

Agricultural technology adoption for smallholder small grain farmers in Zimbabwe. Implications for food system transformation and sustainability

RESEARCH ARTICLE

Tryphina Dube-Takaza^a, Blessing M Maumbe^{b,Ⓐ} and Cosmas Parwada^c

^aPhD student, Faculty of Agricultural and Environmental Sciences, Department of Agribusiness, Women's University in Africa, 1515 Pine Street, Marondera, Zimbabwe

^bDeputy Vice-Chancellor, UNICAF University, 99 Jason Moyo and 4th Street, Harare, Zimbabwe

^cRegional Coordinator, Department of Agricultural Management, Faculty of Agricultural Science Zimbabwe Open University, 15–16 Hospital Road Hwange, Zimbabwe

Abstract

Food security is a perennial concern in natural regions IV and V of Zimbabwe, that receive low rainfall per annum. Improved small grain varieties and conservation agriculture practices provide a promise for bumper harvests in these dry regions. This study focused on four districts (Binga, Chiredzi, Hwange and Matobo) from these two regions to determine patterns for improved small grain varieties and conservation agriculture technology adoption by smallholder small grain farmers. Data were collected from 281 respondents using structured questionnaires and interviews. The statistical package Stata (version 16) was used to analyse data. Logit and multinomial models were used to compare non-adopters and adopters of technologies in order to show the rationale for adoption. Results indicated that 56% of the sample were non-adopters while 44% were adopters. Adoption patterns varied with location, education, land size, marital status, frequency of extension visits and access to credit. The study recommends increased funding to research institutions that develop high-yield small grain varieties. Comparative studies are recommended in other semi-arid regions of Zimbabwe to support the study findings in informing future policy.

Keywords: conservation agriculture, small grain, technology adoption, varieties

JEL-codes: Q00, Q1, Q2, Q5

[Ⓐ] Corresponding author: maumbebm@gmail.com

1. Introduction

Globally, agriculture remains the mainstay of economic activity and a key issue for sustainable livelihoods. Besides poverty alleviation, agriculture is a major revenue stream for all categories of farmers. In Zimbabwe, the majority of the population lives in rural areas where livelihoods are hinged on agriculture. The need to increase yields through agricultural technology adoption (ATA) cannot be overemphasised. This study argues that agricultural technology adoption takes away the guesswork out of agriculture and provides more predictable and better yields in semi-arid regions. In spite of evidence supporting the argument, limited ATA by smallholder farmers in these regions is an issue of great concern. This paper provides a glimpse of this problem using data collected from four districts (Binga, Chiredzi, Hwange and Matobo) which lie in the semi-arid regions of Zimbabwe.

2. Background

A report by the United Nations warned that the world was facing multiple and complex climatic change-induced challenges in the 21st century and beyond (FAO, 2016). Food insecurity in the face of a growing population was one of the world's colossal challenges that required evidence-based solutions. Food security is a priority issue among the 17 Sustainable Development Goals (SDGs) which are integrated but adaptable to the specific needs of each nation. All nations of the world have committed themselves to surmounting the twin challenges of poverty and hunger through comprehensive and sustainable ways (United Nations, 2015). Various studies concur that food security is a global issue that can be addressed by the adoption of modern agricultural technologies (FAO, 2016; Glover *et al.*, 2020; Muchuru and Nhamo, 2019). Further empirical evidence suggests that resilient small grain production is the panacea to perennial food insecurity in arid regions that are largely affected by climate change (Glover *et al.*, 2020; Mathew, 2015; Muchuru and Nhamo, 2019). Agriculture experts note that small grains are more effective in drought-prone areas. They are considered as more nutritious than corn, which is considered an unsuitable crop in these agricultural areas. The crude protein (CP) for small grains is higher than that for maize. Maize, sorghum and pearl millet have CP values of 9.2, 10.4 and 11.8, respectively (Kumar *et al.*, 2018). Furthermore, owing to the richness of millets in polyphenols and other biologically active compounds, they are also considered to impart a role in reducing the rate of fat absorption, slow release of sugars (low glycaemic index) and thus reducing the risk of heart disease, diabetes and high blood pressure (Kumar *et al.*, 2018). Similarly, the study is supported by reports that millets have high levels of essential elements such as iron, zinc, calcium and protein (ICRISAT, 2021).

Agricultural benefits of conservation agriculture (CA) are primarily improved soil structure and increased organic matter, eventually leading to more fertile land (FAO, 2015). As a result, water and nutrients are used more efficiently, protecting soil whilst increasing agricultural production (FAO, 2015). Currently, the adoption of these small grain varieties and CA in terms of area under these crops is poor. Generally, yields of sorghum and millet by smallholder farmers in Zimbabwe are low, hardly reaching 0.5 t ha⁻¹ (FAO, 2016). In the agro-ecological regions IV and V of Zimbabwe, maize production continues to dominate compared to small grain crops owing to high yields (Brazier, 2015). Low small grain yields are a problem for small-scale plot holders in the dry prone regions of Zimbabwe in developing and adopting large-scale small grain seed production relative to maize. The decline in productivity makes small grains very unattractive to farmers in semi-arid regions (FAO, 2016). Therefore, small grains face the major drawback of lower yields per hectare compared to maize. As such, most farmers prefer to grow the maize crop, regardless of the regions they reside. This is largely due to the fact that smallholder farmers carry on growing local landrace (recycled) of small grain varieties characterized by low yields, resulting from poor crop management (Zeven, 1998). Farmers do not value the small grain crops as they do cash crops like tobacco, hence, they grow these crops without the addition of fertilizers, and have poor marketing channels and limited knowledge on value addition (FAO, 2018).

The argument was that the adoption of small grains which are drought tolerant improves agricultural productivity leading to poverty alleviation. Adoption of genetically engineered small grain seed varieties can translate into increased incomes for smallholder farmers in dry regions (Muchineripi, 2014; Muzari *et al.*, 2013; Proietti *et al.*, 2015; UNDP, 2018). Emphasizing the rationale for increasing food production amid climate change challenges, Andaluz (2018), a technology expert opined that the world was operating in a circular economy where economic, environmental and social impacts must be considered simultaneously (Andaluz, 2018). He further noted the importance of ATA as a way to develop climate change resilience. Together with several other similar clarion calls from proponents of ATA, there have been more and more voices from different parts of the globe which are advocating for the adoption of crops and cultivars which can adapt to semi-arid conditions (Mathew, 2015; Muchuru and Nhamo, 2019; Muzari *et al.*, 2013). Despite the calls that are supported by empirical evidence, some smallholder farmers in arid ecological regions are hesitant to adopt improved small grain varieties for various reasons. The problem of low adoption of improved small grain varieties is prevalent in Zimbabwe's low rainfall agro-ecological regions.

Zimbabwe has five agro-ecological zones which are commonly referred to as natural regions. An agro-ecological zone refers to an area whose delimitation is based on climate combinations of climatic characteristics, landform and recommended land usage. This study focused on four districts (Binga, Chiredzi, Hwange and Matobo) which are located in Zimbabwe's natural regions IV and V as shown in Figure 1.

Natural Regions IV and V are semi-arid areas that experience rainfall of 450–650 mm per annum. Seasonal droughts and prolonged dry spells are common features in these two regions. These zones receive below normal rainfall which is unreliable for crop production, apart from a few isolated areas where drought-tolerant varieties can be produced for subsistence (Integrated Food Insecurity Phase Classification (IPC) 2020). The study sites lie as follows: Binga: latitude 18°13'11" S, longitude 27°41'29" E, altitude 799 m asl; Chiredzi: latitude 21°67'81" S, longitude 31°31'70" E, altitude 411 m asl; Hwange: latitude 18°03'39.3" S, longitude 26°13'62.9" E, altitude 889 m asl; and Matobo: latitude 21°05'33" S, longitude 28°33'81" E, altitude 980 m asl. These four districts are not suitable for the production of maize which is the most preferred staple food in Zimbabwe. While smallholder farmers in the studied districts grow both small grains and maize

Small grain growing areas (Research sites) in Zimbabwe.

