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Adoption of New Sorghum Varieties in Mali Through a Participatory Approach

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Abstract: Although it is commonly accepted that farmers' participation in the process of technology development can improve adoption rates, few studies have tested this relationship. We tested the role of farmers' participation in the decision to adopt new sorghum varieties in the Sudan Savanna of Mali. We applied a conditional mixed-process method to data collected from 496 households in 58 villages the national agricultural research program (Institut d'Economie Rurale) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) worked through farmer organizations to test varieties in farmer-managed trials and implement seed production activities. We found that the intensity of participation positively affects adoption rates on household plots. Intensity of participation was measured as the ratio of participants in the household to the total number of participants in the village. Several plot manager and household characteristics influence adoption, including education and proximity of the plot manager with head of household, household assets, and labor availability. This study draws attention to the importance of farmers' participation as a sustainable practice that can stimulate the adoption of new technology and, in doing so, enhance food security. Future research should explore the intrahousehold dynamics of farm input adoption, and the role of different forms of participation in the innovation process.

Keywords: sorghum; innovation adoption; participatory approach; sustainable practice; Mali

1. Introduction

Adoption is the raison d'être of any agricultural innovation [1–4]. No matter how important innovation is, if new varieties are not diffused and adopted, the varietal innovation process is considered inefficient [5]. In this study, we consider varietal innovation as the development of a new variety or the improvement of an existing variety, in order to meet farmers' preferences. We use varietal innovation and varietal improvement interchangeably. In light of demographic growth, rapid urbanization and climate change in the Sahel region, varietal innovation is crucial to increase agricultural productivity and in turn, food security and incomes of small farmers [6,7]. The lack of attention to the expectations of farmers explains largely the weak adoption rate of varietal innovations [8]. Although Mali has invested for decades in research concerning the varietal improvement of sorghum, the use of new varieties remain relatively limited. Sorghum is the most grown and consumed cereal in the world, just after maize, rice, wheat, and barley. In Mali, it is the first crop consumed by rural populations [9]. It is grown in subsistence farming. The share of sorghum traded worldwide is still weak, representing 3% of total marketed grain [10]. Current estimates range from 13% to 33% depending on the estimation method used [6,11–13].

For several decades, both practitioners and academic researchers have highlighted the critical role that farmers have, or should have, in the agricultural innovation process. A more participatory approach should be preferred to traditional top-down processes [14–17]. For example, Witcombe et al. [18] argue that farmers' participation in the innovation activities better integrate their preferences. In Mali, participatory plant breeding (PPB) is the main approach followed by the national agricultural research and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to improve sorghum. This varietal innovation process takes into account farmers' preferences, involves farmers in collaborative testing, and promotes farmer-managed new variety diffusion [7,11].

By sustainable practice we refer to farming activities that include the social, economic and environmental dimensions [19]. We consider farmers' participation in the varietal improvement of sorghum in Mali as a sustainable practice insofar as it [5,7,9,20,21]: (1) Involves both men and women, taking into account their needs and preferences (social or inclusive dimension); (2) creates opportunities for seed production and commercialization by farmer organizations and their members (economic dimension); and (3), integrates the local materials and conditions of farmers (environmental dimension). The environmental aspect of this innovation process is that much of the improved germplasm in Mali has also derived from the local Guinea race of sorghum rather than imported, highly-bred germplasm. The Guinea race of sorghum possesses "a suite of traits" that are crucial for adaptation across the Sudan Savanna zone of West Africa [22–24]. These include photoperiod sensitivity that enables the crop to better match the length of the growing season when rainfall is highly variable and uncertain. The Guinea-race of sorghum is planted across a broad geographic range and is composed of numerous, polymorphic farmers varieties; some scientific studies have indicated that it comprises more genetic diversity than other races (see [25]). Adaptation and genetic diversity enabled farmers' varieties to survive the great Sahelian droughts of the late 1970s–1980s. The plant of the Guinea-race is characterized by open glumes and lax panicles that reduce grain damage from insects and molds, and thus the need for insecticides. Further, the improved varieties studied here were tested by farmers themselves under their own low-input conditions, with and without fertilizer, across a range of growing environments.

