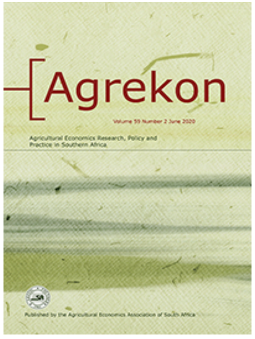

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Impacts of improved sorghum varieties intensification on household welfare in the mid-Zambezi Valley of Zimbabwe

Joseph P. Musara [a,b] and Lovemore Musemwa[a]

[a]Department of Agricultural Economics, Education and Extension, Bindura University of Science Education, Bindura, Zimbabwe; [b]Faculty of Life Sciences, Gwanda State University, Filabusi, Zimbabwe

ABSTRACT

Attaining food and income security is a persistent challenge among small holder farmers of Southern Africa. Improved sorghum varieties are widely regarded as a panacea to extreme poverty. The paper uses endogenous switching regression to determine impacts of improved sorghum varieties intensification on household welfare. Household dietary diversity score and household food insecurity access score were used as outcome variables and proxies for food security. Cross-sectional data were generated in the Mid Zambezi Valley of Zimbabwe in 2016 from 380 households in a survey conducted with five purposively selected wards. Social association groups, average weighted market prices, household income, age of principal decision maker, dependency ratio, ownership of draught power and storage facilities have significant ($p <$ 0.01) implications on the adoption decision. Counterfactual analyses shows that farmers who allocate more land towards improved sorghum varieties are relatively better off in food diversity and food access. Intensifying improved sorghum varieties can increase dietary diversity by 35% while reducing food insecurity by 29–34%. Social networking can be strengthened through local, government and private partnerships to facilitate generation and efficient dissemination of sorghum production and marketing information. Improving the market prices can increase market size and enhance efficiency along strategic value chain nodes.

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1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is important for households to gain access to nutritive food and income in Africa (Mukarumbwa and Mushunje 2010; Dicko et al. 2006). The crop has for long been marginalised from mainstream development strategies in Southern Africa due to lack of access to high yielding varieties, limited government and private sector support, weak and limited marketing channels and changes in tastes and preferences among consumers (Adegbola et al. 2013). Interestingly, sorghum driven food and income security interventions remain important discussion points in the rural development debate in this region (Jayne, Mather, and Mghenyi 2010). Most countries in Southern Africa, including Zimbabwe are small open economies experiencing food and income insecurity due to limited livelihood options triggered by high costs of production, low uptake of high yielding crop varieties and limited trading channels (Scoones et al. 2011). These countries also inherently depend on agricultural activities for GDP growth prospects, forex generation

CONTACT Joseph P. Musara jpmusara@gmail.com Department of Agricultural Economics, Education and Extension, Bindura University of Science Education, P. Bag 1020, Bindura, Zimbabwe; Faculty of Life Sciences, Gwanda State University, P.O. Box 30, Filabusi, Zimbabwe

and employment. In the advent of declining performance in the sector and increased incidences of food and income insecurity, a number of interventions have been implemented by both the public and private domains to support the subsector (Matshe 2009). Re-embracing sorghum in the national food security strategies has strongly re-emerged as a viable approach mainly targeted at the small holder resource constrained farmers located in arid and semi-arid zones (Haussmann et al. 2012). Driven this revolution, successful cases of cooperation along strategic sorghum value chain nodes have been reported by Makindara et al. (2013) and Rohrbach and Kiriwaggulu (2007) in Tanzania.

Sultan et al. (2013) reported the welfare effect of adopting high yielding and hybrid sorghum seed in the Sudan Savanna of West Africa. They noted that adoption of the high yielding sorghum seed varieties resulted in higher yields, harvest share that is sold and dietary diversity. It is however important to examine the welfare impacts of the aforementioned decisions among small-scale farming households in semi-arid Zimbabwe. We acknowledge that in the semi-arid environments of Zimbabwe, farmers are at least aware of the potential benefits of increasing land under sorghum. They however do not necessarily focus on the food security implications of the varieties planted and the benefits of increasing the scale of production. Limited studies (Smale et al. 2018; Mafuru, Norman, and Langemeier 2007) have examined the welfare impacts of high yielding sorghum varieties production decisions on household welfare. They found that sorghum related activities of adopting high yielding varieties and intensifying them have food security gains. In Zimbabwe, there is a dearth in information and knowledge on the food security impacts of high yielding sorghum varieties. This study hypothesised this as the main driver for the low uptake of high yielding sorghum varieties by small holder farmers in semi-arid Zimbabwe. To bridge this gap, the study adopts a combination of the nearest neighbour technique and endogenous switching regression modelling to ascertain causality of increased land allocation towards improved sorghum varieties on welfare as shown by food security indicators of diversity and access.

