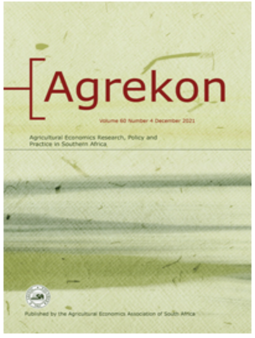

Routledge
Taylor & Francis Group

Agrekon

Agricultural Economics Research, Policy and Practice in Southern Africa

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ragr20

Factors influencing farmers' dis-adoption and retention decisions for biofortified crops: the case of orange-fleshed sweetpotato in Mozambique

Wellington Jogo, Temesgen Bocher & Frederick Grant

To cite this article: Wellington Jogo, Temesgen Bocher & Frederick Grant (2021) Factors influencing farmers' dis-adoption and retention decisions for biofortified crops: the case of orange-fleshed sweetpotato in Mozambique, Agrekon, 60:4, 445-459, DOI: 10.1080/03031853.2021.1956555

To link to this article: https://doi.org/10.1080/03031853.2021.1956555

Published online: 02 Aug 2021.

AGREKON
2021, VOL. 60, NO. 4, 445–459
https://doi.org/10.1080/03031853.2021.1956555

Factors influencing farmers' dis-adoption and retention decisions for biofortified crops: the case of orange-fleshed sweetpotato in Mozambique

Wellington Jogo[a], Temesgen Bocher[b] and Frederick Grant[c]

[a]International Potato Center, Lilongwe, Malawi; [b]Save the Children International, Nairobi, Kenya; [c]International Potato Center, Kampala, Uganda

ABSTRACT
Despite their proven effectiveness in addressing micronutrient deficiencies, adoption of biofortified crops among smallholder farmers remains low. Using a cross-sectional survey dataset of 1538 households randomly selected from 15 districts in Nampula and Zambezia provinces of Mozambique, this study examined the factors influencing farmers' dis-adoption and retention decisions for biofortified OFSP varieties. Data on household socio-demographic characteristics; knowledge, attitudes, perceptions and practices on OFSP production and nutrition were fitted to a Heckman bivariate probit model with sample selection to empirically assess the determinants of sequential adoption and dis-adoption decisions. The results showed that adoption and dis-adoption of OFSP is significantly influenced by a combination of farmers' socio-economic characteristics (age, gender, nutrition knowledge, education, access to planting material), consumption (taste, dry matter content) and agronomic (yield, early maturity, drought tolerance) traits. However, the agronomic traits and access to planting material are particularly key for the retention of OFSP varieties. These results suggest the need for breeding efforts to improve the agronomic traits of biofortified OFSP to match or better local non-biofortified varieties and establish seed delivery systems for sustainable adoption of biofortified OFSP.

ARTICLE HISTORY
Received 18 August 2020
Accepted 7 July 2021

KEYWORDS
Biofortified food crops; dis-adoption; retention; Mozambique

1. Introduction

Malnutrition remains a major public health problem in Mozambique. Micronutrient deficiencies, especially vitamin A deficiency (VAD), are serious problem, with an estimated prevalence of 69% in children under the age of 5 years and 14% in pregnant women (Aguayo et al. 2005). VAD leads to weakened immune systems, growth limitations, night blindness, Xerophthalmia and increased mortality (Low et al. 2007). Although supplementation and fortification programs can be effective strategies to combat VAD, their sustainability can be an issue in some contexts and an integrated approach that includes food-based approaches may be optimal.

Among the biofortified crops[1] orange-fleshed sweetpotato (OFSP) has emerged as an important food-based intervention to address chronic VAD (Low et al. 2007; Hotz, Loechl, de Brauw, et al. 2012, Hotz, Loechl, Lubowa, et al. 2012; de Brauw et al. 2018). Conventionally bred OFSP are rich in beta carotene, the precursor to vitamin A. Just 125 grams of OFSP meets a young child's daily vitamin A needs (Low et al. 2009). In addition to beta carotene, OFSP is also a major source of dietary energy

CONTACT Wellington Jogo w.jogo@cgiar.org

and has good levels of several other micronutrients (vitamin C, K, E and several B vitamins) and minerals (potassium, phosphorus, magnesium, iron and zinc).

Although initial efforts to promote OFSP in Mozambique started with imported varieties, since 2011, nineteen locally bred, adapted varieties with better yields, high beta carotene, high dry matter and drought-tolerant have been released (Andrade et al. 2017). Effectiveness studies conducted in Mozambique and elsewhere have shown that introducing OFSP along with nutrition education resulted in increased vitamin A intake among children 6–35 months and 3–5 years of age and women (Hotz, Loechl, de Brauw, et al. 2012, Hotz, Loechl, Lubowa, et al. 2012; Webb Girard et al. 2017; de Brauw et al. 2018), improved vitamin A status (Low et al. 2007; Webb Girard et al. 2017) and reduced the incidence and severity of diarrhoea among children (Jones and de Brauw 2015). However, like all new agricultural technologies, for OFSP varieties to contribute to the improved welfare of rural households, farmers must first adopt them.

Technology adoption is one of the most extensively studied topics in agricultural economics, including literature investigating factors affecting the adoption and diffusion of agricultural technologies. Most adoption studies provide strong evidence that adoption decisions are significantly influenced by farmers' socio-economic, demographic, cultural and institutional factors and their subjective perceptions of the attributes of the technology (Feder et al. 1985; Adesina and Baidu-Forson 1995; Adesina and Zinnah 1993). However, a major drawback of most adoption studies is their focus on cross-sectional analyses of adoption patterns which ignore possible changes in farmers' adoption behaviour over time in terms of technology dis-adoption, retention and alterations of the original technology (Glover, Sumberg, and Andersson 2016).

Recent literature has focused on farmers' post-adoption behaviours of retention and dis-adoption using either household-level panel data or quasi-panel data created from farmer recall data (Moser and Barrett 2006; Hanssen 2015; Simtowe and Mausch 2018; Sanou, Savadogo, and Sakurai 2017).

Regarding biofortified crops, such as OFSP, studies have shown that, like other agricultural technologies, their adoption is influenced by socio-economic, demographic, cultural and institutional factors of farmers and their perceptions on the agronomic and sensory attributes of the crops (Mazuze 2004; Shikuku et al. 2017; Okello et al. 2019; Adekambi et al. 2020). However, there is a dearth of studies that critically analyse farmers' adoption behaviour for biofortified crops over time, in terms of dis-adoption and retention and the factors that drive these adoption patterns. A key exception is the study by Jenkins et al. (2018) which, in addition to studying the factors influencing farmers' adoption explicitly considered retention of OFSP varieties using qualitative interviews of ninety-five producers, consumers and market actors.

Our paper seeks to build on this literature by analysing the factors that influence farmers' initial adoption and subsequent retention or dis-adoption decisions for OFSP varieties using a quantitative approach based on a large-scale household survey. We believe that a thorough understanding of the adoption and retention process is critical for designing strategies to sustain the nutrition impacts of OFSP interventions.