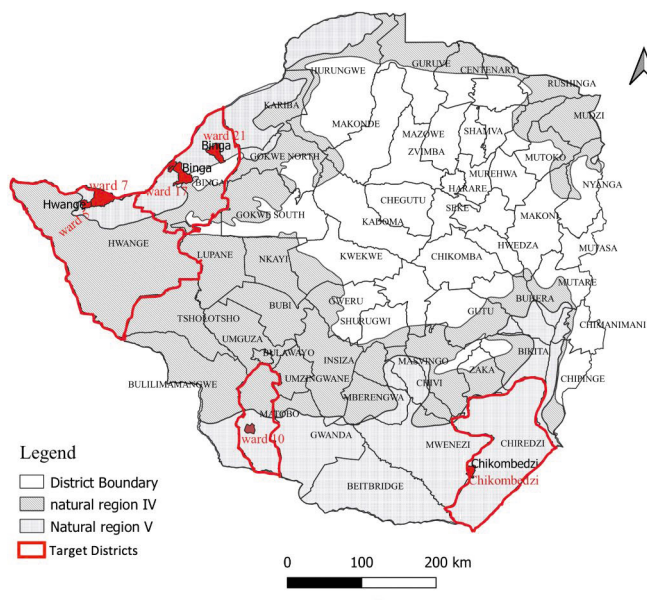


Figure 1. Research sites that are in Regions IV and V. Source: Generated by authors (2021).

crops, adoption of improved small grain seeds was low despite the perennial inadequate returns that are realised from landrace seed (Muchuru and Nhamo, 2019; Mukarumbwa and Mushunje, 2010). This study was conducted to determine the small grain adoption patterns in regions IV and V of Zimbabwe with a view to recommend strategies which could be deployed to accelerate improved small grain seed adoption in the study sites.

3. Research questions

1. What are the determinants of adoption of improved small grain varieties and CA for smallholder small grain farmers in drought-prone regions of Zimbabwe?
2. Which policy can be recommended to ensure the full adoption of improved small grain seed and CA for smallholder small grain farmers in drought-prone regions of Zimbabwe?

4. Related literature

Recent research has escalated the ATA discourse since the wide-scale adoption of agricultural technologies which led to increased production during the Green Revolution in the 1960s (Estudillo and Keijiro, 2006; Stevenson *et al.*, 2013; Stone *et al.*, 2014). Since then, technological innovation has continued to develop high-yielding crop varieties which are adaptable to unfavourable weather conditions. Thus, agricultural productivity and efficiency have accelerated, yielding desired agricultural outputs at reduced production costs (Andaluz, 2018; Djibo and Malam Maman, 2019; Hailu *et al.*, 2014; Muzari *et al.*, 2013).

ATA was examined at different levels including household, firm, industry and national levels (Beyene, 2019; Djibo and Malam Maman, 2019). These studies used different concepts, theories and methodologies. Oftentimes, findings from some of these research studies concurred while others produced conflicting results (Brown *et al.*, 2018). Some ATA studies have focused on either a sole new innovation such as an irrigation structure or improved seed varieties among many other emerging technologies. Still, other ATA studies focused on a set of new innovations which they treated as a unique package (Dorfman, 1996). The latter category aligns with some authors who felt that, farmers often combine different new technologies in order to maximize the potential benefits of each of them (Mukasa, 2016). Such adoption decisions are described as multivariate adoption while adoption of a single technology entails a univariate process (Denning and Lewis, 2019; Moore, 2014). A large body of literature (Brown *et al.*, 2018; Djibo and Malam Maman, 2019; Ugochukwu and Philip, 2018; UNDP, 2018) suggests that the technology adoption pattern follows an S-shaped (sigmoidal) curve. Rogers believed that, adoption of new technology starts slowly with few adopters and rises later before levelling off (Rogers, 2003). The number of adopters rises as knowledge about the technology spreads and then slows down as a greater proportion of potential end users adopt the technology (Denning and Lewis, 2019; Moore, 2014). The constraints that slow technology adoption during the early phases of the diffusion process tend to differ and decline as the technology reaches its final stage of diffusion process (Djibo and Malam Maman, 2019; Feder *et al.*, 1985).

In his study, Rubas (2004) found that, the size and distribution of the benefits of new technology adoption were determined by the timing of adoption (Rubas, 2004). He noted that, early adopters enjoyed a better share of the benefits of a new technology compared to later adopters (Rogers, 2003). He further opined that, the incentive to adopt some technologies is reduced as the adoption rate increases and may go to zero shortly before everyone adopts (Rogers, 2003). While this angle sheds valuable insight into the determinants of ATA, this knowledge cannot be applied wholesomely to explain the low adoption of improved small grain seed and CA which is obtained in the four research sites for this study. Our argument aligns with Ugochukwu and Philip (2018), who discovered that the impact that agricultural technologies differ from region to region. Despite the known benefits of agricultural technology, adoption itself is not uniform across different regions. Similarly, ATA differs among farmers within the same regions. Some studies have shown that in spite of the perceived benefits of agricultural technology, some actors will not adopt it (Beyene, 2019; Feder *et al.*,

1985; Muzari *et al.*, 2013). In the section that follows, we reviewed adoption literature to help us develop a better understanding of the factors of improved small grain seed varieties and CA adoption by smallholder farmers producing the crop in studied research sites.

The decision to adopt a new technology involves five stages that include knowledge (awareness); persuasion, potentially by gaining enough information on the characteristics, benefits, and costs of new technology; decision; implementation; and confirmation (Rogers, 2003). He goes further to outline the process by making the following remarks:

The process of adoption begins with awareness about the new innovation that could be through extension agents or social networks. This is then followed by evaluation of the perceived traits of the technology and possible benefits of getting that technology. Once benefits have been weighed the decision is made either to adopt or reject the innovation. Critical factors include the timing of the introduction as well the location of technology introduction (Rogers, 2003). Evidence suggests the possibility of continued rejection of technology over time or a choice for delayed adoption (Denning and Lewis, 2019; Mathew, 2015).

Other studies (Feder *et al.*, 1985; Ugochukwu and Philip, 2018) suggest various reasons for non-adoption which include traits of the technology, such as relative gain, complexity and compatibility of potential adopters. Other common factors cited include prices, weather conditions, labour availability and market constraints such as inputs and output, credit and information among many others (Andaluz, 2018). The convergent views from the majority of the reviewed studies were that adoption decisions are slowed by uncertainties among multiple other factors (Denning and Lewis, 2019).

Focusing on Zimbabwe, it became apparent that it was not immune to trends in global erratic weather patterns exacerbated by worsening climate change (Mathew, 2015; Muchuru and Nhamo, 2019; UNDP, 2018). Climate variability is one of the main challenges faced by smallholder farmers, especially in rural areas where the majority of Zimbabwe's population (67%) lives and their livelihoods depend entirely on agriculture (Moyo and Akpan 2018). Thus, in semi-arid regions of Zimbabwe, specifically regions IV and V, the introduction of improved small-grain varieties has been viewed as a panacea for improving food security in the face of climate change. In this respect, there have been a rising demand for the growing of small grains such as sorghum (*Sorgho bicolor*), pearl millet (*Pennisetum*) and finger millet (*Eleusine coracana*) instead of maize (*Zea mays*) production in the two low rainfall regions of Zimbabwe (Phiri, 2019). The rationale for shifting to small grain production hinged on the belief that, small grains are drought tolerant and more ecologically compatible with semi-arid weather conditions as equated to maize which requires more rainfall (Dube *et al.*, 2018). Small grains have proven to be adapted to climate variability and possess a lesser risk of disappointment as compared to maize.

The study's analysis of the reviewed studies was that despite the numerous prior studies on ATA, policies that were informed by findings from these studies have not managed to address the problem of low acceptance of improved small grain cultivars and CA by small-scale farmers in Zimbabwe's low rainfall regions IV and V. The study noted with concern that most of the studies reviewed were conducted from countries other than Zimbabwe. Given the complexity of ATA, its context specificity and its perceptual subjectivity, this study considered that findings from the reviewed literature remain inconclusive. Hence, their findings were not expected to explain with certainty the low rate of improved small grain seed and CA adoption by smallholder small grain farmers in our four case study sites. This triggered us to conduct this study which documented the specific obstacles which undermined the adoption of improved small grain seed varieties and CA in regions IV and V of Zimbabwe.

5. Methodology

This mixed methods cross-sectional research study in which quantitative aspect accounted for most of the research was adopted. Thematic analysis was used for qualitative data.

