mwungu et al., 2018)
Draft Power (DRAFTPower)	Dummy 1= draft power available 0= otherwise	+	The greater the number of cattle owned, the lower the likelihood of adoption of bio-fortified crops. (Denneke and Haji, 2014).

<sup>5</sup> Dependency ratio refers to the number of dependents (aged zero to 14 and those aged 65 and above) in a household divided by the number of agriculturally active i.e. working age (from 15 to 64 years).

Irrigated land (IRRIGATION)	Dummy 1 = if household has some irrigated land	-	Irrigation increases options for crop diversification. A negative relationship with adoption is hypothesized
<b>Institutional factors</b>			
Agricultural Extension (EXTENSION)	Dummy 1= Access to agricultural extension services 0= otherwise	+	Facilitating access to information about technology is expected to have a positive influence on the intensity of adoption (Melesse, 2018).
ISAL membership	Dummy 1= if household member belongs to an ISAL group 0 = otherwise	+	Membership to ISAL groups is likely to have positive influence on adoption. Groups provide easier access to relevant information (Mwungu et al., 2018).
Access to market information (MARKETINFOACCESS)	Dummy 1 = if household has access to inputs and output markets information	+	Access to market information is vital for farmer decision making, particularly with regards to adoption of new technology (Simtowe et al., 2011). Market information access is hypothesized to have positive influence on adoption.
Access to credit (CREDIT)	Dummy 1=yes 0 = otherwise	+	Credit has a positive effect on adoption. It allows farmers to purchase any inputs e.g fertilizer that may be associated with a new technology (Mudombi, 2013).



## Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

Bringing Rigour and Evidence to Economic Policy Making in Africa

- Improve quality.
- Ensure Sustainability.
- Expand influence.

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