The rest of the paper is organised as follows. Section 2 presents a background to the study area focusing on characterising agriculture, sweetpotato production and malnutrition status. We then provide a brief description of the data used in the study in Section 3. Next, we present the analytical framework for analysing dis-adoption and retention decisions in Section 4. The empirical model and estimation strategy are presented in Section 5. Results of the study are presented and discussed in Section 6. Finally, conclusions and implications drawn from the results are discussed.

2. Study context

This study was conducted in two provinces of Nampula and Zambezia in northern Mozambique. The two provinces are major agricultural production zones for the country, accounting for almost 40% of the total area under cultivation and 43% of farm households. However, despite their high agricultural potential, the two are among the provinces worst affected by malnutrition, with stunting levels for children under 5 years of age of 55% for Nampula and 45% for Zambezia, both of which are above the national average of 43% (Ministry of Health [MISAU] 2011). One of the major drivers of malnutrition is low dietary diversity, with household diets dominated by cassava and maize, the two main crops produced by farmers in these provinces and in the country at large.

Sweetpotato is the third most important staple crop after cassava and maize in these two provinces and in the country at large (Walker et al. 2006). At a national level, 35% of the farmers, mostly women, grow sweetpotato mainly for household consumption with limited surplus sold on the market (Labarta 2009). The Zambezia province is the second-largest sweetpotato producing province after Tete. Despite a marked increase in the production of OFSP varieties over the last twenty years, white-fleshed varieties remain dominant. The national agricultural surveys show that in 2015 OFSP varieties accounted for 20% of the total area under sweetpotato and 32% of the total sweetpotato production (Ministério da Agricultura e Segurança Alimentar 2015).

While the white-fleshed varieties are high in carbohydrates, they do not contain beta carotene which is present in high amounts in OFSP varieties. Yet despite their nutrition value and general acceptance among Mozambican farmers and consumers (Labarta 2009; Naico and Lusk 2010; Jenkins et al. 2015), OFSP varieties are less preferred partly due to their low drought tolerance and dry matter content (Mazuze 2004; Naico and Lusk 2010). However, varieties that were released since 2011 include several that were bred specifically for drought tolerance and high dry matter content among other important traits.

VAD is a major problem in the study area. In a study in selected districts in the two study provinces, Ganhão et al. (2017) showed that the median daily vitamin A intake for children 6–24 months of age is approximately 170 µg, which is lower than the recommended daily intake of 300–400 µg. To contribute to addressing malnutrition in these two provinces, the International Potato Center (CIP) implemented the Viable Sweetpotato Technologies in Africa (VISTA) project to promote the production and consumption of OFSP varieties among smallholder farmers. The project was implemented in two phases: a pilot phase that covered six districts for two years (2014–2016) and an expansion phase (2017–2019) that scaled out the intervention to ten additional districts. Over the five-year implementation period, the project targeted a total of sixteen districts; eleven in Nampula: Nampula city-Rapale, Monapo, Meconta, Murrupula, Mogovolas, Moma, Larde, Angoche, Malema, Mecuburi and five in Zambezia: Alto Molocué, Gurue, Gile, Mocuba and Nicoadala.

3. The data

The data for this study are based on a 2018 survey of 1538 households from 15 VISTA project intervention districts in Nampula and Zambezia provinces. The project intervention consisted of three components: dissemination of planting material of 15 OFSP varieties not previously tested for local adaptability to farmers through a network of decentralised vine multipliers and sweetpotato agronomy training of extension officers and farmers; nutrition education through community counselling sessions and cooking demonstrations and, market development. The intervention was rolled out in the target districts in phases, 5 of the 15 districts were first to be exposed to the intervention from 2014 and the expansion districts that were exposed from 2016.

A multi-stage sampling procedure was used in selecting households for the study. First, the 2,297 households who were interviewed during a previous survey in 2017 were listed to create the sampling frame from which the 1,538 households for the 2018 survey were randomly selected. Initially, the total sample of 1,538 households was proportionately allocated to the 15 districts based on the proportions of interviewed households per district in the 2017 survey. Having determined the number of households to be sampled from each district, two administrative posts were randomly selected in each district. Then, in each selected administrative post, two localities were randomly selected comprising of one control and one intervention locality, resulting in four localities per district and sixty localities in total. Finally, households for the interview were randomly selected from the list of households interviewed in the 2017 survey in the selected locality. The number of households interviewed per district was equally divided among the four selected localities in the district, to get the number of households interviewed per locality.

A structured household questionnaire was used to collect data on household socio-demographic characteristics; crop production and sales; knowledge, attitudes and practices on sweetpotato; preferred attributes for sweetpotato varieties; growing of OFSP in previous and current seasons; nutrition and vitamin A knowledge; intake of vitamin A rich foods including OFSP, dietary diversity and food security status. The study protocol was reviewed and approved by the Institutional Review Board (IRB) in the Social and Nutrition Sciences Division of CIP. Verbal informed consent was obtained from all participating subjects before the interview. The individual in the household most knowledgeable about sweetpotato production by the household was the respondent to the questionnaire.

4. Analytical framework

Following Uaiene, Arndt, and Masters (2009), Uematsu et al. (2010), Hassen (2015), and Simtowe and Mausch (2018), adoption of OFSP varieties and subsequent retention or abandonment decisions are modelled using the general utility maximisation framework. Using this framework, a farmer will adopt OFSP varieties if the expected utility benefit from adoption is greater than that from non-adoption. Thus, a farmer will adopt OFSP varieties if:

$$Y_1^* = E[U^A] - E[U^N] > 0 \tag{1}$$

On the contrary, a farmer will not adopt the OFSP varieties if the expected utility benefit of adopting is less than that of non-adoption:

$$Y_1^* = E[U^A] - E[U^N] < 0 \tag{2}$$

where Y_1^* is the latent net utility benefit of adopting or not adopting OFSP varieties; U^A and U^N are the utilities of the farmer from adoption and non-adoption of OFSP, respectively.

Once a farmer decides to adopt OFSP varieties, the subsequent decision is to either retain or dis-adopt (abandon) the varieties. A farmer will retain the varieties if the utility benefit realised from adopting them is greater than the ex-ante expected utility from adoption:

$$Y_2^* = (U^A | Y_1^* > 0) > E(U^A | Y_1^* > 0) \tag{3}$$

where Y_2^* represent the net utility benefit for a farmer associated with retention of OFSP. The first term on the right-hand side of Equation (3) represents the actual utility realisation from adoption of OFSP, while the second term is the ex-ante expected utility from adoption.

