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How scalable are stress tolerant maize varieties? An examination of knowledge, seed access and affordability heterogeneity effect in Tanzania

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Abstract

Maize farmers in Sub-Saharan Africa (SSA) are repeatedly exposed risks of low productivity and crop failure resulting from both biotic and abiotic stresses. As such, investments that bolster farmers against the negative impacts of stresses such as drought, pests and diseases become necessary. Stress-tolerant maize varieties (STMVs) offer hope as an adaptation strategy to maize stresses. The varieties have been developed and deployed in several countries in Eastern, West and Southern Africa, by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with other GIAR centers, National Research Institutions and seed producers. They are being disseminated to the farming communities through the National Agricultural Research and extension systems and in collaboration with the seed companies; however, as a relatively new technology, their adoption is limited to a few farmers and empirical studies on their scalability are scanty. We use empirical data from Tanzania to examine the scalability of STMVs conditional on knowledge about STMVs by farmers, seed availability and affordability. The data reveal that despite their low sample adoption rates of about 10%, STMVs are potentially scalable to 39%, 46% and 52% of farmers once knowledge, seed access and affordability constraints, respectively, are addressed.

Keywords: Stress tolerant maize varieties, scaling, knowledge, seed access, affordability Tanzania

1 Introduction

Maize farmers in Sub-Saharan Africa (SSA) are repeatedly exposed to risks of low productivity and crop failure resulting from both biotic and abiotic stresses. As such investments that bolster farmers against the negative impacts of stresses such as drought, pests and diseases become necessary. Recent years have witnessed the development of stress tolerant maizevarieties (STMVs) designed to help small-scale farmers manage stresses and hence offer hope as an adaptation strategy to maize stress. These varieties have been developed since 2006 and deployed to over 13 countries in Eastern, West and Southern Africa, by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with other CGIAR centers, National Research Institutions and seed producers (CIMMYT, 2017; Fisher et al., 2015). In addition to stress tolerance, the varieties often have other attractive traits, such as better responsiveness to inputs and good nitrogen use efficiency (Fisher et al., 2015). They are well-adapted to SSA and include hybrids and open-pollinated varieties. STMVs are expected to increase maize yields by 20-30 percent, reduce yield variability and reduce production risk. Nonetheless, the STMVs are not yet widely adopted because they are relatively new, and little is known about their potential for wide spread adoption.

A great deal is known about technology adoption by a small number of smallholder farmers, yet the adoption of improved technologies and practices by a small number of adopters will not accomplish development goals. As expressed by USAID (2017), for development interventions to yield maximum impact, programming requires a facilitative approach for widespread adoption of improved technologies and practices at the population level, also known as scaling. The scaling or widespread adoption of proven technologies and practices is largely defined as the process of sustainably increasing the adoption of a credible technology or practice, or a package of technologies and practices, with quality to retain or improve upon the demonstrated positive impact of the technology or practice and achieve widespread use by stakeholders (USAID 2017).

The scaling strategy for STMVs involves a number of stakeholders including CIMMYT, the public sector (NARI and NARES), the private sector (seed companies and agro-dealers) as well as non-Governmental organizations (NGOs). CIMMYT develops germplasm and provides precommercialized hybrids to the NARS and seed companies for National Performance Trials (NPTs) before release. Once released the NARS and seed companies may proceed with the production of foundation seed and the commercialize through certified seed production. The certified seed is then sold to farmers through agro-dealers or through the distribution agents by the seed company. To complement such scaling efforts, some studies have bee conducted to understand the diffusion processes of STMVs, their adoption rates, determinants and their impacts on farm productivity, food security and household welfare (Fisher et al., 2015, Wossen et al., (2017). However, studies on the scalability of STMVs arescanty.

It is against this background that this study aims to explore the potential for scaling STMVs in Tanzania under the knowledge, physical seed access and affordability heterogeneity. This type of analysis is critical for understanding the current bottlenecks in STMV scaling and for a proper planning and the building of a more concerted effort involving both the private and public sectors towards expediting the widespread adoption of STMVs. Moreover, the study is expected to contribute to understanding the potential demand for STMVs and the information generated is useful in determining the potential areas of intervention in the seed value chain in order to reach the tipping point, after which the rate of adoption should increase exponentially with less support. We apply the average treatment effect framework (ATE) proposed by Diagne and Demont (2007) but go a step further to also consider the availability and price affordability of seed. Our extension from these studies is premised on the fact that beyond the awareness of the new variety and availability/accessibility of seed, the affordability of that seed is a critical factor affecting the scaling of improved varieties. We thus consider households, knowledge of STMVs, access to seed and access to seed at an affordable price to be heterogeneous. Indeed, households for whom the seed is not affordable are unlikely to adopt the variety of their choice even if they know it and the seed may be physically available in their locality.

The rest of the paper is organized as follows: Section 2 discusses analytical methods while data sources and descriptive statistics are presented in section 3. The results and discussions of potential for scaling adoption and determinants are presented in section 4, and the conclusions are presented in section 5.

2 Analytical Framework

In analyzing adoption decisions, we need to address whether a potential adopter is informed about the STMV's existence, has access to seed and at a price that is affordable. STMV adoption not only depends on an individual having information about their existence and their performance attributes, it also depends on whether the seed for STMV is available and if it is sold at price a farmer can afford. Once the STMVs are released, information about their existence is disseminated through multiple channels that include: (i) on-farm trials; (ii) demonstration plots controlled by agricultural extension agents; (iii) field days for farmers; (iv) agricultural shows to which farmers are invited and farmer-to-farmer exchange of information occurs; and (v) varietal promotion. The seed is usually produced by private seed companies and can be distributed by government, public sector agencies, cooperatives, and the private sector—agro dealers or, as is often the case, by a combination of all of these.