2. Conceptual framework

Appreciating the multiple social, economic and institutional challenges associated with the adoption of high yielding varieties in the study area, the study defines adoption as the decision to allocate some portion of the arable land towards any of the selected (Macia and Silla) high yielding sorghum varieties during the study period. This definition categorised the farmers as adopters and non-adopters of the high yielding sorghum varieties. Macia is an open-pollinated white grained variety produced under the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) seed programme. The variety has desirable characteristics including early maturity, good disease and drought tolerance. Rukuni et al. (2006) reports that the average yield for the variety in high-risk areas where maize cannot do well is about 600 kg/ha. Silla is a medium to late maturity white variety which has high yielding potential and is tolerant to most of the common sorghum diseases. Rohrbach and Kiriwaggulu (2007) report that the main uses of this variety are for human consumption, livestock feed and beer brewing, hence its wide acceptability in most farming communities.

We further define intensive production of high yielding sorghum varieties as a state when a farmer has passed the adoption decision stage and decides to allocate more land towards the high yielding sorghum varieties.[1] The study is guided by Amare, Asfaw, and Shiferaw (2012) who defined intensification in terms of additional demand for a production factor as pulled by observed and/or anticipated benefits. In this case, farmers anticipate higher productivity levels and higher aggregate sorghum output from the decision to take up high yielding varieties rather than continue using the retained seed. Data censoring was then used to define intensifiers as those farmers who allocated at least 50% of the available arable land towards high yielding sorghum varieties. We accept that intensification is not fixed but a dynamic set of processes characterised by adaptability in order to generate incentivising returns. The study however focuses on decisions observed during the 2015/16 cropping season.

The improved sorghum varieties production intensification processes have a bearing on the household food security status through increased and relatively stable yields from the crop. We therefore trace and unpack the governing pillars of food security using the Household Dietary Diversity Score (HDDS) and Household Food Insecurity Access Score (HFIAS). Sorghum intensification also has an implication on market prices and hence indirectly affects the income levels of households. In both scenarios, since we are using survey based observational data on household behaviour, causality is cautiously inferred.

Informed by previous work by Asfaw et al. (2012), the study appreciates that in reality, it is almost impossible to objectively measure absolute causal effects of the high yielding sorghum varieties adoption decision on welfare at the individual level. As such, we circumvent this and adopt the average causal effects to understand the relationships under study. In this case therefore we assign a dummy variable (D_i) showing the two states of high yielding sorghum varieties production (=1) and high yielding sorghum varieties non-production (=0) to the relationship between those farmers who intensify(Y_1i) against those who do not (Y_0i) to generate:

$$Y_i = Y_{0i} + D_i(Y_{1i} - Y_{0i}) \tag{1}$$

where Y_i is the welfare indicator (HDDS or HFIAS) for the ith farmer (household).

3. Empirical estimation of welfare impacts

The wellbeing effects of high yielding sorghum varieties intensification can be expressed by indicators such as income, output, and incidences of limited food diversity. Guided by previous work we let Y_i be the dependant variables (HDDS and HFIAS) and the aim is to estimate the effect of the intensification decision on these (Kluve, Lehmann, and Schmidt 2008). The study lets Y_1 to represent the welfare value given the condition that the selected household is subjected to the targeted treatment i.e., allocates at least 50% of available arable land towards high yielding sorghum varieties ($P = 1$) and Y_0 be the same variable under the <50% allocation state ($P = 0$). In this case, the welfare that is observed can therefore be expressed as

$$Y = PY_1 + (1-P)Y_0 \tag{2}$$

This implies that if $P = 1$ then Y_1 can be observed and if $P = 0$ we then the observed state is Y_0. To estimate the impact of intensification of improved sorghum varieties, the study uses the Average Treatment Effect on the Treated (ATET) which is:

$$ATET = E(Y_1 - Y_0|P = 1) = E(Y_1|P = 1) - E(Y_0|P = 1) \tag{3}$$

Equation (3) shows the net gain in welfare from intensifying high yielding sorghum varieties production. In reality, we can only observe the outcome variable for the allocation state, $E(Y_1|P = 1)$ and cannot do the same for farmers who allocate, assuming they had not allocated more land towards high yielding sorghum varieties, $E(Y_0|P = 1)$. Counterfactual analysis caters for this reality by matching the control and the treatment (Abdulai and Huffman 2014; Di Falco and Veronesi 2013). This implies mimicking the randomisation technique that is widely used in experiments. To achieve this, the Nearest Neighbourhood Method (NNM) was used in the study (Becerril and Abdulai 2010). Matching estimators are primarily governed by the assumption that the decision by a farmer to allocate more land towards high yielding sorghum varieties is conditional on a set of observed covariates, X_i.

$$(Y_1, Y_0) \perp P|X \tag{4}$$

This supposition suggests that the counterfactual welfare indicators in the group that is treated are the same as the welfare change that is observed for the non-treated group.

$$E(Y_0|X, P = 1) = E(Y_0|X, P = 0) = E(Y_0|X) \tag{5}$$

The postulation therefore eliminates selection bias in the improved sorghum varieties land allocation decision and eliminates the positive state on the basis of unobservable gains from being an intensive high yielding sorghum varieties farmer. Guided by Amare, Asfaw, and Shiferaw (2012), we compute ATET as

$$\begin{aligned} ATET &= E(Y_1 - Y_0|X, C = 1) \\ &= E(Y_1|X, C = 1) - E(Y_0|X, C = 1) \end{aligned} \tag{6}$$

where Y_1 is the outcome that is treated, Y_0 is the outcome that is untreated, and C is the treatment status which equals 1 for treatment and 0 otherwise.