According to Hassen (2015) and Neill and Lee (2001), the initial adoption and subsequent retention or dis-adoption decisions can be explained by two discrete sequential decisions. The first decision is whether or not to adopt OFSP varieties, while the second is the decision to either retain OFSP production or dis-adopt it if it has been adopted in the first instance. The two dependent variables in both decision processes are dichotomous. Both the adoption (Y_1^*) and retention (Y_2^*) decisions are latent unobservable variables that are represented by two latent stochastic variables, y_1^* and y_2^* representing the first transition from non-adoption to adoption and adoption to retention, respectively. These two latent variables are assumed to be functions of observable variables as follows:

$$y_{i1}^{*}=\beta_{1}x_{i1}^{'}+\varepsilon_{1}=\begin{cases}1 \text{ if } y_{i1}^{*}>0\\ 0 \text{ if } y_{i1}^{*}\leq 0\end{cases} \tag{4}$$

$$y_{i2}^{*}=\beta_{2}x_{i2}^{'}+\varepsilon_{2}=\begin{cases}1 \text{ if } y_{i2}^{*}>0\\ 0 \text{ if } y_{i2}^{*}\leq 0\end{cases} \tag{5}$$

where y_{i1}^{*} and y_{i2}^{*} represent the utility that the *i*th household derives from adopting and retaining OFSP varieties, respectively. β_1 and β_2 are vectors of parameter estimates, $x_{i1}^{'}$ and $x_{i2}^{'}$ are vectors of observable characteristics that affect adoption or non-adoption and retention of OFSP varieties, respectively; ε_1 and ε_2 are error terms.

The two latent stochastic terms y_{i1}^{*} and y_{i2}^{*} are still unobservable, and what the authors observe are their two binary counterpart variables y_1 and y_2 representing the adoption (or non-adoption) and retention (or dis-adoption) decisions, respectively. These two variables satisfy the following conditions:

$$y_{i1}=\begin{cases}1 \text{ if } y_{i1}^{*}>0\\ 0 \text{ if } y_{i1}^{*}\leq 0\end{cases} \tag{6}$$

$$y_{i2}=\begin{cases}1 \text{ if } y_{i2}^{*}>0\\ 0 \text{ if } y_{i2}^{*}\leq 0\end{cases}$$

In addition to being sequential, the two decisions y_1 and y_2 are interrelated, as shown in Equation (6). Only if $y_{i1}=1$ ($y_{i1}^{*}>0$) will y_{i2} take on the value of 1 for retention or 0 for abandonment. In other words, retention or dis-adoption of OFSP is only observed if there is adoption in the first place. Otherwise, if $y_{i1}=0$ ($y_{i1}^{*}<0$) implying that adoption of OFSP does not occur in the first step, then y_{i2} is not observed. Consequently, the retention or dis-adoption of OFSP is observed for only the smaller number of households in the original sample who adopted OFSP. It is only that smaller sample that enters the estimation of the retention equation (Equation (5)). This results in the censoring of the original sample (Sanou, Savadogo, and Sakurai 2017), which gives rise to sample selection bias.

It is assumed that the unobserved error vector (ε_1, ε_2) is distributed bivariate normal with zero mean and independently to explanatory variables $x_{i1}^{'}$ and $x_{i2}^{'}$ where:

$$\varepsilon_1\sim N(0,\ 1)\varepsilon_2\sim N(0,\ 1)\text{corr}(\varepsilon_1,\varepsilon_2)=\rho \tag{7}$$

The objective of the econometric analysis is to maximise the likelihood function. The log-likelihood function of the model is given by the following equation:

$$InL=\sum_{i}^{N}\{y_{i1}y_{i2}(In\varphi_2(x_1\beta_1,\ x_2\beta_2,\ \rho)+y_{i1}(1-y_{i2})In\varphi_2(x_1\beta_1,\ x_2\beta_2,\ -\rho)+(1-y_{i1})In\ \varphi_1(-x_1\beta_1))\} \tag{8}$$

where i = 1,2,3 … N, φ_1 is the univariate normal distribution and φ_2 is the bivariate normal distribution; y_{i1} and y_{i2} are the binary variables taking unity if farmer *i* adopts OFSP and if farmer *i* retains OFSP, respectively, and 0 otherwise. ρ is the correlation coefficient between ε_1 and ε_2. If ρ=0 then the two decisions are independent of each other.

5. Empirical model and estimation strategy

Our empirical model consists of Equations (4) and (5) representing the two sequential decisions. As these two discrete decisions are interrelated, it is likely that the error terms of the two equations (ε_1 and ε_2) are correlated and estimating them using a single equation estimation approach will lead to biased and inefficient estimates (Greene 2008). To obtain unbiased and efficient estimates, joint estimation of the two decisions taking into account sample selection and the correlation of error terms between the two decisions is necessary. Accordingly, we follow Hassen (2015), Uematsu et al. (2010), and Simtowe and Mausch (2018) in applying a Heckman bivariate probit model with sample selection to jointly estimate the two equations.

To check the robustness of the results from the Heckman bivariate probit model, we additionally simultaneously estimated the two equations using a seemingly unrelated (SURE) probit model proposed by Zellner (1962) for simultaneous estimation of equation systems accounting for error correlations.

The dependent variables for this study relate to the adoption and subsequent retention of OFSP varieties. Accordingly, the dependent variables are two interrelated variables y_{i1} which is a dummy variable taking a value of 1 if the household adopted OFSP varieties and 0 if not adopted; and y_{i2} is similarly a dummy variable taking the value of 1 if OFSP is retained and 0 if abandoned. Although there are many orange-fleshed varieties that were released and disseminated to farmers in Mozambique, our analysis pools all of them together, making no distinction on the number of varieties adopted.

The selection of the exogenous explanatory variables for the empirical analysis is based on theoretical and empirical literature on technology adoption and retention or abandonment and data availability. In line with previous studies, we hypothesise that adoption and subsequent dis-adoption and retention decisions for OFSP varieties are influenced farmers' demographic, socio-economic and institutional factors and perceptions on the agronomic and sensory attributes of the varieties (Adesina and Baidu-Forson 1995; Hassen 2015; Uematsu et al. 2010; Simtowe and Mausch 2018; Mazuze 2004; Shikuku et al. 2017; Jenkins et al. 2018; Adekambi et al. 2020; Mwiti et al. 2020). Table 1 presents the selected specific variables, their definitions and their *a priori* expected effect on adoption and retention of OFSP varieties.

Age of the household head, which captures farming experience, can influence adoption and retention decisions either positively or negatively. Older household heads can use their farming experience to evaluate new technologies and therefore likely to adopt new technologies than their younger counterparts. On the contrary, however, younger farmers could be more risk-taking and more willing to take up new technologies than their older counterparts. Empirical findings on the effect of age of household head on the adoption of OFSP varieties show both positive and negative relationship (Adekambi et al. 2020; Mwiti et al. 2020). In line with these mixed findings, we hypothesise that the effect of age on both adoption and retention will be either positive or negative.

In Mozambique, like in most African countries, sweetpotato is a woman's crop. Additionally, OFSP has been promoted for its nutrition value mostly targeting women as part of the vulnerable group and caregivers to young children. Therefore, although previous studies found no significant gender impacts (Adekambi et al. 2020; Mwiti et al. 2020), we expect women-headed households to be more likely to adopt and retain OFSP than their male counterparts.