As the STMVs are new and the target population is not universally exposed to them, observed sample adoption rates do not consistently represent the true population adoption parameters, even when based on a randomly selected sample. The reason is that researchers and extension workers have a tendency to target progressive farmers first, while farmers self-select into exposure (Diagne, 2006). To account for selection bias, Diagne and Demont (2007) use the counterfactual average treatment effect (ATE) framework, which allows for both nonparametric and parametric methods to derive consistent estimates. The average treatment effect (ATE) parameter measures the effect or impact of a "treatment" on a person randomly selected in the population (Rubin, 1974; Wooldridge, 2002). But as expressed by Donstop et al. (2013), apart from a lack of awareness, there are is another constraint, which is the lack of access to seed. The farmer can be aware of STMV but cannot become an adopter if (s)he does not have access to them. The awareness and access to the seed of STMVs are, therefore, both necessary conditions for adoption. Donstop*etal.,* (2013) also show that while it is possible to observe farmers can be aware of improved varieties without getting access to their seed, it is not possible to observe the access to seed status among farmers that are not aware of the existence of STMVs (Figure 2). By extension, the farmers can be aware of STMVs without having access to their seed at an affordable price, but we do not know the status in terms of accessibility to affordable STMV seed among farmers that are unaware of the existence of STMVs and among those that have no physical access to seed. As in the case of Donstop et al. (2013), in this paper, we use the term "access" to imply physical availability of the seed in the farmer's environment and not the acquisition availability (affordability). Our extension in this study is that we also explore how the acquisition (price) affordability of STMV seed affects adoption rates.

To obtain the access and affordability variables, we collected information on all possible reasons for not adopting the STMVs through individual interviews among households that were aware of STMVs but did not adopt them (Figure 2). At the first stage, all farmers were asked whether they knew specific STMVs. At the second stage, for those who reported having knowledge (denoted by "w") of STMVs (w=1), the following specific question was asked: "Did you grow any of the STMVs in the 2018 planting season?" When a farmer responded that (s)he did not grow any STMV, (s)he was asked to provide reasons for not growing them. A wide range of responses were recorded; however, of interest were responses related to seed accessibility and seed affordability. We denote "s" to stand for the (physical) access to seed status of a farmer, with s=1 for farmers who had access to seed and s=0 for farmers who had no access to seed. For farmers who did not know about STMV (that is w=0), they were not asked the questions related to access to seed. As expressed by Donstop et al. (2013), this implies that we do not have information on access to seed status of the farmers who were not aware of STMVs. Indeed, some of the farmers who are not aware of STMVs may actually have access to STMV seed even though they are not aware of their existence. As expressed by Donstop et al. (2013) this could be the case, for example, when the variety is present in the village, but the farmer is not aware of the variety. We denote "p" to stand for the acquisition affordability seed status of a farmer, with p=1 for farmers that had access to seed at an affordable price and p=0 for farmers who had no access to affordable seed. For farmers who did not know about STMV (that is w=0), they were not asked the questions related to seed affordability. As in the case of the availability of seed, this also implies that we do not have information on access to the "affordable" seed status of the farmers who were not aware of STMVs. Indeed, some of the farmers who are not aware of STMVs may actually be able to afford STMV seed even though they are not aware of their existence.

[Insert Figure 2: Flow chart showing the construction of the access to seed and to affordable seed variable]

Based on the earlier explanation, the physical access to seed status variable is either 0 or 1 and it is only observed among individuals that are aware of STMVs. Hence the awareness and the physical access–unrestricted potential adoption rate is always greater than or equal to the awareness–unrestricted one. Similarly, the awareness-, physical access- and acquisition affordability-unrestricted potential adoption rate is always greater than or equal to awareness- and physical access–unrestricted potential adoption rate.

In what follows, we extend the ATE adoption framework proposed by Diagne and Demonte (2007) to estimate three types of potential adoption rates; (i) the awareness-unrestricted; (ii) the awareness –access-unrestricted; and (iii) the awareness-access-affordability-unrestricted STMV population potential adoption rates and the associated adoption gaps in Uganda, as well as the determinants of STMV awareness, access , affordability, and adoption.

We adopted the potential outcome framework of Rubin (1974), in which every farmer in the population has *theoretically* eight potential adoption outcomes:

(i) an outcome with awareness and access to seed at an affordable price, say y_{111} (that is, y_{111} is the outcome when $w = 1, and\ \ s = 1\ and\ \ p = 1$)

(ii) an outcome when is aware and has access to seed but when seedis sold at a price farmers cannot afford, say y_{110} (that is, y_{110} is the outcome when $w = 1, and\ \ s = 1\ and\ \ p = 0$)

(iii) an outcome with awareness, with affordable seed price, but farmers do not have access to seed, say y_{101} (that is, y_{101} is the outcome when $w = 1, and\ \ s = 0\ and\ \ p = 1$)

(iv) an outcome with awareness of STMV, but one does not have access to seed and the seed price is not affordable, say y_{100} (that is, y_{100} is the outcome when $w = 1, and\ \ s = 0\ and\ \ p = 0$)

(v) an outcome without awareness of STMV, but having access to seed and at a price that isaffordable, say y_{011} (that is, y_{011} is the outcome when $w = 0, and\ \ s = 1\ and\ \ p = 1$)

(vi) an outcome without awareness of STMV and with access to seed but the seed price is not affordable, say y_{010} (that is, $y_{010}$is the outcome when $w = 0, and \ \ s = 1 \ and \ \ p = 0$)

(vii) an outcome without awareness of STMV and with no access to seed but the seed price is affordable say y_{001} (that is, $y_{001}$is the outcome when $w = 0, and \ \ s = 0 \ and \ \ p = 1$)

(viii) an outcome without awareness of STMV and without access to seed and when the seed price is not affordable say y_{000} (that is, $y_{000}$is the outcome when $w = 0, and \ \ s = 0 \ and \ \ p = 0$).

Hence, the observed adoption outcome y can be expressed relative to the eight potential adoption outcomes as:

$$y = wspy_{111} + ws(1-p)y_{110} + w(1-s)py_{101} + w(1-s)(1-p)y_{100} + (1-w)spy_{011} + (1-w)\ s\ (1-p)y_{010} + (1-w)(1-s)y_{001} + (1-w)(1-s)(1-p)y_{000} \qquad (1)$$

Since awareness, physical seed access, and seed price affordability are necessary conditions for adoption in that order, we have$y_{101} = y_{100} = y_{001} = y_{010} = y_{001} = \ y_{011} = y_{000} = 0$.

Hence, equation (1) is reduced to:

$$y = wspy_{111} \qquad (2)$$

The potential outcome is always 0 when the farmer is not aware, and/or does not have access to seed and/ornot have access at an affordable price. It follows that y_{111}, which is the potential outcome, is also the treatment effect of a given farmer when the farmer is aware, has physical seed access and seed access at an affordable price. The average treatment effect of awareness andphysical access to seed at an affordable price is expressed as the expected value $E(y_{111})$.