The ATET relationship in (6) was then transformed to:

$$ATET = E(Y_1\ |P(X), P = 1) - E(Y_0|P(X), P = 1) = \alpha \tag{7}$$

This shows that ATET is a difference between the treated group's welfare indicator (that which is observable) and the treated group's welfare indicator assuming that it had not been treated (that which is unobservable). The latter component is the counterfactual scenario which needs to be treated.

We appreciate that there might be endogeneity of improved sorghum varieties intensification in the welfare models. The first step done is to include a richly selected set of covariates which encompass significant attributes about the population and the surroundings as guided by literature and observations in the study area. The multinomial soil fertility instrumental variable[2] was captured as a multinomial treatment indicator variable and was also captured in the analyses. The study also employed the maximum likelihood technique to fit an endogenous two-stage switching regression to cater for the unobserved effects. Considering the household welfare indicators described above, Y_{0i} is assigned for non-intensifiers and Y_{1i} for intensifiers.

Guided by Abdulai and Huffman (2014), we let the switching regressions be captured as

$$P_{ip} = 1(z_{ip}\gamma + u_{ip} > 0) \tag{8}$$

$$\text{Regime 1:} \quad Y_{0ip} = X_{0i}\beta_0 + \varepsilon_{0ip} \quad \text{if } P_{ip} = 0 \tag{9}$$

$$\text{Regime 2:} \quad Y_{1ip} = X_{1i}\beta_1 + \varepsilon_{1ip} \quad \text{if } P_{ip} = 1 \tag{10}$$

Equation (8) is the selection equation determining as to which regime applies for a particular state. Equations (9) and (10) describe the relationship that exist among the variables of concern in each of the two regimes and are the endogenous switching regime model. The error terms are distinctive and assumed to be trivariate normally distributed with a mean of zero. Since logically individual farm households can only be observed in either state, $P_{ip} = 1 or\ P_{ip} = 0,$ but never in both states, then the covariance of Equations (9) and (10) is zero.

4. Methods

The study was conducted in the Mid Zambezi Valley of Zimbabwe. Specifically, Mbire district was purposively selected as it falls in the prime sorghum producing zones of Zimbabwe where the crop has the prospects to generate food and income security gains. The district is located at −16°09′32″ S and 30°34′21″ E and lies at an average elevation of 373 m. Temperatures in the area average 30°C and the average annual rainfall received ranges from 350 to 550 mm (Baudron et al. 2012). Despite poor soils, erratic rainfall and crop destruction by wildlife, households in the Mid Zambezi Valley still depend on agricultural practices for subsistence and cash income. Cross-sectional data were collected from 380[3] households randomly selected from five Wards which provided a sampling frame obtained from extension officers. From the 380 sorghum farmers, 252 grew high yielding sorghum varieties during the period under consideration with 185 intensifiers and 67 non-intensifiers. A pretested questionnaire was administered and augmented with a Focus Group Discussion which was facilitated by the researcher so as to gain in-depth information from the farmers. One consolidated focus group discussion was done with 11 participants made up of 2 representative farmers from each of the five wards and the District Agricultural Extension officer. The main aim was to explore their attitudes and experiences with the two targeted high yielding sorghum varieties in a way that the questionnaire could not adequately capture. This was done after the survey as a data collection triangulation strategy since the focus group discussion guide was derived from some issues raised during the questionnaire interviews.

4.1 Measuring food security

Food security is universally acceptable as an integral component of welfare and can be analysed at varied levels (Cafiero et al. 2014). Even though coping strategies indicators[4] have not been extensively adopted in food security-related researches, the Coping Strategy Index (CSI) was successfully used by Mabuza et al. (2016). The technique reduces the chances of categorising food insecure households as being food secure. The Food Security Ratio (FSR) has also been used by Silvestri et al. (2016) to show how own production and purchases can meet household energy needs. However, it is usually inaccurate since determining the exact values of the two inputs is a challenge with most social science-based studies. Musemwa et al. (2015) also adopted the Household Food Insecurity Access Prevalance (HFIAP) in South Africa's Eastern Cape Province. They further noted that the most frequently used indicators of food security revolve around consumption. The study therefore used indicators which focused on the diversity of consumed food and adequacy of food access. The Household Dietary Diversity Score and Household Food Insecurity Access Score were isolated due to their ability to comprehensively capture food security status.