In this study, we contribute to the literature on participatory and innovation research by testing whether the participation intensity of households in sorghum improvement activities influences adoption of new varieties. We augment the literature by analyzing the relationship between participation and adoption relationship from the perspective of agricultural sustainability. We also propose an original way to measure participation through its intensity. We define "participation intensity" as the number of the household members who participated in test and production activities for new sorghum seed varieties compared to the total number of participants in the village. We also control for other factors that can influence the adoption decisions such as characteristics linked to the plot, plot manager and household. For this purpose, we exploit cross-sectional data collected in 2014/2015 from households in the Sudan Savanna of Mali. We apply a conditional mixed process (CMP) model to test the effect of participation intensity on adoption, while controlling for potential endogeneity bias.

The paper is structured as follows. Section 2 presents a literature review concerning determinants of agricultural innovation adoption, while Section 3 gives the main elements of the research methodology. Section 4 is dedicated to the results and their discussion. Finally, the last section concludes the study and proposes some political and managerial implications, as well as some avenues for future research.

2. Literature Review

2.1. Traditional Determinants of Adoption

Countless studies have analyzed the determinants of innovation adoption in the agricultural sector, in particular since the rise of the green revolution in developing countries (see [3,4]). Concerning the adoption of new varieties, perhaps the most cited factors have been risk and uncertainty, farmer learning through experience or observation (social learning), as well as plot (land) and household characteristics [1,3,4,26–28]. Plot characteristics, including soil quality, while recognized, have been more difficult to measure and incorporate until more recent literature.

In their survey concerning the adoption of new sorghum and millet varieties in Central and West Africa, Camara et al. [29] identified two categories of factors affecting adoption: (1) factors linked to the variety itself (e.g., higher yields or traits such as insect, disease or drought resistant), and (2) factors associated with the objectives of the farmer (e.g., conservation or culinary quality). In Mali, Sanogo and Teme [30] showed the influence of some trait preferences of farmers, while Ndjeunga et al. [31] identified the importance of human capital level in the national agricultural research system. Smale et al. [12] found that the status of the plot manager (e.g., gender and age) influenced the use of new varieties on sorghum plots. Other studies identified the reasons why Malian farmers do not adopt or abandon new varieties of seeds, such as lack of information concerning the existence and the interest of the new varieties, the limited access to the seeds, issues linked to biophysical factors (i.e., damage due to birds or infertility of soils), and the absence of commercial markets [29,32].

In agricultural settings, innovation introduction comes through information sources, communication channels and social learning. Several authors brought details concerning the way those determinants influence adoption [33–36]. Farmers working in the same environment often face similar needs, which favors a social learning process to support adoption in which farmers learn from each other [33,35]. D'Souza and Mishra [37] state that generally, farmers in developing countries obtain their information from family, friends, or neighborhood networks. Farmers' interactions in their community or tribe can be more important sources of information and more efficient than extension services, as observed for the case of manioc adoption in Nigeria [38]. Still, in addition to numerous studies undertaken during the green revolution, recent research recognizes the crucial role of extension services in the adoption of new technologies [39,40]. Concerning gender differentiation, Thériault et al. [41] showed that technology adoption decisions are influenced differently following the gender of plot managers, as male managers have greater access to extension services, in comparison with female managers. In banana farming systems of Uganda, Katungi et al. [42] found that men had more social capital then women, enabling them greater access to innovation information and explaining higher adoption rates of agricultural inputs among men.