If we consider awareness as a treatment, the awareness-unrestricted potential adoption outcome can be derived from equation (2) by setting $w = 1$ and expressed as follows:

$$y_1^* = spy_{111} \qquad (3)$$

Similarly, by setting$s = 1$, the physical seed access-unrestricted potential adoption outcomey_1^{**} is defined as:

$$y_1^{**} = wpy_{111} \qquad (4)$$

After setting$p = 1$, the seed acquisition affordability-unrestricted potential adoption outcome can also be expressed as:

$$y_1^{***} = wsy_{111} \tag{5}$$

Similarly, the awareness and physical seed access-unrestricted potential adoption outcome is by setting $(w, s) = (1, 1)$expressed as:

$$y_{11}^{*} = py_{111} \tag{6}$$

The awareness and acquisition affordability-unrestricted potential adoption outcome isby setting $(w, p) = (1, 1)$ expressed as:

$$y_{11}^{**} = sy_{111} \tag{7}$$

The physical seed access and acquisition affordability -unrestricted potential adoption outcome is by setting $(s, p) = (1, 1)$ expressed as:

$$y_{11}^{***} = wy_{111} \tag{8}$$

The average treatment effect (ATE) of awareness, physical seed access, and acquisition affordability as measured by the expected value $E(y_{111})$ is the potential adoption rate when the full population is aware of STMVs and has physical access to the seed for STMVs at a price affordable by the full population. This is different from the potential adoption rate when the full population is only aware of STMVs $E(y_1^{*})$, and it is also different from the potential adoption rate when the full population only hasphysical access to STMV seed $E(y_1^{**})$. It is also different from the population potential adoption rate when the full population has access to seed at an affordable price (with some not necessarily being aware), which is measured by the parameter $E(y_1^{***})$. Three more joint bivariate potential adoption rates (equations 6-8) correspond to awareness and physical access to seed (y_{11}^{*}), awareness and acquisition affordability of seed (y_{11}^{**})and physical seed access and acquisition affordability of seed (y_{11}^{***}).

To distinguish the seven population potential adoption rates, we call parameter $E(y_{111})$ the awareness-physical seed access-at affordable prices unconstrained potential adoption rate (ATE_{wsp}), whereas $E(y_1^{*})$, $E(y_1^{**})$ and $E(y_1^{***})$ are called awareness unconstrained (ATE_w), access unconstrained (ATE_s), and affordability–unconstrained (ATE_p) population potential adoption rates, respectively.$E(y_{11}^{*})$, $E(y_{11}^{**})E(y_{11}^{***})$ are called the joint bivariate potential adoption rates corresponding to awareness and physical seed access (ATE_{ws}), awareness and seed affordability (ATE_{wp}) and physical seed access and seed affordability ATE_{sp}), respectively.

Among the 7 population potential adoption rates defined above, we restrict our empirical estimation to only 3: ATE_w=E(y_1^*), ATE_{ws}=E(y_{11}^*), and ATE_{wsp}=E(y_{111}). The exclusion of the two marginal potential adoption rates (related to physical seed access(ATE_s) and acquisition affordability(ATE_p)) from the empirical analysis is justified by the fact that the two variables (ie$s$ and p) are observed only for the aware sub-sample (ie, for $w = 1$) which makes it difficult to estimate them without further assumptions. The same is true for the excluded joint bivariate potential adoption rate related to physical seed access and acquisition affordability ($ATE_{sp} = E(y_{11}^{***})$). The exclusion of the joint bivariate potential adoption rate related to awareness and acquisition affordability ($ATE_{wp} = E(y_{11}^{***})$) from the empirical analysis is justified by the fact that it measures the same quantity as the potential adoption rate under unrestricted joint awareness,-physical access and -acquisition affordability ($ATE_{wsp} = E(y_{111})$) since it is measured only for those with physical access to seed ($s = 1$).The choice of three potential adoption rates ATE_w=E(y_1^*), ATE_{ws}=E(y_{11}^*), and ATE_{wsp}=E(y_{111}) for the empirical analysis is justified by their policy relevance in two ways. First, understanding the marginal adoption changes resulting from awareness creation should inform policy on the level of investment required for improving the adoption of STMVs through activities that enhance the awareness about STMVs among the farming population. Second, understanding the marginal increase in adoption rates resulting from increased seed availability and affordability should be useful to seed suppliers in forecasting the potential demand for STMV seed at given market prices and should also inform public policy regarding the magnitude of price support required to enhance farmer's adoption of STMVs.

The findings of this paper are novel in that it is among the first of studies that attempt to estimate the joint average treatment effect of joint awareness, physical seed access and acquisition affordability measured by the expected value E(y_{111}). This differs from the marginal adoption rate corresponding to awareness(y_1^*), defined in Diagne and Demont (2007) and also differs from the joint bivariate potential adoption rate corresponding to awareness and physical access E(y_{11}^*)defined by Donstop (2013).

In this paper the observed population adoption rate parameter (which is consistently estimated by the sample adoption rate computed from a random sample) is, a measure of the population joint awareness-physical access-acquisition affordability and adoption rate (which is the same as the population joint awareness, seed access, at affordable prices and adoption rate as $E(y) = E(wspy_{111})$and not a measure of the population joint awareness and adoption $E(wy_{11})$rate as argued in Diagne and Demont (2007). Hence, in what follows, we use the notation JEAAA (joint awareness-access-affordability and adoption) for the observed population parameters $(E(y))$. It is also clear from the above that $E(y) \leq E(y_1^*) = E(spy_{111}) \leq E(y_{111})$ and $E(y) \leq E(y_{11}^*) = E(py_{111}) \leq E(y_{111})$ (since w, s *and* p are binary), meaning that the awareness-unconstrained, and awareness-physical access-unconstrained, potential adoption rates are both greater than the observed actual adoption rate but always lower than the awareness- physical seed access-acquisition affordability unconstrained potential adoption rate.

We can then define three adoption gaps with one attributable to lack of seed access at affordable prices (equation 9), lack of physical seed access (equation 10) and lack of awareness (equation 11)as follows:

$$GAP_{wsp} = E(y) - E(y_{111}) = JEAAA - ATE_{wsp} \quad (9)$$

$$GAP_{ws} = E(y) - E(y_{11}^*) = JEAA - ATE_{ws} \quad (10)$$

$$GAP_{w} = E(y) - E(y_1^*) = JEA - ATE_{w} \quad (11)$$

where $ATE_{wsp}$is the average treatment effect parameter whenjointawareness, physical seed access and seed at affordable prices is the treatment variable. $ATE_{ws}$is the average treatment effect parameter when awareness and seed access, jointly is the treatment variable and ATE_w is the average treatment effect parameter when awareness is the treatment variable.