4.1.1 Household dietary diversity score (HDDS)

HDDS is defined as a measure based on a recall of all food and/or drink items consumed by the household members during the preceding 24 h. It is a very valuable proxy for food security and has widely been used in literature across the world in various contexts (Musemwa et al. 2015). Its main strength is that it has a very strong co-relationship with key food security indicators such as the adequacy of a household's intake of important nutrients. Literature acknowledges that analysing dietary diversity using individual foodstuffs has a weaker nutrient adequacy prediction capacity than when using food groups (Lo et al. 2012). Dietary diversity is a varied and composite consumption-based indicator showing nutrient availability and reflects on the household's income capacity (as shown by per-capita income) to consume multiple food stuffs. High HDDS values can be confidently used to reflect on balanced diets and lower incidences of malnutrition.

High intakes of starch-based diets will yield low HDDS values which are an indication of limited micro nutrients. Mango et al. (2014) generated the HDSS from 14 food groups consumed inside the household excluding those consumed separate from the household. However, Lo et al. (2012) used a scale of 0–6 in a study conducted in Taiwan. We adopted the six-point scale given the limited diversity observed from the universe of food items which yielded 93 items. The study used 252[5] households who were the improved sorghum seed users among 380 sampled households and questions were presented to them so that they recalled food and drink stuffs consumed in the past 24 h. We then classified the foods into 6 distinct categories with a score of *1 for yes and 0 for no*. The classifications were grains and rice, fat and oils, dairy, meats, vegetables and fruits.

$$HDDS = \sum_{i=1}^{6} X_i \tag{11}$$

where *HDDS* is the score and X_i is the food group consumed by household members.

4.1.2 Household food insecurity access score (HFIAS)

The HFIAS is an access measure of the extent of household food insecurity over the previous 30 days. The measure is an indicator of the food insecurity status of the household in terms of insufficient supplies of food and assumed quality thereof. It also factors in anxiety about household food insecurity which is an important indicator. Musemwa et al. (2015) noted that HFIAS is a more subjective measure since it captures the household members' perception about the consumed diets and this may completely miss the nutritional composition of these diets. The score pays attention to consumption-oriented tactics and is concerned with the household members' emotional reactions to food insecurity as they perceive it. Using the survey, a score was generated based on a much-held assumption that based on long-term consumption experiences, respondents were able to relate to their food insecurity status with some level of confidence. Eight distinct categories of occurrences were isolated in the study as

> 1 = Anxiety about food (in)adequacy; 2 = Eating foods of a limited variety; 3 = Eating less-preferred foods; 4 = Inability to eat even the less-preferred foods; 5 = Eating smaller meals than needed; 6 = Eating fewer meals in a day; 7 = Going to bed hungry; 8 = Failing to obtain food of any kind during the whole day or night.

The progression from 1 to 8 shows increasing insecurity. A binary response was used as *yes (1) and no (0)* depending on whether any of the 8 occurrences were experienced in the household over the previous 30 days. A severity question which was based on the frequency of occurrence was assigned as a follow up to the occurrence observation over the same period. A scale was developed as, *1 = rarely, 2 = sometimes, and 3 = often.* This implies that the range[6] for the HFIAS was 0–24. The HFIAS was therefore computed as

$$HFIAS = \sum_{i=1}^{8} X_i F_i \qquad (12)$$

where *HFIAS* is the insecurity score; X_i is the food insecurity occurrence observation and F_i is the frequency of occurrence.

5. Effects of sorghum intensification

Estimating impact of an innovation on the welfare of a household can be done using indicators such as income, consumption and yield changes (Mango et al. 2014). The study uses a similar approach with differential land allocation decisions towards improved sorghum varieties in semi-arid rural areas of Zimbabwe. Doing this basing on non-experimental events is usually challenging since we have to deal with the unobserved outcome dimension for the inclusion state (Di Falco and Veronesi 2013) which occurs in the event that farmers who have allocated more land towards sorghum had not done so. This challenge is easily addressed in experiments by randomly assigning a control whose outcomes represents the pseudo non-intensification state. However, it is imperative to note that deciding to allocate more land towards improved sorghum varieties as a state is not randomly distributed in a sample but peculiar to an individual household's potential to utilise the available information and resources. This implies potential systematic differences between farmers who intensify and those who do not intensify production of improved sorghum seed varieties. It is therefore necessary to use econometric techniques which account for this potential selection bias whenever innovation impact evaluation studies are carried out (Asfaw et al. 2012).

Di Falco and Veronesi (2013) adopted the matching approach which is also technically based on the ATE philosophy. This study used a combination of matching techniques with Average Treatment Effect on the Treated (for the observable outcome) and endogenous switching regression (for the unobservable outcome). This approach has also been successfully used in agricultural innovation impact evaluations (Ngeno 2017). Switching validates the matching results and this eliminates the challenge of having non-zero treatment effects which do not necessarily reflect the direct impact of an innovation but other factors including non-separability. Switching therefore eliminates hidden selection bias that might set in due to some latent variables (Kluve, Lehmann, and Schmidt 2008). In the present context, confounding is also assumed minimal since we controlled for alternative, non-causal explanations for anticipated observations in the relationship between the dependent and independent variables.