5.1 Theoretical and conceptual frameworks

The study explored the determinants of improved small grain varieties adoption in our four case study sites (Binga, Chiredzi, Hwange and Matobo districts) through the lenses of a Diffusion of Innovation Theory (DIT) and a Technological Adoption (TA) Conceptual framework. The DIT was selected as the guiding theory on the strength of its key assumption that technology adoption uncertainty is a major obstacle to the adoption of technology (Denning and Lewis, 2019; Moore, 2014). The particular relevance of this theory to the study was its enlightening argument that ideas and information about new technology spread through social interaction in communities, a process that provides more community members with the opportunity to adopt. Prior to the study, the DIT was used extensively to inform ATA research studies and it has proved extremely useful in studies that motivated efficient agricultural productivity (Andaluz, 2018; Beyene, 2019; Glover *et al.*, 2020).

On the other hand, we selected the TA conceptual framework because it focused on the core of the study which dealt with the adoption of both improved small grain varieties and CA by smallholder farmers in the study locations. There is overwhelming consensus from recent studies that the key objective of agricultural technology was to increase productivity and achieve better yields (Beyene, 2019; Hailu *et al.*, 2014; Muchuru and Nhamo, 2019; Muzari *et al.*, 2013). Looking at the argument in this paper, it is apparent that a strong connection between small grain improved varieties adoption and increased yields exists in the study areas because seed varieties were engineered to be resilient to low rainfall conditions (Beyene, 2019). Similarly, CA is correlated to increased yields as the concept maximizes the limited moisture in low rainfall areas of the study. As a result, the conceptual framework we used was appropriate for our study.

Together, the AT (conceptual framework) and the DIT (theory) provided this study with a world view of the participants' decision-making processes which led to improved small grain seed adoption, CA adoption or non-adoption and the relationships between the obstacles to adoption. In turn, the understanding gained helped in the formulation of appropriate research questions that enabled us to collect relevant data which addressed our research objectives. This view aligned with the thought that a combination of a conceptual and theoretical framework in a single study is essential because it keeps researchers focused on key elements of the studied phenomenon (Lacey, 2010). Furthermore, the conceptual and theoretical frameworks adopted helped this study to organise related and interrelated concepts that were at the core of our study. By so doing, the research managed to unfold the context-specific challenges that slowed the adoption of improved small grain seed varieties and CA in our study sites. However, in using a theoretical and conceptual framework, the study acknowledged that the distinction between the two research concepts was debatable. Important to this study are the guiding theory and conceptual framework which helped elucidate the obscure factors of improved small-grain variety adoption and CA acceptance by small grain farmers in four research sites. Together, the chosen theory and conceptual framework provided the empirical foundation on which we developed our research questions and arguments.

Binary logistic and multinomial regression models were both used to determine ATA patterns in the studied areas.

5.2 Logit and multinomial models

The logit and multinomial models were used for comparison of farmers who adopted a production technology with those who did not adopt to see if the differences offered insights into the rationale for adoption. The rationale to use binary model is that, when a farmer is faced with a decision to adopt agricultural technologies, he/she can decide to either adopt or discard the technology. The study used the concept technology adoption interchangeably with either improved small grain seed adoption or Conservation Agriculture (CA). The dependent variable for our research was the farmer having to choose between adopting or not adopting agricultural technologies. The study defined adopters as the households who have treated at least one

plot/farm with improved small grain seed varieties or CA. Coding as follows: 1 = “adopters”, if the farmer was an adopter of improved small grain seed varieties or CA; and 0 = “non-adopters”, if the farmer had not adopted either improved small grain seed varieties or CA.

A smallholder small grain farmer could decide to use CA only, improved seed variety only, a combination of CA and improved varieties or none of the technologies in their agriculture land holdings. Multinomial models are well suited to identify the factors that influence small-scale grain producers to make these decisions.

In multinomial models, there are k alternatives instead of dichotomized choice and the level of alternatives are the same. The multinomial framework has advantages over a multivariate framework in that it can evaluate both alternative individual choices and combinations of choices (Khonje *et al.*, 2015).

This was the situation with improved seed varieties as well as conservation agriculture technologies in this research. Furthermore, self-selection bias and interaction between choices of alternative practices are accounted for by the model (Croston *et al.*, 2007). The study employed a Multinomial logistic regression model because of the number of choices one would prefer to adopt.

The binary logistic model

The binary regression model predicts the logit of the response variable (agricultural technologies adoption 0/1) from the explanatory variable(s). The probability of the farmer being an adopter of agricultural technologies is projected by odds ($Y = 1$); that is, the ratio of the likelihood that $Y = 1$ to the chances that $Y \neq 1$ (Croston *et al.*, 2007).

$$\text{Odds } Y = P(Y = 1) / (1 - P(Y = 1)).$$

The logistic regression model is stated as follows:

The logit (Y) is given by the natural log of Odds;

$$\ln\left(\frac{P(Y_i=1)}{1-P(Y_i=1)}\right) = \text{LogOdds} = \text{Logit}(Y)$$

$$\text{Logit}(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_n X_n + \varepsilon_i$$

where Y = dependent variable (adoption) with 1 = adopters and 0 = non-adopters;

ε_1 = error term, β_0 = intercept,

$\beta_1 - \beta_n$ = regression coefficients of the explanatory variables which are to be estimated,

$X_1 - X_n$ = explanatory variables

$P(p)$ = probability of adopting agricultural technologies;

$1 - p$ = probability that a farmer does not adopt agricultural technologies; and

$\ln$ = natural log.

With the explanatory variables (Table 1) of this model, logistic regression for ADOPTION in the study is expressed in the following formula:

$$\text{Logit (ADOPTION)} = \beta_0 + \beta_1 \text{AGE} + \beta_2 \text{EXPERIENCE} + \beta_3 \text{HOUSEHOLDSI} + \beta_4 \text{EDUCARE} + \beta_5 \text{EXTENSION} + \beta_6 \text{LANDSIZE} + \beta_7 \text{LABOUR} + \beta_8 \text{SEX} + \beta_9 \text{AFFILIATION} + \beta_{10} \text{LOCATION} + \beta_{11} \text{CONTRACT} + \beta_{12} \text{CREDIT} + \beta_{13} \text{MARITAL} + \beta_{14} \text{PERCEPTION} + \beta_{15} \text{CLIMADAPT} + \beta_{16} \text{WEATHACC}$$

Multinomial model

In the multinomial model, the likelihood of K alternatives for an i th smallholder small grain farmers were computed as:

$$P(Y_i) = \frac{K}{X_i} = \frac{e^{Z_{ik}}}{\sum_{j=1}^k e^{Z_{ij}}} = \frac{e^{X_i \beta_k}}{\sum_{j=1}^k e^{X_i \beta_j}}$$

the chances derived from the equation above have positive values. Since the total probability of $P(Y_i = j)$ is 1 and because we can only identify $K - 1$ probability as independent, normalization process is made (Schwab, 2002). The model describes the behaviour of farmer i in choosing to adopt small grain improved varieties j over other alternative practices. The multinomial model has the potential of taking a number of choices, where one alternative is different from other, that is $Y_i = 1$ and $Y_i \neq 1$ is not the same (Pedhazur, 1997). Therefore, relative risk ratios are used to explain the alternatives (Schwab, 2002).

Table 1. Explanatory variables, description and expected outcomes

Variable name	Description and measurement type	Variable	Expected outcome ($\pm$)
AGE (X_1)	Age of head of household(years)	Continuous	+
EXPERIENCE (X_2)	Experience in farming	Continuous	+
HOUSEHOSI (X_3)	Household size	Count	+
EDUCARE (X_4)	Number of years spent in school	Continuous	+
EXTENSION (X_5)	Frequency of extension visits per year (1 = does not visit, 2 = once, 3 = twice, 4 = more than twice)	Categorical	+
LANDSIZE (X_6)	Land size of arable land (Ha)	Continuous	–
LABOUR (X_7)	Proportion of household contributing to farm labour	Continuous	+
SEX (X_8)	Sex of the head of household (1 = male, 2 = female)	Binary	+
AFFILIATION (X_9)	Affiliation to farming groups (Dummy 1 = yes, 2 = no)	Binary	+
LOCATION (X_{10})	District (Dummy 1 = Chiredzi, 2 = Matobo, 3 = Hwange, 4 = Binga)	Categorical	+
CONTRACT (X_{11})	Contract farming (Dummy 1 = yes, 0 = no)	Binary	+
CREDIT (X_{12})	Access to credit (Dummy 1 = yes, 0 = no)	Binary	+
MARITAL (X_{13})	Marital status (Dummy 1 = single/divorced/widowed, 2 = married)	Categorical	+
PERCEPTION (X_{14})	Perception of extension advice (Dummy 1 = very useful, 2 = somewhat useful, 3 = not useful)	Categorical	+
CLIMADAPT (X_{15})	Receiving training on climate adaptation (Dummy 1 = yes, 2 = no)	Categorical	+
WEATHACC (X_{16})	Access to weather information (Dummy 1 = yes, 2 = no)	Categorical	+