According to the ATE framework, the awareness-unrestricted (ATE_w) the joint awareness-physical access-unrestricted(ATE_{ws}), and the joint awareness- physical access- affordability-unrestricted(ATE_{wsp}) potential adoption rates can be defined for various subpopulations by the values$x$in the support of some random variable Xas the average treatment effects conditional on x,$E\ (y_1^*\ |X\ = x)$, $E\ (y_{11}^*\ \ |X\ = x)$, and $E\ (y_{111}|X\ = x)$; Erespectively (the conditional ATE parameters). It follows that the potential adoption rates in the subpopulation aware of STMVs, in the subpopulation aware and with physical seed access, and in the subpopulation aware and with physicalseed access at affordable prices correspond to the average treatment effect on the treated (ATT) parameters and expressed as follows:

$$ATT_w = E(y_1^*|w = 1) \quad (12)$$

$$ATT_{ws} = E(y_{11}|w = 1, s = 1) \quad (13)$$

$$ATT_{wsp} = E(y_{111}|w = 1, s = 1, p = 1) \quad (14)$$

The potential adoption rates in the untreated subpopulations are given by the respective ATE on the untreated (ATU) as follows:

$$ATU_{w} = E(y_1^*|w = 0) \quad (15)$$

$$ATU_{ws} = E(y_{11}^*|w = 0, s = 0) \quad (16)$$

$$ATU_{wsp} = E(y_{111}|w = 0, s = 0, p = 0) \quad (17)$$

Furthermore, as in Diagne (2006, 2010) and Diagne and Demont (2007),we will define the awareness, awareness -physical seed access, and awareness-physical access- acquisition affordability population selection bias (PSB) parameters that measure the extent to which the three treatment status variables are not randomly distributed in the population, respectively, as:

$$PSB_w = ATT_w - ATE_w = E(y_1^*|w = 1) - E(y_1^*) \quad (18)$$

$$PSB_{ws} = ATT_{ws} - ATE_{ws} = E(y_{11}^*|w = 1, s = s_1 = 1) - E(\ y_{11}^*) \quad (19)$$

$$PSB_{wsp} = ATT_{wsp} - ATE_{wsp} \quad (20)$$

$$= E(y_{111}|w = 1, s = s_1 = 1, p = p_1 = 1) - E(\ y_{111})$$

The empirical estimation involves the application of the ATE framework to provide consistent estimates of $E(y_1^*),\ E(y_{11}^*),\ and\ E(y_{111})$. In fact, the parameters for y_1^* are identified and estimated exactly the same way as in Diagne and Demont (2007) using the w (awareness) variable while for the case of y_{11}^* and y_{111}, we use the ws and wsp variables, respectively. As shown in Figure 2, all three variables are only observed for the farmers that are aware of STMVs (that is, for farmers with $w = 1$) but the products $ws\ and\ wsp$ are known for all farmers, as also shown above. It is assumed that the conditional independence assumption holds in all cases. As expressed in Donstop et al., (2013) it is assumed that the distributions of the treatment status variables $w, ws\ and\ wsp$ are independent of the distribution of the potential outcomesy_1^*, y_{11}^* and y_{111} , conditional on a vector of covariates x. That is, using the standard notation for conditional independence (A1): $w \perp y_1|x$, $w, s \perp y_{11}|x$ and $w, s, p \perp y_{111}|x$. By the propriety of conditional independence, assumption (A1) also implies that $w \perp y_1^*|x$ (Donstop et al., 2013). Therefore, we can use the same identification results and estimation procedures as in Diagne and Demont (2007) to identify and estimate parameters related to the three treatments.

1 Data and descriptive statistics

1.1 Survey design

The study was conducted in December 2018and surveyed 720 households in 39 villages across 17 Districts and ten Regions, covering both project areas and potential spillover areas (see Figure 1). Surveyed areas included: Morogoro region (Kilosa, Morogoro rural and Mvomero districts); Iringa region (Iringa district); Mbeya region (Mbeya district); Tabora region (Nzega district); Manyara (Mbulu and Babati districts); Simiyu region (Bariadi district); Tanga region (Korogwe and Tanga districts); Dodoma region (Kondoa District); Arusha region (Karatu, Meru and Arusha Districts); and the Kilimanjaro region (Moshi rural and Hai Districts)— A three- stage sampling technique was used, combining purposive and random sampling. The first stage selected Regions, both Project areas and likely spillover areas. The second stage involved the selection of villages, using probability proportional to size (pps) sample design. The third stage involved a random sampling of households within each village.

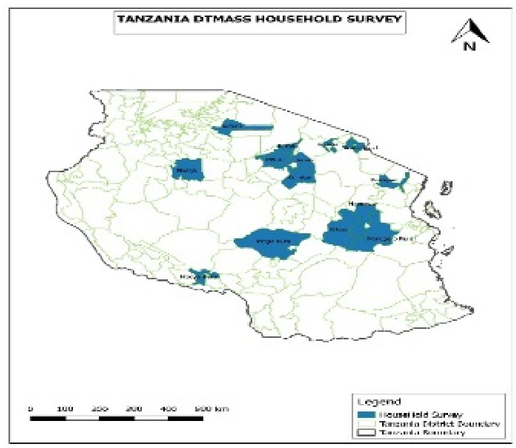

Figure 1: Map showing areas where the survey was conducted

1.2 *Definition of dependent variables*

We define adopters as households that reported planting at least one STMV. In our sample, 10% of the households reported having planted at least one STMV in one of their maize plots. There are several drivers to adoption, but clearly, in seed-related technologies, as is the case in this study; two key variables are of consideration. First, a household cannot adopt STMVs if they are not exposed or aware of their existence. Hence, the decision on whether to adopt STMVs is only relevant toa non-random subsample of households that are aware of the existence of STMVs. We assessed the awareness of STMVs by asking respondents whether they had heard of at least one of the STMVs listed in the questionnaire. We measured the awareness of at least one STMV as a dummy variable, taking the value of one if the respondent acknowledged being aware of STMV and zero otherwise. Other important variables in the adoption of seed-related technologies relates to the availability and affordability of the seed itself. We constructed a dummy variable for seed availability by asking respondents that were aware of the existence of STMVs but did not adopt them to give reasons for no- adoption. Based on this question, we were able to identify two extra categories of households: (i) households that were aware of STMVs and that had physical seed access if they wanted to purchase, and (ii) households that were aware of the existence of STMVs and had affordable access to seed. The difference between the two groups is that the former focuses on the supply side of seed, thus making seed available to the farmer while the latter is confounded by both the supply, and demand side, as farmers may fail to purchase seed even when it is availed to them at a price higher than they can afford. Out of 720 farmers in the sample, 27% were aware of STMVs, 21% had seed access (regardless of affordability), while 19% had seed access at a price they could afford.