2.2. Participation, Sustainability, and Varietal Adoption

Previous research has generally assumed that farmers' participation allows the resolution of weak adoption rates, by enriching and accelerating information collection by farmers [14,43] while benefiting from their selection and evaluation expertise, as well as from their knowledge of local conditions [44,45]. The participatory approach also allows researchers to better describe and identify preference traits of farmers, which are often diverse and complex while relevant for technology adoption decision-making [46,47]. Trait preferences are not only linked to biophysical factors, but also to socio-economical, cultural, and individual factors, and these can evolve [27]. This requires giving famers an active role, in order to favor a better understanding of those traits during varietal improvement activities [48]. Several studies have shown farmers' participation in varietal improvement activities as a determinant of adoption in sub-Saharan Africa. These include studies on sorghum varieties in Burkina Faso [49], the NERICA rice variety in Ivory Coast [50], sweet potato varieties in Uganda [51], maize varieties in Ethiopia [8] and Nigeria [52], as well as millet varieties in Nigeria [43].

Addressing challenges, such as food security, livelihood development, and climate change, requires innovation process that is more sustainable [53,54]. Farmers' participation in innovation processes is one route that can contribute to achieving this goal. Sustainability in agriculture or sustainable agriculture refers to farming activities can include environmental, social and economic aspects [19]. A few studies [15,55,56] drew a link between farmers' participation in varietal innovation and sustainability. According to those authors, a participatory approach goes hand in hand with sustainability goals as it can: (1) Encourage social interactions and social equity (social dimension); (2) reinforce farmers' and farmers' organizations autonomy (economic dimension); and (3) facilitate local adaptation of the developed varieties and maintain or increase varietal diversity (environmental dimension). From a social or inclusive perspective, it is recognized that when men and women farmers are involved in the varietal improvement process, their preferences regarding specific traits are better integrated, which makes the process more successful [57]. Some authors have insisted on inclusiveness, which gives a voice to farmers, including the most marginalized ones (e.g., poorer, women or youth) [54,58,59]. Therefore, we consider farmers' participation in varietal innovation process as a sustainable practice. By contrast, several previous studies have considered innovation outcomes, such as adoption of improved crop varieties, as a sustainable practice [19,60].

Even if varietal improvement programs relying on active collaboration with farmers have been part of the strategy of the national agricultural research since the 2000s in Mali, to our knowledge, no empirical research has tested the importance of participation in the adoption process. Additionally, studies on the relationship between participation and adoption relationship from the sustainability perspective are few. To fill this gap, we examine the relationship between the participation intensity of household in sorghum varietal improvement activities, considered as sustainable practice, and the adoption of those new varieties.

3. Methods

3.1. Data Sources

Our sample comes from a dataset collected by a study team of the Institut d'Economie Rurale (IER) and Michigan State University under the GISAIA project (*Guiding Investments in Sustainable Agricultural Intensification in Africa*). A census was conducted in early 2014 among all households (2430) producing sorghum in the 58 villages where farmer-managed variety tests and seed production activities had been implemented by IER and ICRISAT through collaborating farmers' organizations.

Sorghum is cultivated across Mali's agroecologies, from the border with Ivory Coast (1400 mm annual rainfall) to the border of the Sahara desert, where rainfall is too low to support crop cultivation. Adaptation requirements for new sorghum varieties are specific to each ecology. The study villages are located within 800–1000 mm isohyets of the Sudan Savanna. The villages are located in the Cercles of Kati, Dioila, and Koutiala. Kati has a less intensified, sorghum–maize–millet system and a high population density, with farmers producing some higher value crops such as groundnuts and vegetables. Farming systems in Dioila and Koutiala are more intensified, with a stronger history of cotton production and vertically-integrated institutional structures.

We focus on the households whose members answered the census question concerning the participation of their members in testing or production activities related to new sorghum varieties. We combine responses to this question with detailed data on plots, plots managers, households, and market from a sample survey conducted with a subsample of 628 households that were randomly chosen from the census list. Sample survey data were collected between August 2014 and June 2015.