$\pm$ indicates a positive or negative relationship with the dependent variable. Source: Generated by the authors (2021)

Relative risk ratio (RRR) compares the probability of a choice (adoption of agricultural technology) in each cluster and is easier to understand. Considering a farmer selecting among K alternatives in a choice set and let X_i be the covariates explaining the choice of the farmer. The general model focuses on the farmer as the element of scrutiny and uses specific characteristics as independent variables. The independent variables who have been the characteristics of the farmer, are constant over the alternatives (Khonje *et al.*, 2015). The likelihood that individual j selects alternative K is:

$$\pi_{jk} = \frac{\exp(\beta_k X_j)}{\sum_{l=1}^k \exp(\beta_l X_j)} = \frac{1}{\sum_{l=1}^k \exp[(\beta_l - \beta_k) X_j]}$$

where β_l, β_k are k vectors of unknown regression parameters (each of which is different), even though X_j is constant across alternatives. Since $\sum_{l=1}^k \pi_{jk} = 1$, the k sets of parameters are not unique. By setting the last term set of coefficients to null (that is $\beta_k = 0$) the coefficients β_k is called the RRR and it represent the effects of the X_i variables on the likelihood of choosing the k th alternative over the last alternative. In fitting the model, we estimate $K - 1$ sets of regression coefficients (Khonje *et al.*, 2015).

Empirically, the model can be expressed as;

$$Y_i = \beta_0 + \sum_{i=1}^{14} \beta_i X_i + \varepsilon_i$$

Where Y_i is dependent variable is the adoption of the alternatives (improved varieties only, CA only, Combined and none)

X_1-X_{14} represents the independent variables such as marital status of farmer, access to credit, age of farmer, etc β is the regression parameters to be estimated and ε_i is an error term accounting for unobserved characteristics and measurement errors (Khonje *et al.*, 2015).

A cross-sectional research design was used to focus on four districts (Binga, Chiredzi, Hwange and Matobo). We collected data through face-to-face interviews, documentary analysis, observations, structured and semi structured questionnaires, key informants, focus group discussions (FGDs), participatory, primary and secondary sources, video and audio recording. The instruments were first pilot tested for validity and reliability. A sample of 281 participants were drawn from a target population which comprised smallholder small grain farmers.

Both probability and non-probability sampling techniques were utilised in participant selection and recruitment. The use of probability sampling was to ensure every respondent had an equal chance of being included in the sample whilst non-probability was for in depth research. Multi-stage random sampling was employed in two districts (Hwange and Matobo) that were not engaged on contract farming, two wards per district were selected and four villages (two villages per ward) were randomly selected. The main purpose of multi-stage sampling was to select farmers which are concentrated in few districts. The study employed simple random sampling to identify farmers who were growing either or both small grain crops. For farmers that were into contract farming (Binga and Chiredzi) non probability/convenient sampling was carried out. Simple random purposive sampling was employed for districts engaged with contract farming. We conducted eight focus group discussions, two per district. Stratified random sampling was used on value chain actors (Ministry of Agriculture, Seed breeders, Input suppliers) as there is a great deal of variation in terms of functions by each value chain actor hence the purpose was to ensure that every stratum was adequately represented. Convenience and judgmental sampling were used to select local leadership that were from sampled villages as they were readily available. A representative sample was randomly selected with a specific sample size per district calculated proportionally as follows: Binga (60), Chiredzi (95), Hwange (72) and Matobo (54), giving a total of 281 farmers.

The statistical package Stata (version 16) was used to analyse household data and to present information on technology adoption for smallholder small grain farmers. The logit and multinomial models were used for comparison of farmers who adopted a production technology with those who did not adopt to see if the differences offered insights into the rationale for adoption. Descriptive analyses were employed where frequency tables were generated and responses cross tabulated with each factor (extension services, education level, age, farm size, family size, sex of household head). Cluster analysis was utilised in determining whether there were identifiable groups of households with similar adoption patterns. Thematic analysis was utilised in identifying and capturing research themes and patterns from responses and interpretations recorded during data collection.

6. Results and Discussion

The section discusses the results of technology adoption across the four study sites. The key objective was to determine the technology adoption patterns with particular focus on improved small grain seed and CA. Data were statistically analysed using 'STATA version 16', and ANOVA and the results are presented and discussed below.

6.1 Descriptive statistics results on improved small grain varieties adoption patterns

Table 2 summarises the participants' socio-demographics, showing sample size, number of adopters, non-adopters, *p*-values, standard deviations (SD), and ranges (IQR). Pearson Chi-square test and *t*-test values are also shown in the table.

Technology adoption across the districts (Table 2) was 56% for non-adopters and 44% for adopters. In this study, most of the adopters were from Hwange (26.4%) followed by Chiredzi and Binga with 24.8% each and Matobo had the least (24%). Adoption patterns varied with location ($\chi^2(3) = 9.4, p = 0.03$). For the area not under contract farming or *pfumvudza* the farmers used retained seed (land races) and did not practice conservation farming citing unavailability of improved seed as well as labour constraints to practice CA. The study revealed that farmers only got certified seed on condition that they were either on contract farming or they were practicing *pfumvudza*.

Studies have shown that despite seeming benefits of agricultural innovation, other actors will not accept (Beyene, 2019; Feder *et al.*, 1985; Muzari *et al.*, 2013; Rogers, 2003; Ugochukwu and Philip, 2018). The high adoption rate in Hwange was attributed to the small land holdings (0.6 ha) which made it easy for farmers to grow small grains under the CA model. The CA model, popularly known as *pfumvudza* in vernacular, was a Government of Zimbabwe (GoZ) initiative which provided free improved seeds during the 2020/2021 planting season. The objective of the CA was to secure food security at household level. In Chiredzi, farmers had difficulties in practicing CA on their 10 hectares land holdings. However, the district had the second highest adopters because it had the largest number of contract farmers as compared to the other districts. These contract farmers were loaned improved seed varieties by contractors who eventually purchased their grains. For arable land outside contract farming or *pfumvudza* across the districts, farmers used retained seed (land races). Unavailability of improved seed was cited as the reason for non-adoption of improved seed varieties.

There was strong association between marital status and technology adoption. 50.6% of marrieds were non-adopters compared to 46.4% single headed households who were adopters of small grain varieties ($\chi^2(1) = 0.66, p = 0.001$). The results are in disagreement with other studies which presented married farmers as possessing discrete contacts with extension officers and agro-dealers in comparison to single headed households who depend more on their married counterparts as their dependable sources of agricultural information (Kondylies and Mueller, 2013; Peterman *et al.*, 2010). Adoption patterns were projected to be higher amongst marrieds in comparison to singles as marrieds assist each other in carrying new technologies and were more involved in farming activities in the study sites which were located in rural areas in Zimbabwe.

Table 2. Socio-demographic, household and production characteristics distribution and association between adopters and non-adopters.

Variable	Total (%) (N = 281)	Non-adopters (N = 156)	Adopters (N = 125)	p-value
Socio-demographic				
Location (%)				
Binga	21.3	18.5	24.8	0.03 ^{a*}
Hwange	25.6	25.0	26.4	
Matobo	19.2	15.3	24.0	
Chiredzi	33.8	41.0	24.8	
Marital status (%)				
Single	9.6	3.2	17.6	0.001 ^{a*}
Married	48.8	50.6	46.4	
Divorced	33.8	37.2	29.6	
Widowed	7.8	8.9	6.4	
Affiliation to farm groups (%)				
Yes	58.1	57.7	59.2	0.717 ^a
Age of HH (years): mean (SD)	50.5(12.4)	51.4(12.3)	49.5(12.5)	0.203 ^b
Number of years spent in school: median (IQR)	1(2)	2.5(3.0)	3.3(3.8)	0.073 ^b
Highest education level (%)				
No primary	30.6	27.6	34.4	0.011 ^{a*}
Primary	55.9	63.5	46.4	
Secondary	12.1	7.7	18.4	
Tertiary	1.43	1.3	0.8	
Sex of HH (%)				
Male	48.7	48.7	53.6	0.416
Female	51.3	51.3	46.4	
Household composition				
Total household size	4.9(1.9)	5.1(1.8)	4.8(1.9)	0.103 ^b
Labour size	3.9(2.9)	4.1(3.0)	3.7(2.6)	0.281 ^b
Production information				
Total arable land owned(ha): mean (SD)	0.8(1.1)	0.8(1.0)	0.9(1.1)	0.312 ^b
Total land leased(ha): mean (SD)	1.9(4.2)	2.2(5.2)	1.7(2.5)	0.305 ^b
Total land hired: mean (SD)	0.7(0.9)	0.7(0.9)	0.8(0.9)	0.231 ^b
Total land left fallow: mean (SD)	0.9(1.2)	2.3(2.5)	1.9(2.3)	0.312 ^b

SD, standard deviation; IQR, interquartile range.