1.3 Independent variables and descriptive statistics

Table 1 presents descriptive statistics for some of the explanatory variables used in the analysis disaggregated by the adoption status of the households. About 86% of the households were male-headed, and there was no difference in the proportion of male-headed households between adopters and non-adopters. The average household size was 5.7 persons per household, with adopting households reporting a little fewer households (5 persons) than the non-adopters (5.8 persons). The average land holding size was 3.3 ha and adopting households had significantly larger landholdings (4.49 ha) than the non-adopters (3.17 ha). To capture access to information, farmers were asked whether they received information about new varieties. Following this, farmers were asked to mention their main sources of such information. About 21% of the sampled households reported receiving information about new maize varieties in 2018. More adopters (25%) reported receiving information about new maize varieties than the non-adopters (21%), suggesting that the access to information on new maize varieties affected the likelihood of cultivating at least one STMV. On the sources, other farmers, field day demonstrations and the government were the most prefered for learning information on new maize varietes. Membership in social groupings such as cooperatives, farmer groups, and in faith-based organizations can have a significant impact on adoption (Bandiera and Rasul 2006). In our survey, membership in farmer groups was quite high and reported by 62% of the respondents, but there was no difference in membership rates between adopters and non-adopters.

Table 1: Descriptive statistics by the adoption status of STMVs

	Full Sample (n=864)	Adopters (n=120)	Non-adopters (n=744)	Mean difference
Household size	5.7	5.0	5.8	0.6**
Gender (1 male, 0 female)	0.86	0.91	0.85	0
Age (yrs)	52.19	51.47	52.26	0.79
Years of education	6.31	7.0	6.23	0.76**
Farm size (ha)	3.30	4.49	3.17	1.32**
Social capital and access to information				
Received Information on new varieties (%)	21	25	21	0
Sources of information on new seed varieties (%)				
Government	22	23	22	0
Field days/Demonstration plots	28	30	14	0.15**
Input suppliers	17	20	17	0.2
Other farmers	42	44	42	0
Membership in group(1=yes, 0=otherwise)	62	58	62	0.4
Distance to the market (km)	8.38	7.07	8.53	1.46
Households with incomes enough to save (%)	9.4	10	9.3	0
Received information on expected rainfall patterns (1 =yes, 0=otherwise)	0.53	0.60	0.52	0.08
Household owning livestock (1 =yes, 0=otherwise)	0.84	0.85	0.84	0
Households are aware STMVs (%)	27	100	18	0.81**
Household have access to seed (%)	21.3	100	12	0.87**
Households who can afford STMVs seed (%)	18	100	9	0.90**

*, ** and *** imply that difference between adopters and non-adopters is statistically significant at 90%, 95% and 99% level (t-tests are used for differences in means)

Information on predicted weather conditions enables farmers to prepare and act accordingly. About 53% of the respondents had received information regarding rainfall patterns though there was not a significant difference among those adopting and not adopting STMVs.

2 Results and Discussions

2.1 Drought-tolerant maize Diffusion and Adoption: a descriptive analysis

We use the concept "diffusion" to imply awareness or knowledge of theSTMVsby the farmers. In the adoption literature, however, the terms "diffusion" and "adoption" are mostly used interchangeably (Rogers, 1976; Sunding& Zilberman, 2001). Feder *et al*., (1985) describes technology adoption as a multistage process the decision-maker undergoes from the time they get exposed to the technology through to the time they decide to start using theSTMVs.Central to the adoption decisions is the role of information about the technology. A lesser discussed issue in adoption literature is the role of the physical seed availability and accessibility at affordable prices and how they affect adoption. As depicted in Fig.3, the adoption process starts with the potential adopter becoming aware of the existence of STMVs. The second stage involves information acquisition, through which the potential adopter gets to know STMV attributes and builds perceptions (Adesina and Forson 1995).While this phase determines whether the producer has heard about the STMVs, it is also a learning phase during which the potential adopter gets to further understand the attributes of a technology. Consistent with this notion, Klotz *et al.* (1995) posit that a producer's optimal information level is the solution to an underlying utility-maximization problem characterized by an income-leisure trade-off and that conditional upon the producer being aware of a new technology, the decision of whether to adopt the new technology is made. Most adoption literature (Diagne and Demont, 2007; Simtowe et al., 2016; Kabunga*et al*., 2012) assumes that conditional on awareness, seed should be available and accessible, hence farmers are expected to immediately move in to the trial and experimentation stage. However, experimentation and trial only occur on two conditions: (1) that seed is physically available; thus, seedis produced by the seed supplier and locally available; and (2) that seed is affordable to the farmer: thus availed at prices commensurate with farmer's incomes. Thus, we include in between the third and fourth stages an assumption of seed availability and accessibility. The fourth stage then involves trial or experimentation by the potential adopter on a small portion of land before adoption. The individual then goes through the fifth stage, which involves the actual STMV adoption, which is again conditioned on the availability of and accessibility to the seed. After adoption, a farmer may decide to continue or discontinue using it depending on the experience and benefits. We follow the definition of Feder *et al.* (1985) of adoption as the decision to use an innovation in long-run equilibrium given full information about its potential. We thus confine the definition of adoption to the growing of one or more of the drought-tolerant maize varieties by a farmer.

Table 2 depicts results of STMV diffusion and adoption[1]. About 27 percent of the respondents expressed awareness of at least one STMV. Knowledge of STMVs was more prevalent in Manyara (34%), Arusha (30%) and Tabora (24%) regions. However, only 10% expressed ever growing one of the STMVs.