As the OFSP intervention included nutrition education, one would expect household heads with more formal years of education to be better able to acquire, process, utilise and retain new knowledge than the less educated. And if, as de Groot et al. (2016) and Caeiro and Vicente (2020) argue, the nutrition knowledge gained and retained significantly affects OFSP adoption, then a positive relationship between education and OFSP adoption and retention is expected. However, previous OFSP adoption studies (Adekambi et al. 2020; Mwiti et al. 2020) found education to be insignificant, consistent with the finding of de Brauw et al. (2018) that nutrition knowledge gained only marginally affects adoption and other factors may be more important. Thus, the expected sign for education can be either positive or negative.

In addition to education of household head, we also sought to more directly analyse the effect of nutrition knowledge on OFSP adoption and retention using a vitamin A knowledge score constructed based on the responses to questions related to vitamin A (its importance, consequences of its deficiency and its main sources). In line with de Groot et al. (2016) and Caeiro and Vicente (2020), we expect its sign to be positive.

Table 1. Definition of model variables.

Variable name	Definition	Expected signs	
		OFSP_adoption	OFSP_retention
Dependent variables			
OFSP_adoption	=1 if the farmer ever grew any OFSP variety before 2017/18 season, 0 otherwise		
OFSP_retention	=1 if the farmer grew an OFSP variety before the 2017/18 season and was still growing one in 2017/18 season (the year of the survey), 0 otherwise		
Explanatory variables			
Age	Age of household head in years	+/−	+/−
Gender	Gender of household head: 1= Male, 0=Female	−	−
Education	Years of formal schooling of household head	+/−	+/−
KnowVitA	Vitamin A knowledge score for the head of the household: ranges from a minimum of 0 to a maximum of 8	+	+
Lowlandaccess	Dummy variable = 1 if farmer has access to lowland (valley bottom), 0 otherwise	+	+
Cropsold	Number of crops sold on the market in 2017/18 harvest season	+	+
NumChild	Number of children under 5 years of age in the household	+	+
Landsize	Arable landholding size owned by the household measured in hectares	+	+
VinePurchase	Dummy variable = 1 if a household purchased vines in the last 3 years, 0 otherwise	+	+
Taste	Dummy variable=1 if farmer perceives that taste of roots is the most important attribute in choosing what sweetpotato variety to grow, 0 otherwise	+	+
Dry matter	Dummy variable=1 if farmer perceives that dry matter is the most important attribute in choosing a sweetpotato variety to grow, 0 otherwise	+	+
Maturity	Dummy variable=1 if farmer perceives that early maturity is the most important attribute in choosing what sweetpotato variety to grow, 0 otherwise	+	+
Yield	Dummy variable = 1 if farmer perceives that yield is the most important attribute in choosing what sweetpotato variety to grow, 0 otherwise	+	+
Droughtres	Dummy variable = 1 if the farmer perceives that drought resistance is the most important attribute in deciding what sweetpotato variety to grow, 0 otherwise	+	+
DistrictEx	Dummy variable 1 if the district was in phase 1 of VISTA project (Nampula city, Rapale, Monapo, Meconta, Murrupula, Alto Molocue and Gurue), 0 otherwise	+	+

Women and children under five years of age were the primary targets for most OFSP interventions. Accordingly, OFSP adoption studies have included the number of children under 5 years of age as an explanatory variable and was found to positively influence adoption of OFSP varieties in some studies (Adekambi et al. 2020; Mwiti et al. 2020) but insignificant in others (e.g., Mazuze 2004). We hypothesise a positive sign for this variable.

Landholding size was found to have an insignificant impact on OFSP adoption (Mazuze 2004; Mwiti et al. 2020; Adekambi et al. 2020). However, as households with larger landholdings are expected to easily allocate part of their land to try out new technologies, a positive sign is expected.

Access to planting material is a major constraint to the adoption and retention of OFSP varieties (Jenkins et al. 2015, 2018; de Brauw et al. 2018). Given the unimodal rainfall pattern in Mozambique, the ability of farmers to conserve their own planting material during the dry season or purchase from vine multipliers significantly influences the adoption and retention of OFSP varieties.

Farmers in Mozambique mostly rely on lowlands to conserve vines during the dry season. Thus, following Okello et al. (2019), we include access to lowland as an explanatory variable. Additionally, some farmers are willing to pay for OFSP vines (Labarta 2009). Accordingly, to capture farmers' access to planting material through conservation and purchases, we included three variables: access to lowland, vine purchase and crop income. As our crop income data was unreliable, we resorted to using the number of crops sold on the market as a proxy. We expect all three variables to be positively related to the adoption and retention of OFSP varieties.

Adoption and retention of OFSP varieties is significantly influenced by farmers' perceptions on the varietal agronomic and sensory attributes (Jenkins et al. 2018; de Brauw et al. 2018; Shikuku et al. 2017; Mwiti et al. 2020; Adekambi et al. 2020). In rural Mozambique, like in most rural settings in developing countries, farmers operate in an environment of incomplete or missing markets, implying that production and consumption decisions are inseparable (Singh, Squire, and Strauss 1986). Further, field evidence shows that sweetpotato is mainly grown for household consumption, suggesting that farmers' consumption preferences are bound to influence adoption decisions. *A priori*, we expect farmers' who perceive high yields, early maturity, drought resistance, taste and high dry matter as important attributes in choosing sweetpotato varieties to grow to be more likely to adopt and retain OFSP varieties in line with previous studies (Shikuku et al. 2017; Adekambi et al. 2020; Mwiti et al. 2020; Naico and Lusk 2010).

Lastly, the differences in the level of exposure to the intervention for the sixteen districts are controlled for by including a dummy variable in the model to reflect districts which were intervened right from the pilot phase and those that were introduced in the expansion phase of the project. *A priori*, we expect that households from the pilot districts had longer experience with OFSP varieties and are therefore more likely to adopt and retain OFSP varieties than those from the expansion districts.

6. Results and discussion

6.1 Descriptive results

Descriptive statistics showing the four categories of adoption of OFSP varieties, which are adopters, non-adopters, dis-adopters (abandoners) and retainers and means of explanatory variables by three adopter categories (non-adopters, dis-adopters and retainers) are shown in Table 2. The results show

Table 2. Means statistics for model explanatory variables by adoption categories.