^a Pearson Chi-Squared test.^b 2-sample independent *t*-test/non-parametric equivalent.^c -Fisher Exact test.

Source: Primary data (2021);

Although the participants' education levels varied, it was generally low among the majority of participants. The majority of the farmers (86.5%) had primary education and below. However, there was an association between participants' education level and adoption of improved small grain seed. Statistical result show that education level was significantly high ($p < 0.01$) among adopters with the median years spent in school 3.3 (SD = 3.8) compared to non-adopters median of 2.5 (SD = 3.0). Education makes a farmer more amenable to advice from an extension agency or able to deal with technical recommendations that require a certain level of numeracy or literacy remains valid (CIMMTY, 1993). The same logical reasoning applied in the case of smallholder small grain farmers in our study sites.

Institutional determinants of technology adoption

Table 3 shows that access to credit was more among adopters compared to non-adopters. Results show a strong association between improved small seed varieties adoption and access to credit ($p = 0.018$). The smallholder small grain farmers who had access to credit were contract farmers. The majority of adopters used credit to acquire small grain inputs hence these motivated farmers to adopt improved small grain varieties. Farmers using retained seeds complained about the lack of cash or credit as a limiting factor to adopt new technology.

Adopters had more access to extension services of 2 visits per year (40.8%) in comparison to non-adopters (29.5%). Results show that technology adoption was significantly associated with higher frequency (3 or more) of extension visits ($\chi^2(3) = 8.64$, $p = 0.034$). The extension contact in this population was very low, with higher proportion (45.5%) reporting no visit in a year. Similar study findings were reported that in Southern Africa. Extension service delivery service for small grain is mainly inefficient with limited effective interaction between extension agents and farmers (Ricker-Gilbert *et al.*, 2011).

6.2 Binary logistic results

Improved seed varieties adoption technology

The variables associated with adoption of improved seed varieties are discussed in the section that follows. Adoption of improved varieties varied by district. Farmers from Binga had 5.31 times higher odds of adopting improved varieties as compared to farmers from Chiredzi holding other variables constant (OR = 5.31 (95% CI: 2.19–12.9)) and the association was highly statistically significant ($P < 0.001$). The high adoption rate

Table 3. Other socioeconomic or weather characteristics bivariate association between adopters and non-adopters

Variable	Total (%)	Non-adopters (%)	Adopters (%)	Pearson Chi-Squared test		
				df	Test statistic	p-value
Access to credit						
Yes	43.4	37.2	51.2	1	5.55	0.018*
No	56.6	62.8	48.8			
Extension visits (per year)						
0	22.4	19.9	25.6	3	8.64	0.034*
1	27.1	30.8	22.4			
2	34.5	29.5	40.8			
3 or more	16.0	19.9	11.2			
Perception on extension advice						
Very useful	94.7	91.3	100	1	1.37	0.509 ^b
Somewhat useful	5.3	8.7	0			
Contract farming						
Yes	25.6	30.1	20.8	1	3.14	0.076
No	74.4	69.9	79.2			
Access to weather information						
Yes	67.0	66.7	69.6	1	0.272	0.602
No	33.0	33.3	30.4			

df, degrees of freedom.

**Statistically significant at 5%.

^a Fisher exact.

Source: Primary data (2021).

could have been due to the fact that Binga district had enhanced access to improved seed that was provided to farmers by small grain contractors via credit loans. Farmers from Matobo had 2.33 times higher odds of adopting improved varieties as compared to farmers from Chiredzi holding other variables constant (OR = 2.33 (95% CI: 0.91–5.95)). However, the association was marginally significant ($p = 0.08$).

The education level through formal education, was highly significantly ($p < 0.001$) associated with improved varieties adoption. For every one-year increase in number of years spent in formal education, the odds of adopting improved varieties increased 1.20 times holding other variables constant (OR = 1.20 (95% CI: 1.08–1.32)). The higher the educational level of the farmer was, the more likely to adopt improved varieties.

Arable land (Table 4) cultivated was highly significantly ($p < 0.001$) associated with improved variety adoption, for every hectare increase in cultivated land, the odds increased 1.56 times, with the other variables remaining constant. Access to improved seed varieties had a positive influence to size of arable land.

Results on conservation agriculture technology adoption

Marital status (Table 5) was a determinant of CA technology adoption, with those who were widowed (OR = 0.09 (95% CI: 0.02–0.42)) more likely to adopt CA technology in comparison to singles. This could be due to the fact that the majority of farmers who practiced CA did not have draught power and used basins (manual) of which these widowed falls in that category.

Table 4. Logistic regression model results for adopting improved varieties

Variable		OR	SE	95% CI		p-value
				Lower	Upper	
Gender	Male	1				
	Female	0.87	0.28	0.46	1.64	0.66
Age		1.02	0.01	0.99	1.05	0.11
District	Chiredzi	1				
	Matobo	2.33	1.12	0.91	5.95	0.08
	Hwange	1.94	0.9	0.78	4.81	0.15
	Binga	5.31	2.4	2.19	12.89	< 0.001
Education		1.2	0.06	1.08	1.32	< 0.001
Marital	Single	1				
	Married	0.89	0.54	0.28	2.9	0.85
	Divorced	1.96	1.19	0.6	6.43	0.27
	Widowed	0.39	0.32	0.08	1.97	0.25
Affiliation	No	1				
	Yes	0.8	0.27	0.41	1.55	0.51
Land size		1.56	0.23	1.17	2.07	< 0.001
Household size		0.92	0.08	0.78	1.08	0.3
Credit access	No	1				
	Yes	1.65	0.53	0.87	3.11	0.12
Extension visits	0	1				
	1	1.06	0.49	0.43	2.63	0.89
	2	1.57	0.69	0.66	3.72	0.3
	3 or more	0.53	0.3	0.17	1.62	0.27

Table 5. Logistic regression model results for adopting conservation agriculture

Variable		OR	SE	95% CI		p-value
				Lower	Upper	
Gender	Male	1				
	Female	0.84	0.27	0.45	1.57	0.59
Age		0.98	0.01	0.95	1.01	0.12
District	Chiredzi	1				
	Matobo	2.19	1.03	0.87	5.51	0.09
	Hwange	1.77	0.74	0.77	4.03	0.18
	Binga	1.52	0.67	0.64	3.62	0.34
Education		0.96	0.05	0.86	1.06	0.37
Marital status	Single	1				
	Married	0.16	0.08	0.06	0.44	< .001
	Divorced	0.08	0.05	0.03	0.25	< .001
	Widowed	0.09	0.07	0.002	0.42	< .001
Affiliation	No	1				
	Yes	1.34	0.43	0.71	2.5	0.37
Land size		0.88	0.13	0.65	1.18	0.39
Household size		0.95	0.08	0.81	1.12	0.53
Credit access	No	1				
	Yes	1.41	0.45	0.75	2.64	0.28
Extension visits	0	1				
	1	0.56	0.27	0.22	1.42	0.22
	2	1.78	0.75	0.78	4.05	0.17
	3 or more	0.89	0.46	0.32	2.47	0.82

OR, odds ratio; SE, standard error; CI, confidence interval. Source: Primary data (2021).

Key respondents reported that CA technology adoption has been moderate (60%) and the majority of farmers prefer mechanized conservation agriculture (CA). On Conservation Agriculture few farmers (30%) in Binga are adopting CA. Respondents through FGD highlighted that it is difficult to practice CA as it requires a lot of labour. Small grain farmers with large pieces of plots were less likely to adopt CA technologies as compared to those with smaller land holdings. Hwange and Matobo farmers have accepted the CA well and have noticed its benefits in terms of yields. Seventy-five percent of farmers in Matobo district are said to be practicing conservation agriculture. Majority of farmers in Matobo and Hwange districts have 0.6 ha under CA through *Intwasa (pfumvudza)*, which is a government initiative. Since the CA technology is labour intensive and most farmers used manual technique, this explains why adoption of CA was high in the districts that had smaller land holdings (Matobo and Hwange) compared to districts with larger land holdings (Binga, Chiredzi). CA adoption in Chiredzi has been low due to its labour intensive and non-availability of mulch. Chiredzi farmers prefer mechanized CA which is faster compared to basins as their land holdings are big with an average of 10 ha.