Table 2 Diffusion and adoption of STMVs

Characteristic	Total n=720	Morogoro n=100	Iringa n=48	Mbeya n=75	Tabora n=99	Manyara n=100	Simiyu n=50	Arusha n=116	Kilimanjaro n=132
Awareness of STMVs	26.81	45	29.2	8	24.2	34	30	30.2	15.2
Adoption of STMVs	9.86	25	10.4	4	11.1	13	4	8.6	1.5

The disparity between farmers who are aware of STMVs and those who have actually adopted them show that other factors besides awareness adoption. These include, but not limited to seed availability and affordability. There are significant differences in adoption rates for STMVs between the sample adoption rate and the adoption rate within the exposed sub-sample and the subsample with access to seed. The overall adoption rate among the sub-sample of exposed farmers was 37% compared to a lower adoption rate of 10% for the whole sample, while the adoption rates among those with access to seed was about 46%. However, the adoption rates among the sub samples that are exposed and those that have access to seed are likely to significantly over-estimate the population adoption rate due to the positive selection bias by which the population most likely to adopt gets exposed first and gets access to seed. Diagne (2006) points out that the positive selection bias arises from two sources. The first source is the farmer's self-selection into exposure. The second source of selection bias is the fact that researchers and extension workers target their technologies at farmers who are more likely to adopt. For this study, a third source of selection bias in the context of access to seed is that by which seed traders and distributors sell seed in

[1] A full description of the actual varieties adopted is presented in the annex

regions where they expect higher profits due to a combined effect of lower transaction costs, better prices, and higher volumes to be sold, making seed availability a non-random variable.

2.2 Determinants of exposure to STMV and of access to STMV seed

About 21% of the farmers reported that STMV seed was available to them, while 18% reported having access to seed at prices that they could afford. Based on this categorization, we estimate three probit regressions (Table 3) of factors that affect the propensity of exposure to STMVs (model 1), the propensity of seed availability in addition to awareness (Model 2) and the propensity of access to affordable seed in addition to awareness and seed availability (Model 3). The results across the three models show that several variables show statistically significant coefficients.

2.2.1 Determinants of exposure

For the exposure model (model 1, column 2), information sources: other farmers/relatives, NGO's, and stockists play a positive and significant role in creating awareness of STMV seeds. This underscores the importance of farmers' extension systems, both public and private, in the diffusion of information about new technologies. All income status variables and socio-economic returned insignificant coefficients, suggesting that income did not affect the farmer's awareness of STMVs since most information is usually disseminated at an insignificant cost through fellow farmers, government and NGO's.

2.2.2 Determinants of seed availability in addition to awareness

Model 2 (column 3) presents marginal effects of the probability of households reporting seed availability in addition to being aware of STMVs without considering the seed price. The results show that those households that own televisions had a higher likelihood of the seed being available to them. This could be attributed to the fact that some seed companies may run advertisements from time to time, mentioning the seed prices and the stockists selling the varieties. Other variables did not have a significant influence on seed availability, suggesting that seed availability is also influenced by other supply factors such as the structure, conduct and performance of seed producing and marketing companies that were not included in this analysis.

2.3 Determinants of seed affordability in addition to awareness and availability

Model 3 (column 4) presents results of the likelihood of having access to STMV seed at an affordable price in addition to being aware of STMV.

Table 3: Probit estimates of the determinants of exposure, access and affordability of STMV seed

Variable	Model 1 exposure	Model 2 (exposure-seed access)	Model 3 (exposure-seed access at affordable price)
Age	-0.027	-0.785	-0.182
Gender	0.119	0.682	0.411
Years of education	0.039	-0.014	0.035
Farm size	-0.043	0.239	0.141
Household size	-0.154	-0.935*	-0.534***
Distance to the market	0.086	0.035	0.128
Income status (Reference group: insufficient need borrowing)			
Allows to build savings	0.202	-0.881	-0.046
Allows to save a little	0.110	-0.381	-0.001
Information sources			
Farmer	0.482***	-0.621*	0.288*
Government	0.299	-0.217	0.185
NGOs	0.501*	-0.761	0.009
Radio	0.347	-0.633	0.060
Relatives	0.197	-0.289	0.048
Research Institutions	0.467	-0.776	-0.008
Stockists/agro dealers	0.461**	-0.745	0.283
Marketing group	-0.124	-1.119	-0.793*
Farmer Association	-0.272	-0.835	-0.649
Farmer research group	-0.055	-0.853	0.552
Women's' association	-0.162	1.667*	0.118
Religious groups	0.290	-0.482	0.038
Ownership of a radio	-0.076	0.041	-0.183
Ownership of a tv	0.419**	0.466	0.514**
Ownership of a mobile phone	0.202	-0.650	0.015
Morogoro	0.674*	0.784	0.935**
Arusha	-0.187	-0.384	-0.905
Mbeya	-0.983**	0.760	-0.482
Tabora	0.029	0.849	0.255
Manyara	0.090	0.457	0.376
Simiyu	-0.077	-0.805	-0.441
Kilimanjaro	-0.738*	-0.740	-0.87*
No. of observations	720	720	720
Log likelihood	-299.01	-66.9	-192.73
LR chi^2	93.53	51.11	87.44
Degrees of freedom	30	30	30
Pseudo R^2	0.14	0.28	0.17

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

The results in Table 3 show that contact with other farmers who have adopted STMV and ownership of televisions positively and significantly increases the probability of adopting STMV. This enables the potential adopter to practically see the benefits of STMV and thus influence their decision to adopt them. These findings underscore the need for intensified efforts to create awareness about the existence of STMVs among farmers the need for interventions that enhance the availability and affordability of STMV seed to farmers.

2.4 Predicted potential for scaling STMVs

The results of the predicted adoption rates with and without ATE correction for different STMV population awareness, seed availability and seed affordability, population selection biases and adoption gaps are presented in Table 4. The sample awareness of STMVs in the study area in Tanzania was estimated to be 26.8%, whereas the sample adoption was 10%. Diagne and Monte (2007) show why the observed sample adoption rates are expected to be the same as the ATE corrected joint treatment and adoption rates. Indeed, in the absence of universal diffusion and access to STMV seed among the maize farming population, the observed adoption rate estimates significantly understate the potential adoption rate (i.e. the adoption rate that would be obtained if the whole population were exposed to or have access to the STMVs seed). The predicted adoption rate for the full population after correcting heterogeneity in the awareness of STMV (ATE_w) was 39%. This is higher than the observed sample adoption rate because of the low levels of diffusion of STMVs among the farming community. This indicates that if the entire population of maize farmers was aware of STMVs, the effective demand for STMV seed could have increased from 10% to 39%, resulting in an adoption gap due to the lack of STMV exposure of 29%.