	Means				
		Adopters (*n=448*)			
Variables	Total (*n=1538*)	Dis-adopters (abandoners) (*n = 106*)	Retainers (*n=342*)	Non-adopters (*n=1090*)	F/χ^2 value
Adoption categories					
Adopters	0.29				
Retainers	0.22				
Dis-adopters (abandoners)	0.07				
Non adopters	0.71				
Explanatory variables					
Age	41.42 (13.86)	41.14 (14.71)	42.08 (13.31)	41.24 (13.96)	0.40
Gender	0.77 (0.42)	0.80 (0.40)	0.76 (0.43)	0.77 (0.42)	0.79
Education	4.27 (3.12)	4.21(3.21)	5.29 (3.09)	3.96(3.05)	24.71***
KnowVitA	3.69 (1.82)	3.79 (1.64)	4.18 (1.75)	3.53 (1.82)	17.26***
Lowlandaccess	0.45 (0.49)	0.25 (0.44)	0.71(0.45)	0.39 (0.49)	127.44***
Cropsold	1.09 (1.45)	0.99 (1.13)	1.66 (1.65)	0.92 (1.36)	35.59***
NumChild	0.66 (0.78)	0.66 (0.69)	0.69 (0.86)	0.64 (0.77)	0.61
Landsize	1.93 (1.60)	1.94 (1.44)	2.29 (1.77)	1.82 (1.54)	11.39***
VinePurchase	0.10 (0.31)	0.13 (0.34)	0.18 (0.39)	0.00 (0.27)	33.43***
Taste	0.57 (0.49)	0.65 (0.48)	0.66 (0.47)	0.53 (0.49)	20.59***
Dry matter	0.57 (0.49)	0.65 (0.48)	0.66 (0.47)	0.53 (0.49)	20.59***
Maturity	0.73 (0.44)	0.72 (0.45)	0.86 (0.34)	0.69 (0.46)	37.77***
Yield	0.76 (0.43)	0.82 (0.39)	0.86 (0.35)	0.72 (0.45)	29.61***
Droughtres	0.61 (0.49)	0.69 (0.46)	0.70 (0.46)	0.58 (0.49)	21.29***
DistrictEx	0.63 (0.48)	0.81 (0.39)	0.83 (0.38)	0.55 (0.49)	101.10***

Notes: *, **, *** represent significance at 10%, 5% and 1%, respectively. Figures in parentheses are standard deviations.

that 29% of the surveyed households had grown OFSP varieties in previous seasons (adopters), a figure within the range of 28-36% shown in other studies (Mazuze 2004; Shikuku et al. 2017). On the other hand, 71% had never grown the varieties (non-adopters). Among the adopters, 22% were still growing these varieties in the 2017/18 season (retainers) and 7% had stopped growing them (dis-adopters). Almost 14% of the retainers had grown OFSP varieties in three of the past four seasons.

The mean statistics show significant ($p < .000$) differences in most socio-economic characteristics between OFSP non-adopters, dis-adopters and retainers. For all the significant variables, retainers had higher values than the non-adopters and abandoners, suggesting a positive correlation between these variables and adoption and retention of OFSP varieties.

Table 3 shows that most abandoners cited the lack of planting material of OFSP varieties as the major reason for abandoning growing them. This finding supports previous findings (Jenkins et al. 2015, 2018) that lack of access to planting material is by far the main constraint to the adoption and retention of OFSP varieties in Mozambique. Most farmers rely on lowlands to conserve sweetpotato vines during the dry period, but not all farmers have access to lowlands and, moreover, the lowlands are fast disappearing due to climate change (Makunde et al. 2018).

Although 58% of the interviewed farmers were able to conserve vines during the dry period, only 45% of the surveyed households had access to lowlands. Other farmers who were able to conserve vines during the dry period used methods such as keeping storage roots in the ground to re-sprout and keeping some vines in garden or behind bathroom near the homestead. However, these methods present challenges and as argued by Makunde et al. (2018) and Jenkins et al. (2015), new promising root-based vine conservation methods are well suited for drought-prone areas with limited access to water such as "Triple S"[2] should be widely promoted in Mozambique. Our data shows that only 12% of the surveyed households ever heard of Triple S and of these only 6% were using it.

Poor yield is another reason why farmers abandoned OFSP varieties. The newly released OFSP varieties were bred for higher yields than the local white-fleshed varieties in addition to other important traits. However, farmer observed yields for OFSP varieties were lower than those from white-fleshed varieties, which could be attributed to poor local adaptability of specific OFSP varieties the abandoners grew to their specific agroecological environment. Several of the fifteen OFSP varieties that were disseminated to farmers have very localised adaptability and may therefore perform poorly in some local environments but perform well in others.

Availability of other varieties can lead to the abandonment of OFSP varieties as farmers may prefer those varieties to OFSP for whatever reason. Additionally, farmers will grow varieties that are available to them and it is easier for sweetpotato growers to grow the traditional white-fleshed varieties as the vines are easily available in their communities compared to OFSP vines.

6.2 Econometric results on determinants of adoption and retention of OFSP varieties

The results of maximum likelihood estimation of the Heckman bivariate probit model are presented in Table 4. Several tests for possible violations of regression assumptions were conducted and

Table 3. Main reasons for abandoning orange fleshed sweetpotato varieties.

Reason	% of dis-adopters
Poor yields	25.97
Takes too long to mature	4.76
Planting material for the varieties not available	47.19
Low sugar content	1.30
Susceptible to pests and diseases	2.60
Varieties not marketable	7.80
Availability of other varieties	12.55
Roots are too fibrous	5.19
Gives a lot of vines but few roots	6.06

Table 4. Heckman bivariate probit estimates for the adoption and retention of OFSP varieties.

Explanatory variables	Adoption	Retention
Age	0.006 (0.003) *	0.007 (0.003)**
Gender	−0.121 (0.097)	−0.248 (0.099)**
Education	0.063 (0.014)***	0.073 (0.015)***
KnowVitA	0.047 (0.023)**	0.052 (0.024)**
Lowlandaccess	0.307 (0.082)***	0.612 (0.089)***
Cropsold	0.109 (0.028)***	0.122 (0.028)***
NumChild	−0.053 (0.052)	0.032 (0.052)
Landsize	0.029 (0.024)	0.031 (0.024)
VinePurchase	0.402 (0.117)***	0.372 (0.118)***
Taste	0.178 (0.088)**	0.119 (0.090)
Maturity	0.230 (0.104)**	0.288 (0.122)***
DistrictEx	0.670 (0.092) ***	0.585 (0.098)***
Constant	−2.285 (0.224)	−2.718 (0.241)
Observations	1229	
Wald χ^2	267.28***	
LR test of $\rho = 0$: χ^2	760.76***	

Notes: *, **, *** represent significance at 10%, 5% and 1%, respectively. Figures in parenthesis are robust standard errors.

accounted for to ensure the efficiency and unbiasedness of our estimates. First, we observed that there is potential for the presence of multicollinearity arising from possible correlations among the agronomic and consumption trait explanatory variables. Accordingly, we conducted a correlation analysis between the agronomic and consumption attribute variables which were among the explanatory variables in our model (yield, drought resistance, dry matter, taste, early maturity). The correlation analysis revealed positive and highly significant ($p < .000$) correlations between the farmer preferred agronomic traits of drought resistance, early maturity and high yield. Additionally, the two sensory attributes of taste and dry matter are perfectly correlated, confirming that farmers tend to associate taste with high dry matter content, as reported by Naico and Lusk (2010). Therefore, to avoid the problem of multicollinearity, we dropped some of the trait variables and retained one agronomic trait (early maturity) and one sensory attribute (taste) in our final econometric estimation.