Results on adoption of combined technologies (Improved varieties and CA)

Adoption of combined agricultural technologies varied by location (Table 6). Farmers from Binga had 6.99 times higher odds of adopting combined technologies as compared to farmers from Chiredzi holding other variables constant (OR = 6.99 (95% CI: 1.41–34.73)) and the association was statistically significant ($p < 0.05$). Binga had an advantage over Chiredzi as it had smaller land holdings for adopting CA and at the same time it had contract farmers who were supported by improved seed varieties. It was easier for the district to adopt both technologies.

Table 6. Binary logistic regression model results for adopting both improved varieties and CA

Variable		OR	SE	95% CI		p-value
				Lower	Upper	
Gender	Male	1				
	Female	1.75	1	0.57	5.39	0.33
Age		1.01	0.03	0.96	1.06	0.83
District	Chiredzi	1				
	Matobo	2.33	2.06	0.41	13.14	0.34
	Hwange	2.58	2.12	0.51	12.92	0.25
	Binga	6.99	5.72	1.41	34.76	0.02
Education		1.15	0.09	0.98	1.35	0.08
Marital status	Single	1				
	Married	0.49	0.43	0.09	2.74	0.42
	Divorced	0.59	0.56	0.09	3.85	0.58
	Widowed	—	—	—	—	—
Affiliation	No	1				
	Yes	2.07	1.18	0.68	6.31	0.2
Land size		1.63	0.33	1.09	2.43	0.02
Household size		1.06	0.15	0.8	1.4	0.69
Credit access	No	1				
	Yes	1.75	0.96	0.59	5.13	0.31
Extension visits	0	1				
	1	1.38	1.35	0.2	9.4	0.74
	2	8.43	7.5	1.47	48.22	0.02
	>= 3	1.94	2.12	0.23	16.43	0.54

OR, odds ratio; SE, standard error; CI, confidence interval. Source: Primary data (2021).

Frequency of extension visits per year was significantly associated with adoption of combined technologies. Farmers who reported 2 visits in a year had 8.43 times higher odds of adopting combined technologies as compared to those with no visits holding other variables constant (OR = 8.43 (95% CI: 1.47–48.22)) Results indicate a significant association ($p < 0.05$) between 2 extension visits per year and combined technologies adoption. Extension is a very important aspect in explaining agricultural technology adoption decisions and similarly, increases in research activities imply that there are research-managed, farmer-managed, or on-farm trials that create awareness, which inspires others to test and eventually adopt new technologies and practices (Lambrecht *et al.*, 2014).

Land size was significantly associated with adoption of combined technologies. For every hectare increase in cultivated land, the odds increased by 1.63 times higher odds of adopting combined technologies holding other variables constant (OR = 1.63 (95% CI: 1.09–2.43)).

6.3 Multinomial logistic regression model results

Non-adopters of agricultural technologies

Relative Risk Ratio (RRR) is measure of association used in reporting multinomial logistic regression. When the RRR is less than one there is decreased probability of adopting and if greater than 1 it means there is increased probability of adoption. The factors explaining the non-adoption of agricultural technologies using RRR are shown in Table 7.

Table 7. Multinomial logistic regression for non-adopters of agricultural technologies

Variable		Improved varieties (base outcome) non-adopters				<i>p</i> -value
		RRR	SE	95% CI		
				Lower	Upper	
Gender	Male	Base				
	Female	1.59	0.73	0.64	3.89	0.31
Age		0.99	0.02	0.96	1.03	0.71
Education		0.87	0.08	0.73	1.03	0.1
Marital status	Single	Base				
	Married	1.96	1.28	0.54	7.02	0.3
	Divorced	1.07	0.44	0.48	2.41	0.87
	Widowed	2.26	1.22	0.78	6.5	0.13
Affiliation	No	Base				
	Yes	2	1.09	0.68	5.83	0.21
Land size	0.76	0.2	0.45	1.28	0.3	
Household	1.13	0.1	0.95	1.36	0.17	
Credit access	No	Base				
	Yes	0.59	0.14	0.38	0.93	0.02
Extension	No visit	Base				
	1 visit	1.19	0.39	0.63	2.24	0.6
	2 visits	1.01	0.36	0.5	2.03	0.98
	3 or more	2.24	1.13	0.83	6.02	0.1
Contract	No	Base				
	Yes	1.15	0.7	0.35	3.78	0.81

The base outcome is the adoption of improved variety where the results are compared against non-adopters. Variables that were compared were gender with males being the base of comparison, followed by marital status where singles were the base, affiliation where none was the base and access to credit with none being the base of comparison. For all the variables there were no significant differences except for access to credit. Households who had access to credit were 0.59 less chance to adopt none of the technologies as compared to adoption of improved varieties holding other variables constant (RRR = 0.59 (95% CI: 0.38–0.93)). Results indicate that access to credit increases the probability of using agricultural technology in this population group ($p < 0.05$). It is assumed that, access to credit encourages the adoption of risky technologies through lessening of the liquidity constraint as well as through the improving of household's risk bearing ability (Simtowe and Zeller, 2006).

Adoption of CA only

Years spent in school (Table 8) was associated with adoption of CA only ($p < 0.05$), for every one-year increase in years spent in school the likelihood of adopting CA only was 21% as compared to adoption of improved varieties adjusting for other variables in the model (RRR = 0.79 (95% CI: 0.63–0.98)).

Arable land was significantly associated with adoption of CA only in this population, the probability of adopting decreased by 0.49 times for every one hectare increase in cultivated land holding other variables constant (RRR = 0.49 (95% CI: 0.28–0.84)). The results imply that farmers who had large pieces of land were less likely to adopt CA only as compared to those with small pieces of cultivated land ($p < 0.01$). Results of the study show that affiliation to farmers' groups was significantly associated ($p < 0.05$) with adoption of CA only. However, farmers who were affiliated to farmers group had 1.62 increased probability of adopting CA only as compared to improved varieties only than non-members of farmers group (RRR = 1.62 (95% CI: 0.99–2.64)).

Table 8. Multinomial logistic regression of CA only adopters of agricultural technologies

Variable		Improved varieties (base)	Conservation agriculture		<i>p</i> -value	
		RRR	SE	95% CI		
				Lower	Upper	
Gender	Male	Base				
	Female	1.07	0.2	0.74	1.56	0.74
Age		0.97	0.02	0.93	1.15	0.15
Education		0.79	0.09	0.63	0.98	0.03
Marital status	Single	Base				
	Married	0.19	0.24	0.18	2.19	0.18
	Divorced	0.05	0.01	0.03	0.08	< 0.001
	Widowed	0.25	0.28	0.22	2.26	0.22
Affiliation	No	Base				
	Yes	1.62	0.4	0.99	2.64	0.05
Land size		0.49	0.14	0.28	0.84	
Household		1.01	0.17	0.87	1.41	
Credit access	No	Base				
	Yes	0.86	0.38	0.74	2.05	0.36
Extension	No visit	Base				
	1 visit	0.55	0.24	0.23	1.27	0.16
	2 visits	1.24	1.05	0.24	6.47	0.87
	3 or more	1.66	1.48	0.29	9.5	0.59
Contract	No	Base				
	Yes	0.57	0.41	0.14	2.32	0.15

Source: Primary data (2021).

Farmers who were divorced had 0.05 decreased probability of adopting CA only as compared to CA only than the never married ($p < 0.001$).

Adoption of combined technologies

Household size (Table 9) was significantly associated with adoption of combined technologies compared to improved varieties only. The relative risk ratio 1.17 indicate a 17% increased likelihood for adopting combined improved varieties and CA compared to improved varieties only for every one person increase in household member. With an addition of one person to the household size, result in an increased probability of adopting combined technologies by 1.17 holding other variables constant (RRR = 1.17 (95% CI: 1.01–1.36)).

Frequency of extension visit per year was significantly associated with adoption of combined technologies. Farmers who reported 2 visits per year were 7.63 times higher chance to adopt combined technologies than improved varieties only compared to those with zero visits holding other variables constant (RRR = 7.63 (95% CI: 1.71–34)). Similarly, those who had 3 or more visits had 3.28 increased probability of adopting combined technologies compared to improved varieties only than farmers who reported no visits in this study (RRR = 3.28 (95% CI: 0.99–10.34)). The results showed that increasing frequency of extension visits increased the likelihood of adopting combined technologies.