6. Results and discussion

The results of the study are summarised and presented in this segment. Table 1 shows a summary of the food security indicators in categories. As shown in Table 1, there are significant variations within the isolated categories for both HDDS and HFIAS.

A significant proportion of households who did not intensify production of improved sorghum varieties had lower HDDS values, accounting for about 97% in the 1–2 and 3–4 ranges. The non-intensifying households had high food insecurity as indicated by higher HFIAS values as compared to their intensifying counterparts. A summary of the variables in Table 1 shows that HDDS and HFIAS are significantly different between intensifiers and non-intensifiers of improved sorghum varieties. These variables will be subject to further analyses in the following sections.

Table 2 is a summary of the variables that were included in the empirical analyses.

6.1 Empirical evidence for drivers of improved sorghum varieties intensification

Table 3 shows the normal probit model results for the food security indicators with the selection equation shown in the first column. We included gradient of soil fertility as a valid instrumental variable in the selection equation to assure identification (Ngeno 2017). The instrument is uncorrelated with both the dependant variables (selected welfare indicators), is also highly significant ($p < 0.01$) in all selection models. This is a good indicator that the instrumental variable is valid. A strong co-relationship with the intensification decision shows that farmers with higher percentages of fertile land are expected to intensify high yielding sorghum varieties production since there is lesser competition for fertile land with other crops such as maize and soyabean. In this scenario, the critical factors influencing the high yielding sorghum varieties intensification decision are the age of principal decision maker, household income and its diversity, availability of storage facilities and the observed market prices.

From Table 3, as the age of the principal decision makers increases, the likelihood of benefiting from food diversity from improved sorghum varieties intensification also increases. This can be attributed to the inclination of the older decision makers towards enhancing activities which they view as profitable. These farmers have household responsibilities such as providing for food, health bills and fees for the household members. Post the initial production stage, they then opt for intensification so as to harness the financial and food security benefits from the innovation.

Table 1. Summary of HFIAS and HDDS categories.

	Proportion (%)		
Indicator category	Non-intensifiers	Intensifiers	Difference-test
Household dietary diversity score (HDDS)			
1–2	97.30	2.70	11.258***
3–4	96.41	3.59	9.356***
5–6	22.97	77.03	−6.887***
Household food insecurity access score (HFIAS)			
0–5	33.0	67.0	−2.564**
6–10	70.6	29.4	5.328***
11–15	88.6	11.4	11.381***
16–20	88.6	11.4	11.381***
21–25	100	0.0	16.785***

Notes: ***; ** and * show *p*-values that are significant at 1%, 5% and 10% levels respectively (for intensifiers versus non-intensifiers).

Table 2. Description of variables included in the models and descriptive statistics.

Variable	Description	Units	Total sample mean	Intensive mean	Non-intensive mean	Diff-test
Dependent						
Productivity	Sorghum produced per hectare during the season	kg/ha	902.73	944.344	691.167	−2.326**
Net returns/ha	Net returns from sorghum production/ha	US$	307.45	329.328	196.250	−2.973***
HDDS	The household dietary diversity score	score	4.192	5.492	3.578	−19.58***
HFIAS	The household food insecurity access score	score	9.408	4.574	11.694	11.78***
Independent						
Arable land	Total arable land for the household	hectare	4.3153	4.1869	4.3759	1.4780
Sorghum land	Land under sorghum production	ha	1.26	1.98	0.89	1.572**
Age	Age of the household head	years	44.721	45.713	44.252	−0.9162
Dependency	Proportion of dependant members in the household	percent	33.258	34.738	32.558	−1.0834
Education	Duration in schooling of household head	years	8.226	7.852	8.4031	1.2525
Ethnicity	Whether household is originally a local (=1, 0 otherwise)	dummy	0.663	0.705	0.643	0.847
Soil fertility	Soil fertility (1 = fertile, 2 = moderately fertile, 3 = not fertile)	dummy	17.579	48.680	2.872	−28.28***
Draught	Number of effective draught animals	number	5.989	6.131	5.922	−0.5796
Male head	Gender of household head is male (=1, 0 otherwise)	dummy	0.718	0.615	0.767	2.345**
Farming experience	Number of years experienced in agricultural practices	years	15.487	15.311	15.569	0.2338
Sorghum experience	Number of years experienced in sorghum production	years	7.679	8.909	7.097	−2.0781**
Crop diversity	The total number of crops grown by the household	number	3.161	3.615	2.946	−3.999***
Income	Real total income for the household	US$	353.021	356.762	351.252	−0.2437
Income diversity	Number of farm and off-farm income sources	number	2.647	2.893	2.531	−3.004***
Aid	Value of sorghum aid received during the season	US$	8.597	14.795	5.667	−4.383***
Extension	Frequency of contact with extension agents in the season	number	5.274	5.336	5.244	−0.2811
Associations	Social groupings to which household members belonged	number	1.697	1.574	1.756	1.4414
Storage	Farmer has adequate storage facilities (=1, 0 otherwise)	dummy	0.4955	0.5	0.492	−0.236
Price	Average weighted price in markets	US$	35.703	40.139	33.605	−5.068***
Buyers	Number of buyers with whom a farmer interacts with	number	3.342	3.754	3.147	−1.8832*
Distance	Time taken to get to main market	minutes	73.647	73.525	73.705	0.0193
Payment time	Time taken for payment to be effected after a sale	days	11.297	11.639	11.136	−0.2201