Subsequently, we calculated the variance inflation factors (VIF) for the two retained attribute variables (early maturity and taste) together with the other model explanatory variables to further check for the possible presence of multicollinearity from all explanatory variables used in the final estimation. The analysis showed that the VIF for the explanatory variables ranges from a minimum of 1.04 to a maximum of 1.31 with a mean VIF of 1.15. Thus, the average VIF is below the threshold VIF of 10, which confirms that multicollinearity is no longer a problem among the explanatory variables included in the final estimation.

The joint estimation of the adoption and retention decisions of OFSP varieties using either the bivariate probit or SURE models is based on the assumption that the error terms between the two decisions are correlated. To check the validity of this assumption, we empirically test the null hypothesis that ρ=0. The likelihood ratio test for ρ= 0 presented in Table 4 is significant ($p <$ .000), and therefore, the null hypothesis of independence of error terms is rejected. In other words, the test confirms that the error terms of the two probit equations corresponding to the adoption and retention decisions for OFSP varieties are significantly correlated and hence the use of bivariate probit and SURE probit models for joint estimation of these two decisions is justified.

The significant ($p < .000$) Breusch–Pagan test presented in Table 5 further confirms the presence of error correlations providing further support for the simultaneous estimation of the two decisions. However, the significant Breusch–Pagan also reveals the presence of heteroscedasticity in our data. To control for the heteroscedasticity, the Heckman bivariate probit model is estimated with robust standard errors.

The results from the estimation of the Heckman bivariate model and SURE probit model are presented in Table 4 and Table 5, respectively. The significant ($p < .000$) Wald Chi-square shown in

Table 5. SURE bivariate probit model estimates for adoption and retention of OFSP.

Explanatory variables	Adoption	Retention
Age	0.002 (0.000)	0.002 (0.000)**
Gender	−0.037 (0.029)	−0.057 (0.026)**
Education	0.017 (0.004)***	0.019 (0.004)***
KnowVitA	0.013 (0.007)**	0.012 (0.006)**
Lowlandaccess	0.093 (0.024) ***	0.154 (0.023)***
Cropsold	0.035 (0.009)***	0.035 (0.009)***
NumChild	−0.017 (0.016)	0.008 (0.014)
Landsize	0.007 (0.008)	0.009 (0.007)
VinePurchase	0.138 (0.038) ***	0.101 (0.035)***
Taste	0.052 (0.027)*	0.021 (0.024)
Maturity	0.059 (0.030)**	0.062 (0.027)***
DistrictEx	0.189 (0.257)***	0.126 (0.023)***
Constant	−0.165	−0.214
Observations	1229	1229
χ^2	209.03***	238.75***
Breusch–Pagan test for independence: χ^2 (1)	801.19***	

Notes: *, **, *** represent significance at 10%, 5% and 1%, respectively. Figures in parenthesis are standard errors.

Table 4 indicates that the Heckman bivariate model fits very well with the data and the chosen model explanatory variables are very relevant in explaining the adoption and retention decisions of OFSP varieties. Overall, the results show that the factors that influence the farmers' initial decision to adopt and subsequent retention of OFSP varieties are similar. However, a few factors are more important in the retention decision than in the adoption decision. These include age, gender and early maturity of the variety and its associated agronomic traits (yield and drought tolerance).

The age of the head of the household is positively related with the adoption and retention of OFSP varieties. This finding is consistent with that of Adekambi et al. (2020) and Mwiti et al. (2020) who found a positive relationship between age of household head, willingness to pay for vines and adoption of OFSP varieties in Ghana and Tanzania, respectively.

The result on the effect of gender of household head on adoption and retention of OFSP varieties is quite interesting. While the gender of the household head does not significantly influence the initial adoption decision for OFSP varieties in line with previous findings (Mazuze 2004; Adekambi et al. 2020; Mwiti et al. 2020), it has a significant ($p < .05$) effect on retention of the varieties. The negative and significant coefficient on the retention decision suggests that, conditional on initial adoption, women-headed households are more likely to retain OFSP varieties than their male-headed counterparts. This could be attributed to the fact that sweetpotato is generally a woman's crop, and moreover, most of the nutrition education activities targeted women as the primary care-givers and therefore, they are likely to appreciate the nutrition value of these varieties and retain them.

Contrary to previous studies (Adekambi et al. 2020; Mwiti et al. 2020; Mazuze 2004), we found education of household head to be positively and significantly ($p < .01$) related to both adoption and retention of OFSP varieties. The OFSP intervention included a nutrition education component and this result could be attributed to the fact that formal education enhances the ability to grasp, synthesise and retain new knowledge which in turn enhances adoption and retention of OFSP.

Our results also show that knowledge of vitamin A is positively and significantly related to the adoption and retention of OFSP. Although our finding contradicts that of de Brauw et al. (2018) who found that nutrition knowledge only marginally affected adoption, it corroborates that of de Groot et al. (2016) and Caeiro and Vicente (2020) who found that nutrition-related knowledge significantly increased adoption and retention of biofortified quality protein maize and OFSP.

The three variables related to access to vines: access to lowland, ability to purchase vines and number of crops sold are all, as expected, positively and significantly related to adoption and retention of OFSP varieties. Although the level of significance remains the same, the coefficient for access to lowland is much bigger in the retention equation than in the adoption one, demonstrating the importance of access to lowland in OFSP adoption and retention, as shown by Okello et al. (2019). Further, easing the vine access constraint through vine purchases using crop income significantly enhances the adoption and retention of OFSP varieties. These findings are supported by findings by Labarta (2009) in central Mozambique that farmers' willingness to pay for OFSP vines is higher than white-fleshed planting material and by Kiiza, Kisembo, and Mwanga (2012) who reported a positive effect of income on the adoption of improved sweetpotato varieties.

As expected, taste, which is associated with high dry matter, has a significant positive effect on the initial adoption decision but, surprisingly, does not significantly impact on the retention decision. This finding suggests that for initial acceptance of OFSP varieties by farmers, taste and high dry matter are significant considerations by farmers as shown by previous studies (Jenkins et al. 2018; Naico and Lusk 2010) but, once accepted, other factors become more important for their retention.

Early maturity and its associated agronomic traits of drought tolerance and yield significantly impact both adoption and retention of OFSP varieties. Moreover, the agronomic traits are more important for retention of the varieties than the consumption traits and vitamin A knowledge, a trend that was also observed in the adoption of biofortified quality protein maize (de Groot et al. 2016). The positive impact of taste, early maturity and yield on OFSP adoption and retention was also shown in previous studies (Jenkins et al. 2018; Shikuku et al. 2017; Adekambi et al. 2020; Mwiti et al. 2020). Early maturity is significant as varieties that mature early allow farmers to bridge the hunger gap, the period before the other staples are harvested. Also, early maturing varieties are able to escape the frequent, lengthy droughts that are experienced in Mozambique and therefore stand a good chance of being retained by farmers.