Correcting for heterogeneity in the joint awareness and physical seed availability, the predicted adoption rate for the full population (ATE_{ws}) was 46%. This means that if, in addition to being aware, all farmers had STMV seed physically availed to them, the effective demand of STMV seed would have been 46%.The corresponding estimate of the adoption gap of 34% resulting from non-availability of seed can therefore be interpreted as the seed access gap, which is the potential demand loss due to non-access to seed (Donstop et al., 2013), which also suggests thatthere is scope for scaling the cultivation of STMVs in Tanzania if seed companies can increase the supply of seed to the farming community after increasing the awareness.

The cost of seed can prevent potential adopters from adopting STMVs. After correcting for heterogeneity in joint awareness-seed availability-accessibility to affordable seed, the predicted

STMV adoption rate for the full population (ATE_{wsp}) is 52%. The corresponding estimate of the adoption gap resulting from the joint lack of awareness, seed access and seed at an affordable price is 43% and significant at 5% level. These adoption gap estimates imply that there is still potential for scaling STMVs adoption once awareness, and seed accessibility constraints are addressed. It should be emphasized that the estimated adoption gaps are solely due to the lack of awareness of the existence of STMVs, lack of seed and farmers not being able to afford the STMVs seed. However, the magnitude of the adoption gaps depends on the same factors that determine the probability of treatment participation and population adoption rates. Hence, by appropriately changing the values of these determinants through appropriate policy actions, the actual adoption through a simultaneous narrowing of the adoption gap and an increase in the population adoption rate can be attained (Diagne, 2010).

The results suggest that scaling STMVs in Tanzania will not only rely on the dissemination of information about STMVs, nor the increased supply of seed; but that it will also depend on the extent to which the set price of seed is commensurate with the purchasing power of farmers. In other words, awareness creation ought to be done simultaneously with seed supply. Moreover, the fact that making seed affordable could scale the cultivation of STMV to almost half of the farmers should be of interest to the government of Tanzania.

Table 4: Predicted STMV adoption rates

* denote statistical significance at 5% level

	Parameter with awareness unconstrained			Parameter with awareness-access unconstrained			Parameter with awareness-access- affordability unconstrained		
ATE-Corrected population estimates	Est	S.E	Z	Est	S.E	Z	Est	S.E	Z
Predicted adoption rate in full population (ATE)	0.385*	0.374	10.29	0.459*	0.039	11.82	0.523*	0.042	12.33
Predicted adoption rate in treated subpopulation (ATT)	0.368*	0.029	12.51	0.458*	0.033	13.86	0.528*	0.034	15.39
Predicted adoption rate in untreated sub-population (ATU)	0.392*	0.043	8.96	0.460*	0.043	10.66	0.523*	0.046	11.16
Joint treatment and adoption rate (JTA)	0.098*	0.007	12.51	0.098*	0.007	13.86	0.098*	0.006	15.39
Population adoption gap (GAP)	-0.286*	0.031	-8.96	-0.362*	0.034	-10.66	-0.425*	0.038	-11.16
Population selection bias(PSB)	-0.017	0.024	-0.68	-0.000	0.026	-0.03	0.004	0.029	0.14
Observed sample estimates									
Rate of treated (N_e/N)	0.268*	0.017	16.23	0.214*	0.015	13.99	0.187*	0.014	12.82
Adoption rate (N_a/N)	0.098*	0.011	8.87	0.098*	0.011	8.87	0.099*	0.011	8.87
Adoption rate among the treated subsample	0.368*	0.041	8.87	0.461*	0.052	8.87	0.529*	0.059	8.87

The results show that the estimated adoption rate within the awareness unconstrained subpopulation (ATT_w) of 37% was smaller than the adoption rate of 46% among the subpopulation with awareness-access-unconstrained(ATT_{ws}). As expressed by Donstop et al., (2013) the gap of 29% between the two adoption rates can be explained by the fact that the subpopulation of farmerswho were aware and had access to seed was included in the subpopulation of farmers who were aware of the variety. For the same reason, the estimated adoption rate within the awareness unconstrained subpopulation (ATT_w) and that among the subpopulation with awareness-access-unconstrained(ATT_{ws})are both smaller than the adoption rate with a subpopulation with awareness-access-affordability unconstrained (ATT_{wsp}) of 52%.The potential adoption rates among the subpopulations of farmers that were not exposed (ATU_w), that were not exposed and had no access to seed (ATU_{ws}) and that were not exposed , had no physical access to seed and at affordable prices(ATU_{wsp}) were 39%, 46%, and 52%, respectively.

3 Conclusions

We have examined the scalability of STMVs in Tanzania under three scenarios; (1) conditional on knowledge of STMV; (ii) conditional on (physical) seed availability in addition to awareness; and (iii) conditional seed affordability in addition to awareness and (physical) availability. We find that the STMV adoption in Tanzania could be scaled out to 39% of the farming population instead of the observed sample adoption rate of 10% if the whole population was exposed to them, suggesting that there is potential for scaling the cultivation of STMVs by 29% if its knowledge can be extended to the masses. Conditional on awareness and seed availability, the adoption rate could increase to 46%, and if in addition to awareness and seed availability, the seed were also made available at an affordable price, the adoption rate could increase to 52%. The findings suggest that unlocking the STMV adoption puzzle will partially depend on relaxing the information constraint and making seed widely accessible and at affordable prices to farmers.

Exposure to STMVs is largely influenced by the extent to which the household has access to information on new varieties through the extension support services, while seed accessibility is largely a function of supply by producing companies. The findings underscore the need for understanding the structural constraints in the commercialization of certified seed by seed companies and in their promotion to the farming community. There is need to understand the market concentration and integration of companies producing STMVs seed, their pricing and promotion strategies, constraints faced and how they can be addressed. Also, adoption can be increased by deploying both market and non-market-based approaches in scaling STMVs in Tanzania. Market-based approaches could support in-country partnerships that enhance seed supply by seed companies and linking farmers to finance institutions to access credit for seed and fertilizer, while non-market-based approaches could further extend and target the seed subsidy program.