6.4 Comparisons of binary and logistic models results

The study compared both the binary and multinomial models (Table 10) to determine consistent statistically significant results across different regression models to capture major findings from the paper.

Table 9. Multinomial logistic regression of combined technologies

Variable		Improved varieties (base)	Combined (CA and improved varieties)			p-value
		RRR	SE	95% CI		
				Lower	Upper	
Gender	Male	Base				
	Female	2.1	1.23	0.66	6.66	0.2
Age		0.98	0.02	0.93	1.03	0.35
Education		1.02	0.13	0.79	1.32	0.87
Marital status	Single	Base				
	Married	0.48	0.51	0.49	3.89	0.49
	Divorced	0.3	0.37	0.33	3.29	0.33
	Widowed	—	—			
Affiliation	No	Base				
	Yes	3.05	3.4	0.34	2.72	0.31
Land size		1.2	0.13	0.97	1.49	0.09
Household size		1.17	0.09	1.01	1.36	0.04
Credit access	No	Base				
	Yes	1.11	0.28	0.67	1.83	0.67
Extension	No visit	Base				
	1 visit	1.34	0.42	0.73	2.48	0.35
	2 visits	7.63	5.82	1.71	34	0.008
	3 or more	3.28	1.99	0.99	10.78	0.05
Contract	No	Base				
	Yes	1.1	0.43	0.51	2.36	0.36

Source: Primary data (2021)

For both models that were measuring technology adoption there were similarities on significances on variables such as extension visits, education, marital status (divorced) and land size. Farmers who reported 2 visits in a year had 8.43 times higher odds and 7.63 times on logistic and Multinomial models respectively. Similarly, studies (Evenson, 2001; Feder *et al.*, 2003; Ginéa and Yang, 2009) reported that, agricultural extension services and education was crucial in achieving rural agricultural development, poverty reduction, and food security. On education there was high significance ($p < 0.001$ and $p < 0.05$) on improved variety technology adoption in logistic and multinomial models, respectively. The higher the educational level of the farmer was, the more likely to adopt improved seed varieties. Some studies argued that a more educated person appreciated and adapts to new technology or ideas quickly than a less educated person (CIMMYT, 1993; Feleke and Zegeye, 2005; Thomson *et al.*, 2014). On marital status (divorced) farmers the odds ratio increased by 0.08 times adoption of CA (logistic model) compared to singles and was highly significant ($p < 0.001$) for both models. This could be due to the fact that the majority of farmers who practiced CA did not have draught power and used basins (manual) of which these widowed falls in that category. On arable land it was highly significantly ($p < 0.001$) associated with improved variety adoption.

However, there were differences on credit access as there was a significant difference ($p < 0.05$) between improved variety adopters and non-adopters in the multinomial model. Similarly, access to credit has been reported to stimulate technology adoption (Mwangi and Kariuki, 2015). On the other hand, the logistic model captured the technology adoption in terms of location where farmers from Binga had 6.99 times higher odds ($p < 0.05$) of adopting combined technologies and 5.31 times higher odds ($p < 0.05$) of adopting improved varieties as compared to farmers from Chiredzi holding other variables constant. This finding is aligned with other studies who found that, “some adoption factors included the time of introducing the technology

Table 10. Comparison of key variables across Logistic and Multinomial models

Variable	Model								
	Logistic					Multinomial			
	OR	Improved <i>p</i> value	CA <i>p</i> value	Both <i>p</i> value	RRR	Non adopters	CA <i>p</i> value	Both <i>p</i> value	Expected outcome
Extension visits	8.43	–	–	0.02	3.28	–	–	0.05	+
Affiliation	–	–	–	–	1.62	–	0.05	–	+
Household size	–	–	–	–	1.17	–	–	0.04	+
Education	1.2	0.001	–	–	0.79	–	0.03	–	+
Education	1.15	–	–	0.08	–	–	–	–	+
Land size	1.56	0.001	–	–	0.49	–	0.01	–	–
Land size	1.63	–	–	0.02	–	–	–	–	–
Credit access	–	–	–	–	0.59	0.02	–	–	+
Location (Binga)	5.31	0.001	–	–	–	–	–	–	+
Location (Binga)	6.99	–	–	0.02	–	–	–	–	+
Location (Matobo)	2.19	–	0.09	–	–	–	–	–	+
Marital status (divorced)	0.08	–	0.001	–	0.05	–	0.001	–	+
Marital status (widow)	0.09	–	0.001	–	–	–	–	–	+

Source: Primary data (2021).

and location of introduction” (Rogers, 2003). All in all, both models had similarities and differences hence they complemented each other in the study.

7. Policy implications for the agribusiness industry

There is need for the government to increase access to credit to farmers in order to enhance technology adoption. Since access to credit was limited to small grain farmers there is need for government and development partners to support farmers in credit access thereby motivating farmers to adopt improved small grain varieties to increase on productivity and yields. As higher yields were associated with improved small grain seed varieties adoption, government should increase funding to promote high yielding varieties thereby reducing use of retained seed. As improved seed availability was limited there is need for GoZ to support breeding institutions so that seed is readily available thereby promoting adoption rate of improved seed.

Since farmers who were on contract farming had increased yields, there is a need for a policy that promotes contract farming funded by the government or financial institutions. There is a need for government to scale up CA in semi-arid regions of Zimbabwe. Farmers who had increased contact with extension services were higher adopters of agriculture technology. To improve extension officer farmer contact, there is a need for government to consider increasing the farmer: extension worker ratio. A small grain policy assists in ensuring that harvesting and processing of small grains is technology-based. It can be promoted by enforcing duty-free importation of the small grain, low-cost harvesting and processing machines including incentivizing their production locally. There is a need for awareness campaigns on the benefits of small grains in terms of nutritive value, as it improves the immune systems. There is a need for intensification of efforts to ensure the full adoption of improved small grain seed and CA in low rainfall regions of Zimbabwe.

8. Conclusion

Adoption of improved small grain varieties and CA in semi-arid regions in the Southern parts of Zimbabwe remains problematic. Results showed that 56% of the sample were non-adopters while 44% were adopters.

Adoption patterns of improved small grain varieties and CA varied with location. Adoption patterns of improved small grain varieties were lower amongst marrieds in comparison to single headed households. Marital status was a determinant of CA technology adoption, with those who were widowed more likely to adopt CA technology in comparison to singles. Access to credit was more among adopters compared to non-adopters. Improved small grain varieties and CA adoption was significantly associated with higher frequency of extension visits per year. The education level through formal education, was highly significantly ($p < 0.001$) associated with improved small grain varieties adoption. Arable land size was significantly associated with improved small grain seed varieties and CA adoption. Household size was significantly associated with adoption of improved small grain seed varieties and CA technologies at study sites. The study recommends increased funding to research institutions that develop high-yield small grain varieties to ensure maximum adoption of small grain seed and CA.

Conflict Of Interest

The authors have no conflict of interests to declare.

Acknowledgements

The authors declare there was no external funding for this research.

References

- Andaluz, E. 2018. *Cracking the nut 2018: promoting agricultural technology adoption and resilience*. Microsoft, New York, NY.
- Beyene, N.A. 2019. Impact of technology adoption on agricultural productivity and income: a case study of improved teff variety adoption in north eastern Ethiopia. *Agricultural & Technology Journal* 20(4): 205–216.
- Brazier, A. 2015. *Climate change in Zimbabwe, facts for planners and decision makers*. Konrad Adenauer Stiftung, Harare.
- Brown, W.M., S. Ferguson and C. Viju. 2018. Farm size, technology Adoption and Agricultural Trade Reform: Evidence from Canada. *Research Institute of Industrial Economics, IFN Working Paper* 1221. Research Institute of Industrial Economics, Stockholm.
- CIMMYT. 1993. *The adoption of agriculture technology: a guide for survey design*. CIMMYT, Mexico City.
- Crost, B., B. Shankar., R. Bennett and S. Morse. 2007. Bias from farmer self-selection in GM crop productivity estimates: evidence from Indian data. *Journal of Agricultural Economics* 58: 24–36.
- Denning, P. and T. Lewis. 2019. Uncertainty. *Communications of the ACM* 62(12): 26–28.
- Djibo, O. and N. Malam Maman. 2019. Determinants of agricultural technology adoption: Farm household's evidence from Niger. *Journal of Development and Agricultural Economics* 11(1): 15–23.
- Dorfman, J. 1996. Modelling multiple adoption decisions in a joint framework. *American Journal of Agricultural Economics* 78(3): 547–557.
- Dube, T., C. Mlilo., P. Moyo., C. Ncube and K. Phiri. 2018. Will adaptation carry the future? Questioning the long-term capacity of smallholder farmers' adaptation strategies against climate change in Gwanda District, Zimbabwe. *Journal of Human Ecology* 61(1–3): 20–30.
- Estudillo, I.P. and O. Keijiro. 2006. Lessons from three decades of Green Revolution in the Philippines. *Journal of Development and Economics* 44(2): 123–148.
- Evenson, R. 2001. Economic impacts of agricultural research and extension. In: Gardner, B.L. and G. Rausser (eds.) *Handbook of agricultural economics*. Elsevier Science, Amsterdam, chapter 11.
- FAO. 2016. *Food and Agriculture Key to achieving the 2030 Agenda for Sustainable Development*. Food and Agriculture Organization of the United Nations. Rome.
- FAO. 2018. *The state of food security and nutrition in the world. Building climate resilience for Food Security and Nutrition*. Food and Agriculture Organization of the United Nations. Rome.