Source: Generated by authors from 2016 sorghum survey data using STATA.
Notes: ***; ** and * show the *p*-values significant at 1%, 5% and 10% levels respectively (for intensifiers versus non-intensifiers). t-test was used for continuous variables and chi-square for categorical variables.

Availability of storage facilities also guarantees reduced post-harvest loses and as such incentivise intensification and higher HDDS values (Asogwa, State, and Okwoche 2012). If intensifying farmers have facilities, then they may store multiple food stuffs and consume them in good state over the year and even during the lean periods where food diversity is limited. Market prices have a positive and significant ($p < 0.05$) bearing on the diatary diversity benefits accruing to the intensifying farmer. Higher market prices have been reported as catalysts for market participation which can be one major reason why farmers decide to intensify. The higher incomes from the marketed produce will

Table 3. Maximum likelihood estimates of HDDS and HFIAS.

		HDSS			HFIAS	
Variable	Sorghum intensification equation Coefficient	Intensifiers Coefficient	Non-intensifiers Coefficient	Sorghum intensification equation Coefficient	Intensifiers Coefficient	Non-intensifiers Coefficient
Age	0.02* (0.010)	0.003 (0.004)	0.003 (0.004)	0.015 (0.01)	−0.06* (0.035)	0.01 (0.024)
Dependency	0.04 (0.007)	0.05 (0.0028)	0.003 (0.003)	0.028 (0.007)	−0.02 (0.023)	−0.03* (0.018)
Education	−0.03 (0.038)	−0.005 (0.014)	0.01 (0.016)	−0.026 (0.039)	−0.05 (0.118)	0.067 (0.089)
Ethnicity	0.17 (0.307)	0.081 (0.123)	−0.066 (0.121)	0.262 (0.308)	0.18 (1.001)	−0.388 (0.662)
Draught	−0.05 (0.042)	0.005 (0.018)	0.009 (0.018)	−0.04 (0.043)	0.09 (0.145)	−0.07 (0.097)
Male head	−0.34 (0.264)	−0.18* (0.108)	0.013 (0.131)	−0.29 (0.269)	−0.31 (0.877)	−0.39 (0.724)
Farming experience	−0.02 (0.021)	0.004 (0.009)	−0.006 (0.007)	−0.021 (0.0219)	0.12* (0.074)	−0.021 (0.039)
Sorghum experience	0.02 (0.024)	0.011 (0.010)	−0.096 (0.009)	0.028 (0.025)	−0.04 (0.083)	0.11** (0.051)
Crop diversity	0.01 (0.092)	0.19*** (0.035)	0.24*** (0.037)	−0.017 (0.087)	−1.88*** (0.3)	−1.57*** (0.2)
Income diversity	0.36*** (0.118)	0.004 (0.045)	0.09* (0.056)	0.37*** (0.122)	−0.88** (0.37)	0.14 (0.308)
Income	0.01* (0.074)	0.003 (0.002)	0.01** (0.003)	0.01* (0.008)	−0.03* (0.002)	0.004 (0.002)
Aid	0.02*** (0.007)	0.003 (0.002)	0.07** (0.003)	0.04** (0.071)	−0.01 (0.020)	0.027 (0.019)
Extension	0.04 (0.004)	−0.01 (0.019)	0.016 (0.019)	0.06 (0.043)	0.05 (0.154)	−0.137 (0.106)
Associations	−0.16 (0.114)	0.04 (0.049)	0.03 (0.049)	−0.164 (0.115)	−0.16 (0.401)	−0.042 (0.268)
Storage	−0.85*** (0.31)	−0.025 (0.115)	0.183 (0.112)	−0.83*** (0.315)	−0.52 (0.938)	0.461 (0.619)
Price	0.03** (0.013)	0.006 (0.006)	−0.002 (0.005)	0.04*** (0.014)	−0.05 (0.051)	0.044 (0.0273)
Buyers	0.06 (0.055)	0.028 (0.020)	−0.04* (0.023)	0.074 (0.057)	−0.29* (0.159)	−0.07 (0.124)
Distance	0.02 (0 .002)	0.001 (0.008)	−0.01 (0.083)	0.002 (0.002)	−0.05 (0.007)	−0.004 (0.005)
Payment time	−0.04 (0.008)	−0.003 (0.004)	−0.06* (0.003)	−0.003 (0.008)	−0.03 (0.0294)	0.006 (0.017)
Soil fertility	0.07*** (0.008)			0.08*** (0.008)		
Constant	−4.83*** (1.27)	4.29*** (0 .568)	2.65*** (0 .469)	−5.33*** (1.376)	22.2*** (4.45)	15.6*** (2.58)
Log pseudo−likelihood	−482.862			−1179.192		
Wald test of independent equations	9.06***			6.20***		