The results for the district dummy confirm that the length of exposure to the OFSP intervention is positively and significantly ($p < .000$) related to the adoption and retention of OFSP varieties. This can be attributed to the fact that, as Caeiro and Vicente (2020) reported, over time, intervention farmers gain more knowledge through experience and perhaps gain more confidence in OFSP. Additionally, the long exposure districts are traditional sweetpotato producing areas where farmers have long experience with sweetpotato and can easily substitute OFSP for white-fleshed varieties.

Table 5 presents results from the SURE probit estimation of the determinants of adoption and retention of OFSP varieties. The results are very much similar to those from the bivariate probit estimation. The similarity of the results between the two approaches proves the robustness of our results.

7. Conclusions and implications

This study examined the factors influencing initial adoption and subsequent dis-adoption or retention decisions by smallholder farmers for biofortified OFSP varieties. Based on the findings, the study concludes that farmers' socio-economic characteristics and perceptions on the agronomic and consumption traits of the varieties influence the adoption and retention of OFSP. In general, the factors that influence farmers' initial adoption decisions and subsequent retention or dis-adoption are similar. However, the degree of importance of some specific factors varies between the two stages.

Our results showed that age of household head, education of household head, vitamin A knowledge, access to lowland, ability to purchase vines, crop income, length of exposure to the intervention and farmers' perceptions on early maturity and its related agronomic traits of drought tolerance and yield are key factors influencing both adoption and retention of OFSP varieties. However, taste is significant in the initial adoption but not in the retention decision, perhaps highlighting that taste is particularly key for initial acceptance and uptake of these varieties but once accepted other factors are more important in their retention. Similarly, while gender had an insignificant influence on the initial adoption decision, we found significant gender differences in the retention decision with women-headed households more likely to retain OFSP varieties than their male-headed counterparts. This finding demonstrates the importance of targeting women in efforts to promote sustained adoption of biofortified crops.

The significance of early maturity and its related agronomic traits (drought tolerance, high yield) in the retention decision demonstrates the importance of agronomic attributes in the retention of biofortified crops. Indeed, studies in other biofortified crops concluded that agronomic traits are more important than consumption traits and farmer' nutrition knowledge in enhancing farmers' retention of biofortified crops. This implies that breeding efforts should target improving both sensory and agronomic traits to match or better traditional white-fleshed varieties for biofortified varieties to be sustainably adopted.

The study further highlighted the importance of quasi-fixed assets, namely, access to lowlands and the ability to purchase vines, in the adoption and retention of OFSP. This probably illustrates the challenge farmers face in conserving and accessing vines and implies the need to widely promote the use of vine conservation technologies adapted to drought-prone areas such as Triple S technology.

Notes

1. Biofortified crops are nutritionally enhanced food crops with increased bioavailability to the human population that are developed and grown using modern biotechnology techniques, conventional plant breeding, and agronomic practices (Garg et al. 2018).
2. The method involves storage of non-damaged small unmarketable roots in dry sand at smallholder farmers' homes during the dry period and sprouting the roots in protected beds, between 5 and 7 weeks before the onset of the rain season (Namanda et al. 2012).

Acknowledgements

This research was undertaken through the Viable Sweetpotato Technologies in Africa (VISTA)-Mozambique project, as part of the CGIAR Research Program on Roots, Tubers and Bananas (RTB) led by the International Potato Center.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was funded by the United States Agency for International Development (grant number 1235-USAID). Additional support from the Foreign, Commonwealth and Development Office (formerly Department for International Development) awarded to International Potato Center is acknowledged.

Data availability statement

The data that support the findings of this study are openly available in dataverse at https://doi.org/10.21223/CN3ZNG.

References

Adekambi, S.A., J.J. Okello, P.E. Abidin, and E. Carey. 2020. Effect of exposure to biofortified crops on smallholder farm household adoption decisions: The case of orange-fleshed sweetpotato in Ghana and Nigeria. Scientific African 8: 1–10.

Adesina, A.A., and J. Baidu-Forson. 1995. Farmers' perceptions and adoption of new agricultural technology: Evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics* 13, no. 1: 1–9.

Adesina, A.A., and M.M. Zinnah. 1993. Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. *Agricultural Economics* 9: 297–311.

Aguayo, V., S. Kahn, C. Ismael, and S. Meershoek. 2005. Vitamin A deficiency and child mortality in Mozambique. *Public Health Nutrition* 8, no. 1: 29–31.

Andrade, M., J. Ricardo, A. Naico, A. Alvaro, G. Makunde, J. Low, and R. Ortiz. 2017. Release of orange-fleshed sweetpotato (Ipomoea batatas [l.] Lam.) cultivars in Mozambique through an accelerated breeding scheme. *Journal of Agricultural Science* 155, no. 6: 919–29.