- Feder, G., E.R. Just and D. Zilberman. 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change* 33(2): 255–298.
- Feder, G., R. Murgai and J. Quizon. 2003. Sending farmers back to school: the impact of farmer field schools in Indonesia. *Review of Agriculture Economics* 26(1): 45–46.
- Feleke S. and T. Zegeye. 2005. Adoption of improved maize varieties in southern Ethiopia: factors and strategy option. *Food Policy* 31: 442–457.
- Glover, D., S.K. Kim and G.D. Stone. 2020. Golden Rice and technology adoption theory: A study of seed choice dynamics among rice growers in the Philippines. *Technology in Society* 60: 101227.
- Guinea, X. and D. Yang. 2009. Insurance, credit, and technology adoption: field experimental evidence from Malawi. *Journal of Development Economics* 89(1): 1–11.
- Hailu, B.K., B.K. Abirha and K.A. Weldegiorgis. 2014. Adoption and impact of agricultural technologies on farm income: evidence from Southern Tigray, Northern Ethiopia. *International Journal of Food and Agricultural Economics* 2(4): 91–106.
- ICRISAT. 2021. *Large study shows regular millet consumption can combat anaemia*. ICRISAT, Bulawayo, available online at <https://medicalxpress.com/news/2021-10-large-regular-milletconsumption-combat.html> (accessed 21 October 2021).
- Integrated Food Insecurity Phase Classification (IPC) (2020). *Acute food insecurity analysis. Zimbabwe. Integrated food security phase classification: evidence and standards for better food security and nutrition decisions*. FAO, Rome.
- Khonje, M., J. Manda., A.D. Alene and M. Kassie. 2015. Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World Development*, 66: 695–706.
- Kumar, A., V. Tomer., A. Kaur., V. Vikas Kumar and Gupta, K. 2018. Millets: a solution to agrarian and nutritional challenges. *Agriculture & Food Security* 7: 31.
- Lacey, A. 2010. The research process in nursing. In K. Gerrish (ed.) *The Research Process*, 6th edn. Wiley-Blackwell, Oxford, pp. 13–26.
- Lambrecht, I., B. Vanlauwe., R. Merckx and M. Maertens. 2014. Understanding the process of agricultural technology adoption: mineral fertilizer in eastern DR Congo. *World Development* 59: 132–146.
- Lavison, R. 2013. *Factors influencing the adoption of organic fertilisers in vegetable production in Accra*. Thesis, University of Accra, Accra.
- Loevisohn, M., J. Sumberg and A. Diagne. 2013. *Under what circumstances and conditions does adoption of technology result in increased agricultural productivity?* EPPI Centre, London.
- Mathew, A. 2015. The feasibility of small grains as an adoptive strategy to climate change. *Russian Journal of Agricultural and Socio-Economic Sciences* 41(5): 40–55.
- Moore, G. 2014. *Crossing the chasm*. Harper Collins, New York, NY.
- Moyo, P. and W. Akpan. 2018. *Coping with climate change in Africa: An analysis of local interpretations in Eastern Cape*. Department of Sociology, University of Fort Hare, Alice.
- Muchineripi, C. 2014. *Grain revolution: finger millet and livelihood transformation in rural Zimbabwe*. Africa Research Institute, London.
- Muchuru, S. and G. Nhamo. 2019. A review of climate change adaptation measures in the African crop sector. *Climatic and Development* 11(2): 1–13.
- Mukana, A. 2016. *Technology adoption and risk exposure among smallholder farmers: panel data evidence from Tanzania and Uganda*. African Development Bank, Abidjan.
- Mukarumbwa, P. and A. Mushunje. 2010. Potential of sorghum and finger millet to enhance household food security in Zimbabwe's semi-arid regions: a review. *Paper presented at the Joint 3rd African Association of Agricultural Economics (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa*.
- Mukasa, A.N. 2016. Technology adoption and risk exposure among smallholder farmers. Panel data evidence from Tanzania and Uganda. *Working paper Series* 233. African Development Bank, Abidjan.
- Muzari, W., W. Gatsi and S. Muvhunzi. 2013. The impact of technology adoption on smallholder agricultural productivity in sub-Saharan Africa: a review. *Journal of Sustainable Development* 5(8): 69–77.

- Mwangi, M. and S. Kariuki. 2015. Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and Sustainable Development* 6(5): 208–216.
- Pedhazur, E.J. 1997. *Multiple regression in behavioral research: explanation and prediction*, 3rd edn. Harcourt Brace, New York, NY.
- Phiri, K.N., T. Dube., P. Moyo., C. Ncube and S. Ndlovu. 2019. Small grains “resistance”? Making sense of Zimbabwean smallholder farmers’ cropping choices and patterns within a climate change context. *Congent Social Science* 5(1): <https://doi.org/10.1080/23311886.2019.1622485>
- Proietti, I., C. Frazzoli and A. Mantovani. 2015. Exploiting nutritional value of staple foods in the world’s semi-arid areas: Risks, benefits, challenges and opportunities of Sorghum. *Journal of Healthcare* 3(2): 172–193.
- Ricker-Gilbert, J., T.S. Jayne and E. Chirwa. 2011. Subsidies and crowding out: A double hurdle model of fertilizer demand in Malawi. *American Journal of Agricultural Economics* 93(1): 26–42.
- Rogers, E. 2003. *Diffusion of innovations*, 5th edn. Free Press, New York, NY.
- Rubas, D. 2004. *Technology adoption: who is likely to adopt and how does timing affect benefits*. Thesis, Texas A&M University, College Station, TX.
- Schwab, J.A. 2002. *Multinomial logistic regression: Basic relationships and complete problems*. Available online at <http://www.utexas.edu/courses/schwab/sw388r7/SolvingProblems/>
- Simtowe, F. and M. Zeller, 2006. the impact of access to credit on the adoption of hybrid maize in Malawi: an empirical test of an agricultural household model under credit market failure. *2007 Second International Conference, August 20–22, 2007*. African Association of Agricultural Economists, Accra
- Stevenson, J.R., N. Villoria., D. Byerlee and M. Maredia. 2013. Green Revolution research saved an estimated 18 to 29 million hectares from being brought into agricultural production. *Proceedings of the National Academy of Sciences of the United States of America* 110: 8363–8368.
- Stone, I.D., A. Flachs and C. Diepenbrock. 2014. Rhythms of the herd: Long term dynamics in seed choice by Indian farmers. *Journal of Technology and Society* 36: 26–38.
- Thomson, K., T. Gelson and K. Elias. 2014. Adoption of improved maize seed varieties in southern Zambia. *Asian Journal of Agricultural Science* 6(1): 33–39.
- Ugochukwu, A. and P.W.B. Philip 2018. Technology adoption by agricultural producers: a review of the literature. In N. Kalaitzandonakes, E.G. Carayannis, E. Grigoroudis and S. Rozakis (eds.) *From Agriscience to Agribusiness*. Springer, Berlin, pp. 361–377.
- UNDP. 2018. *Barrier analysis of small grains value chain in Zimbabwe*. United Nations, Geneva.
- United Nations. 2015. *Transforming our world the 2030 agenda for sustainable development A/RES/70/1*. United Nations, New York, NY.
- Zeven, A.C. 1998. Landraces: A Review of Definitions and classifications. *Euphytica* 104(2): 127–139.