Source: Generated by authors from 2016 sorghum survey data using STATA.
Notes: ***; ** and * indicate *p*-values significant at 1%, 5% and 10% levels respectively.
z-values estimated on robust standard errors in parenthesis.

act as a buffer for securing multiple food baskets for the households due to increased purchasing power in food markets.

From the two regime equations presented in Table 3, it can be concluded that crop diversity significantly impacts on both HDDS and HFIAS. The major crops grown in the study area included maize, sorghum, cotton and soyabean. The ability of households to produce multiple crops can act as a cushion for food diversity and availability (Mutenje et al. 2010). This multiple basket can guarantee food security even in extreme cases where one crop fails. This strategy reduces the multiple financial, production and marketing risks that are common in arid and semi-arid zones of Zimbabwe.

Notable differences are observed with a number of coefficients between the two regimes of intensification and non-intensification. This is an indication that the switching methodology is a more appropriate approach than lumping the output in one regression model. The sex of household head significantly affects the HDDS for intensifiers but is insignificant for non-intensifiers. Household headed by females tend to have higher dietary diversity. This can be attributed to the ability of females to source for various foods including indigenous vegetables and fruits for the family. Discussions with the farmers showed that the cultural systems in the study area are clearly defined in terms of responsibilities with the household head being the principal decision maker. In cases where males headed the households, there were reports of the wives being discouraged from fruit hunting and selling since the husbands insisted on crop production even in the poor seasons. This led to lower dietary diversity for the male-headed households With HDDS, other differences are with income and its diversity, aid, number of buyers in market and payment time. Higher incomes and income diversity increase the HDDS for non-intensifiers while the impact on the intensifying counterparts is insignificant. We attribute this to limited variability in both variables for the intensifying farmers. Mabuza et al. (2016) also reported a similar pattern in Swaziland. They reported that farmers who depended on off-farm income sources were more likely to be food secure compared to those who depended on on-farm income.

Results from Table 3 show that as the number of buyers who relate to the farmer in markets increases, for non-intensifiers, the HDDS decreases. This can be because this reduces their bargaining power since the likelihood of having binding relationships with all buyers will be low due to the high transaction costs of searching for and processing information about each buyer. The benefits from sorghum production remain lower than for intensifiers leading to a low basket of goods that are consumed. This is so because as the bargaining power of the farmers diminish, they will most likely get lower market prices for their produce leading to lower aggregate household income for diverse food purchases.

The aid value also has a significant and positive influence on the HDDS for non-intensifiers. Aid in the study area takes different forms including explicit forms such as seeds and fertilisers. This intervention capacitates resource-constrained small holder farmers into increased and efficient sorghum production hence increasing their food diversity. Additionally, since the non-intensifiers usually get the same quantities of subsidies as intensifiers, we observed that in the study area, in some cases non-intensifying farmers sell the items they would have received as aid to get income. The main aid element given to the farmers was sorghum seed and the study was able to trace these transactions and cases of sold aid. They then use the income to directly purchase food products hence the increase in HDDS.

For HFIAS, differences are reported with age, dependency, income and income diversity, buyers and experience. Interestingly, the income diversity coefficient is negative and significant with sorghum high yielding varieties intensifiers. This is logical because as the income diversity increases, the HFIAS also decreases. As reported by Mango et al. (2014), lower values of HFIAS are favourable as they indicate higher food security.

6.2 Food security impacts of improved sorghum varieties intensification

Using absolute comparisons for the food security indicators could be misleading since it does not accommodate the counterfactual condition. This approach assumes that improved sorghum varieties

Table 4. Counterfactual impact analysis using nearest neighbour method.

Welfare indicator	Actual (household intensify)	Counterfactual (household did not intensify)	Treatment Effect
1. HFIAS	4.57 (0.504)	11.53 (0.071)	6.96*** (0.692)
2. HDDS	5.49 (0.059)	3.63 (0.012)	1.86*** (0.131)

Notes: Generated by authors from 2016 sorghum survey data using STATA.
Bootstrapped standard errors generated using 100 replications of the sample.
Absolute value of the *z*-statistic is placed in parenthesis.
***; ** and * show *p*-values that are significant at 1%, 5% and 10% levels respectively.

Table 5. Multinomial endogenous treatment effect estimates of intensification on welfare.