Caeiro, R.M., and P.C. Vicente. 2020. Knowledge of vitamin A deficiency and crop adoption: evidence from a field experiment in Mozambique. *Agricultural Economics* 51, no. 2: 175–90.
de Brauw, A., P. Eozenou, D.O. Gilligan, C. Hotz, N. Kumar, and J.V. Meenakshi. 2018. Biofortification, crop adoption and health information: impact pathways in Mozambique and Uganda. *American Journal of Agricultural Economics* 100, no. 3: 906–30.
de Groote, H., N.S. Gunaratna, M. Fisher, E.G. Kebebe, F. Mmbando, and D. Friesen. 2016. The effectiveness of extension strategies for increasing the adoption of biofortified crops: The case of quality protein maize in East Africa. *Food Security* 8, no. 6: 1101–21.
Feder, G., R.E. Just, and D. Zilberman. 1985. Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change* 33, no. 2: 255–98.
Ganhão, C., P. Pires, S. Couto, A. Valente, M. Mupueleque, A. Marega, and P. Muoki. 2017. Maternal and children nutrition in northern Mozambique: a mixed methods study. *International Journal of Research* 4, no. 10: 1884–902.
Garg, M., N. Sharma, S. Sharma, P. Kapoor, A. Kumar, V. Chunduri, and P. Arora. 2018. Biofortified crops generated by breeding, agronomy, and transgenic approaches are improving lives of millions of people around the world. Frontiers in Nutrition 5, no. 12: 1–33.
Glover, D., J. Sumberg, and J.A. Andersson. 2016. The adoption problem or why we still understand so little about technological change in African agriculture. *Outlook on Agriculture* 45, no. 1: 3–6.
Greene, W.H. 2008. *Econometric analysis*. 7th ed. San Francisco, CA: Prentice Hall.
Hassen, S. 2015. *Disadoption, substitutability, and complementarity of agricultural technologies: a random effect multivariate probit analysis*. Environment for Development Discussion Paper Series, EfD DP 15-26, Washington, DC.
Hotz, C., C. Loechl, A.D. de Brauw, P. Eozenou, D. Gillagan, M. Moursi, and J.V. Meenakshi. 2012. A large-scale intervention to introduce orange sweetpotato in rural Mozambique increases vitamin A intakes among children and women. *British Journal of Nutrition* 108, no. 1: 163–76.
Hotz, C., C. Loechl, A. Lubowa, J.K. Tumwine, G. Ndeezi, A.N. Masawi, and D.O. Gilligan. 2012. Introduction of b-carotene–rich orange sweet potato in rural Uganda results in increased vitamin A intakes among children and women and improved vitamin A status among children. *Journal of Nutrition* 142, no. 10: 1871–80.
Jenkins, M., C.B. Shanks, and B. Houghtaling. 2015. Orange-fleshed sweetpotato: successes and remaining challenges of the introduction of a nutritionally superior staple crop in Mozambique. *Food and Nutrition Bulletin* 36, no. 3: 327–53.
Jenkins, M., E.B. Shanks, R. Brouwer, and B. Houghtaling. 2018. Factors affecting farmers' willingness and ability to adopt and retain vitamin A-rich varieties of orange-fleshed sweetpotato in Mozambique. *Food Security* 10, no. 6: 1501–19.
Jones, K., and A. de Brauw. 2015. Using agriculture to improve child health: promoting orange sweetpotato reduces diarrhea. *World Development* 74: 15–24.
Kiiza, B., L.G. Kisembo, and R.O.M. Mwanga. 2012. Participatory plant breeding and selection impact on adoption of improved sweetpotato varieties in Uganda. *Journal of Agriculture, Science and Technology A* 2: 673–81.
Labarta, R. 2009. Are small sub-Sahara African farmers willing to pay for vegetative propagated orange fleshed sweetpotato planting material? Evidence from Central Mozambique. Paper presented at the Agricultural & Applied Economics Association AAEA & ACCI Joint Annual Meetings, Milwaukee, WI.
Low, J., M. Arimond, N. Osman, B. Cunguara, F. Zano, and D. Tschirley. 2007. A food-based approach introducing orange-fleshed sweetpotatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *The Journal of Nutrition* 137, no. 5: 1320–7.
Low, J., J. Lynam, B. Lemaga, C. Crissman, I. Barker, G. Thiele, and M. Andrade. 2009. Sweetpotato in Sub-saharan Africa. In *The sweetpotato*, eds. G. Loebenstein, and G. Thottappilly, 359–90. Dordrecht: Springer Science &Business Media B.V.
Makunde, G., M. Andrade, J. Menomussanga, and W. Grüneberg. 2018. Adapting sweetpotato production to changing climate in Mozambique. *Open Agriculture* 3, no. 1: 122–30.
Mazuze, F. 2004. Analysis of adoption and production of orange-fleshed sweet potatoes: The case of Gaza province (Unpublished Master's thesis). Michigan State University, East Lansing, MI 48824, USA.
Ministério da Agricultura e Segurança Alimentar. 2015. *Annuário de Estatísticas Agrárias*. Maputo, Mozambique.
MISAU. 2011. *Moçambique Inquérito Demográfico e de Saúde 2011*. Maputo, Mozambique, MISAU Nutrition Division & INE.
Moser, C.M., and C.B. Barrett. 2006. The complex dynamics of smallholder technology adoption: the case of SRI in Madagascar. *Agricultural Economics* 35, no. 3: 373–88.
Mwiti, F., J.J. Okello, K. Munei, and J. Low. 2020. Farmer demand for clean planting material of biofortified and non-biofortified vegetatively propagated crop varieties: The case of sweetpotato. Scientific African 8: 1–10.
Naico, A., and J. Lusk. 2010. The value of a nutritionally enhanced staple crop: results from a choice experiment conducted with orange-fleshed sweet potatoes in Mozambique. *Journal of African Economies* 19, no. 4: 536–58.
Namanda, S., R. Amour, and R.W. Gibson. 2012. The triple S method of planting sweet potato planting material for areas in Africa with long dry seasons. *Journal of Crop Improvement* 27, no. 1: 64–84.
Neill, S.P., and D.R. Lee. 2001. Explaining the adoption and dis-adoption of sustainable agriculture: the case of cover crops in northern Honduras. *Economic Development and Cultural Change* 49, no. 4: 793–820.

Okello, J.J., N. Kwikiriza, P. Muoki, J. Wambaya, and S. Heck. 2019. Effect of intensive agriculture-nutrition education and extension program adoption and diffusion of biofortified crops. *Journal of Agricultural & Food Information* 20, no. 3: 254–76.

Sanou, B., K. Savadogo, and T. Sakurai. 2017. Determinants of adoption and continuous used of improved maize seed in Burkina Faso. *Japanese Journal of Agricultural Economics* 19, no. 0: 21–26.

Shikuku, K.M., J.J. Okello, K. Sindi, J.W. Low, and M. McEwan. 2017. Effect of farmers' multidimensional beliefs on adoption of biofortified crops: evidence from sweetpotato farmers in Tanzania. The Journal of Development Studies 55, no. 2: 227–242.

Singh, I., L. Squire, and J. Strauss. 1986. *Agricultural household models: extensions, applications, and policy*. London: Johns Hopkins.

Simtowe, F., and K. Mausch. 2018. Who is quitting? An analysis of the dis-adoption of climate smart sorghum varieties in Tanzania. International Journal of Climate Change Strategies and Management 11, no 3: 341–357.

Uaiene, R.N., C. Arndt, and W.A. Masters. 2009. *Determinants of agricultural technology adoption in Mozambique (Discussion paper 67E)*. Maputo: National Directorate of Studies and Policy Analysis, Ministry of Planning and Development.

Uematsu, H., A.K. Mishra, R. Roberts, D.M. Lambert, J.A. Larson, and B.C. English. 2010. Motivation for technology adoption and its impact on abandonment: A case study of U.S. cotton farmers. Paper presented at presented at the Southern Agricultural Economics Association Annual Meeting, Corpus Christi, TX.

Walker, T., R. Pitoro, A. Tomo, I. Sitoe, C. Salência, R. Mahanzule, and F. Mazuze. 2006. *Estabelecimento de prioridades para a investigação agrária no sector público em Moçambique baseado nos dados do trabalho de inquérito agrícola (TIA) (relatório de pesquisa no. 3P)*. Maputo: Instituto de Investigação Agrária de Moçambique.

Webb Girard, A., F. Grant, M. Watkinson, H.S. Okuku, R. Wanjala, D. Cole, C. Levin, and J. Low. 2017. Promotion of orange-fleshed sweet potato increased vitamin a intakes and reduced the odds of low retinol-binding protein among post-partum Kenyan women. *Journal of Nutrition* 147: 955–63.

Zellner, A. 1962. An efficient method of estimating seemingly unrelated regressions and tests of aggregation bias. *Journal of the American Statistical Association* 57: 500–9.