The results further show that universal adoption of STMVs is unlikely even after addressing both information and seed access constraints, which suggest that there are other constraints to STMVadoption. Such constraints may include, but are not limited to, other (e.g. more humid) maize agro-ecologies, the existence of other competing (non-STMV) maize varieties (e.g. other hybrid maize varieties available on the market), as well as a variety attributes currently not present in the STMV portfolio. Some of these constraints can be addressed through further breeding efforts that embed preferred traits into the STMVs without comprising on their performance under drought conditions.

List of abbreviations

ATE	Average Treatment Effect
ATT	Average Treatment Effect on the Treated
ATU	Average Treatment Effect on the Untreated
STMVs	Sress tolerant Maize Varieties
NGO	Non-government Organizations
PSB	Population Selection Bias

Legends

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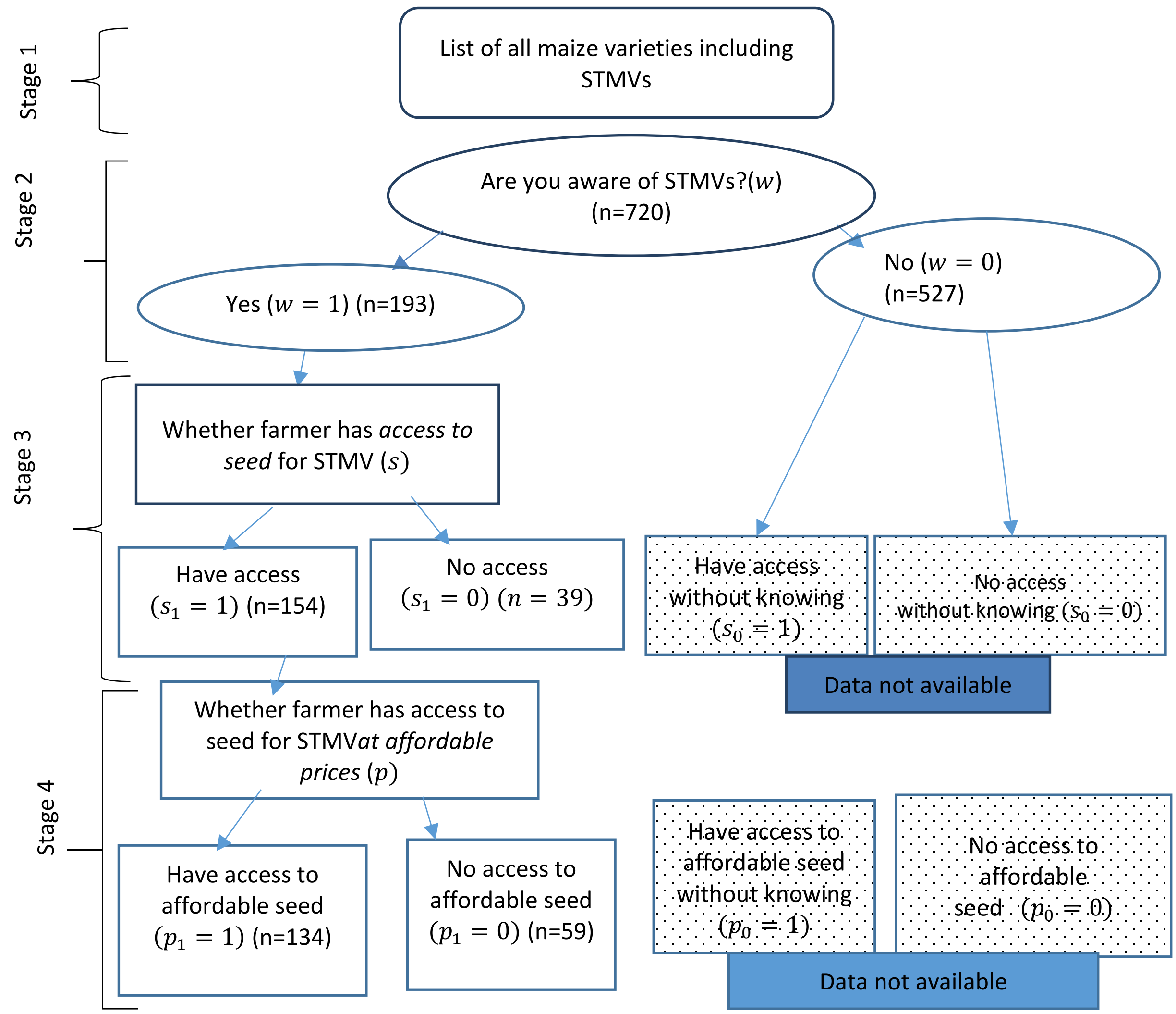

Figure 2: Flowchart linking awareness, seed access and affordability variables

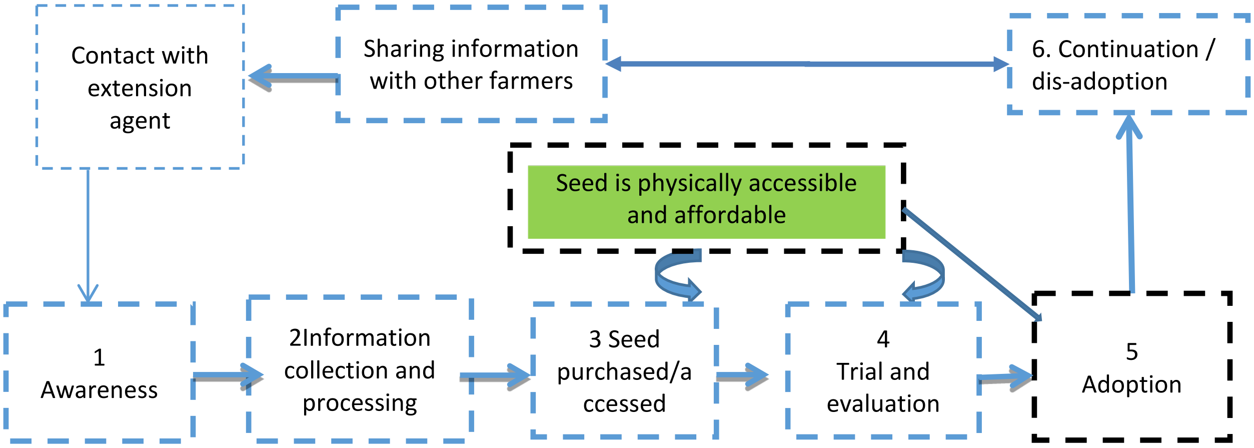

Figure 3: Stages of the adoption process for improved seeds (Source: Authors)