	Exogenous		Endogenous	
Seed variety choice	(1) HFIAS	(2) HDDS	(3) HFIAS	(4) HDDS
M_1S_0	−0.168** (0.077)	0.215*** (0.136)	−0.292** (0.082)	0.349*** (0.065)
M_0S_1	−0.119** (0.028)	0.328** (0.213)	−0.335** (0.041)	0.353*** (0.052)
M_1S_1	−0.144** (0.042)	0.267*** (0.166)	−0.304** (0.106)	0.345*** (0.023)
Selection terms				
λ_{M1S0}			−0.137* (0.055)	0.194** (0.039)
λ_{M0S1}			−0.159* (0.073)	0.223*** (0.050)
λ_{M1S1}			−0.118** (0.010)	0.174* (0.009)

Notes: Generated by authors from 2016 sorghum survey data using STATA.
Standard errors in parenthesis.
***; ** and * indicate *p*-values significant at 1%, 5% and 10% levels respectively.

intensification is determined exogenously but in practice, it can be a potential endogenous variable. Unobservable characteristics of the sampled households could be the cause for the observed differences. For example, the observed differences in the indicators might be a case where a more skilled farmer could have generated higher net returns per hectare without necessarily intensifying sorghum production (Table 4).

There is statistical evidence from the data that households who intensify sorghum production have significantly higher productivity and net returns per hectare ($p < 0.05$). The same observation was made for the food security indicators of HDDS and HFIAS ($p < 0.01$). Chepng et al. (2014) noted significant inefficiencies among sorghum producing households across all scales of production and reported this as a driver for limited intensification prospects. A study conducted by Asfaw et al. (2012) pointed towards the need to adopt more sustainable practices to grease the benefits from intensification.

The study further uses endogenous switching regression to account for potential unobserved heterogeneities in the data. Multinomial endogenous treatment effect results on impacts of intensification of improved sorghum varieties using indicators of food security are shown in Table 5.

Focus is placed on the endogenous results since they account for the factors which are not observed. Results from columns (3) and (4) in Table 5 show that intensification of improved sorghum varieties can increase dietary diversity by about 35% while reducing food insecurity by 29–34%. However, the highest benefits overall are observed with intensification of Macia only (M_1) with Silla also having notable benefits, especially with food security and diversity.

7. Conclusions and implications for policy

The mainstay of the study was to examine the impact of allocating more land towards improved sorghum varieties on food security for rural households using HDDS and HFIAS as proxies. Results from endogenous switching regression analysis show that age of principal decision maker, household income and its diversity, availability of storage facilities and the observed market prices are significantly important in determining the impact of high yielding varieties on welfare status of households.

From the counterfactual analysis, it can also be reported that farmers who decide to allocate more land towards improved sorghum seed varieties are comparatively better off in dietary diversity and food access. Given these observations, there is space for development of locally driven cooperatives which accommodate diverse households. These platforms should catalyse the generation and dissemination of information regarding access to and benefits of affordable improved sorghum varieties. This starting point should be followed by infrastructural development initiatives such as seed banks and storage facilities which unlock the avenues for smallholder farmers in arid marginalised zones to interact efficiently and effectively with link-agents and consumers.

Additionally, age-specific human capital development options need to be opened up so that the farmers can effectively access, process and interpret information. Farmer groups can be developed within the cooperative model so that adult education-oriented training programmes which capacitate farmers are designed and scaled up and out. Youth empowerment initiatives need to be realigned with the potentials of migrating towards market-driven sorghum value chain systems. Overall, reducing transaction costs of doing business can help increase the productivity, net returns and food security position for the households. Since the study area is arid, experiencing low rainfall, high temperatures and limited livelihood options, sorghum intensification can offer a gateway out of food and income insecurity. The government needs to facilitate partnerships of farmers with the private sector players along the sorghum value chain so as to grease the relationships among these strategic stakeholders. For example, farmers need to access highly rewarding markets if the benefits from sorghum high yielding varieties intensification are to be enjoyed.

Notes

1. The adoption results are not captured in this paper but are available upon request from the authors.
2. An instrumental variable, soil fertility was selected and applied across all the welfare models. See the results section for justification of the selected instrumental variable.
3. The sample size calculator with a known population of 14,500 farmers was used to come up with the sample size. This was also validated using a standard sample size table.
4. The current study could not use the Coping Strategy Index (CSI) since farmers could not easily recall the strategies adopted during the review period.
5. A sample of 252 households was used from a total of 380 farmers initially sampled for the main project. The other 128 households were non-users of improved sorghum varieties and where therefore removed from the analysis.
6. A household whose HFIAS score is high has high levels of food insecurity. Different ranges have been reported in literature (Cafiero et al. 2014; Mango et al. 2014) but the present argument still holds. We adopt the narrower spectrum of the responses since wider ranges would imply more possible responses which can compromise the ability of respondents to place their response in a particular specific category.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author, J.P.M. The data are not publicly available due to restrictive distribution clauses in the contract with the funding organisation.

ORCID

Joseph P. Musara http://orcid.org/0000-0002-2226-3616

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