The final sample includes 712 sorghum plots belonging to 496 households. By household we mean a family farm or *Entreprise Agricole Familiale* (EAF). EAF is defined by the 2006 Malian Agricultural Orientation Law as a production unit made of one or more members linked by family relationships and jointly exploiting their productive factors in order to generate resources, including income, under the direction of one of the members who is designated as the EAF head. Given that cultural norms in the farming systems Mali are generally patriarchal and patrilineal, most EAF heads in Mali are senior male household members, but some female heads exist.

In the Sudanese savanna of Mali, the EAF is based on a complex and dynamic production system. It is composed of members with vertical (sons and their family) as well as horizontal (brothers and their family, and spouses) family relationships, and led by a patriarch, the head of the enlarged family. This patriarch can delegate the management of the family production to a family member, generally a son or a brother, who works with the other active members on collective plots in order to meet the food needs of the family. As a matter of fact, the EAF is characterized by collective and individual plots.

Individual plots are allocated by the patriarch and generally cultivated by women in order to meet their own needs and the ones of their children (i.e., scholarships, food). However, in some instances, individual production can be used to meet the food needs of the whole family. Several crops, including sorghum, millet, and maize, are cultivated within an EAF.

3.2. Econometric Strategy

We start with the premise that the adoption of a new sorghum variety (Y) on plot i from household j is function of:

$$Y_{ij} = \beta X_{ij} + \gamma P_{ij} + \varepsilon_{ij}. \quad (1)$$

where, X_{ij} is a vector of factors influencing technology adoption, such as plot, plot manager, and household characteristics, P_{ij} represents the participation intensity of the household, β and γ are the parameter estimates, and ε_{ij} is the error term. Note that only one variety is planted per plot.

Taking into account the possible endogeneity bias between adoption and participation intensity, we assume the following specification:

$$P_{ij} = \alpha X_{ij} + \delta Z_{ij} + \mu_{ij}. \quad (2)$$

where, Z_{ij} is a vector of instrumental variables that allow controlling for the potential endogeneity bias. Parameters α and δ are respectively associated with variables X_{ij} and Z_{ij} in Equation (2). In the presence of endogeneity, the error terms of the two equations are correlated ($Cov\left[\varepsilon_{ij}, \mu_{ij}\right] \neq 0$) and the coefficient estimates are biased.

To be valid, instrumental variables must fulfill two main conditions. First, they must be significantly correlated with the endogenous variable. Second, they should not be directly linked to the dependent variable except through the endogenous variable ($Cov\left[Z_{ij},\ \varepsilon_{ij}\right] = 0$) [61,62]. We choose the number of women in the household who participate in sorghum improvement activities and access to credit in the village as instrumental variables. Those variables are directly linked to participation intensity of the household in sorghum varietal improvement activities but have little influence over the adoption decision of new sorghum varieties. The choice of instruments and their definitions are detailed in the following section.

Given the recursive nature of those equations, in which the depending variable (Y_{ij}) is discrete and the independent variable of interest (P_{ij}) is endogenous and continuous, we opt for the conditional mixed process (CMP) estimation method. Equation (2) is estimated in the first step, followed by Equation (1) in the second step [63]. CMP method is the most well suited to the estimation of recursive equations if the dependent variable is binary and the explanatory interest variable is endogenous and continuous [63]. A probit estimation method with instrumental variables might also have been applied. However, with a discrete dependent variable and an endogenous continuous independent variable, CMP is the most consistent estimator [64]. Models are estimated in STATA 12.

3.3. Variables of the Model

The discrete dependent variable, adoption, is defined as the use of a new (hybrid or improved) sorghum variety on a plot managed by a household member. The set of explanatory variables has been selected according to the adoption literature, as discussed in Section 2.

3.3.1. Participation Intensity

The main variable of interest is participation, which is measured as the ratio of household members who participated in testing and seed production activities of new sorghum varieties to the total number of village participants. It has been shown that, when farmers lead varietal tests in their fields, their learning and knowledge improve and their uncertainty vis-a-vis the new varieties is reduced [65]. Farmers' testing during a varietal improvement process can explain adoption [66].

In Mali, the participatory approach can allow farmers and farmers' organizations to benefit from the sorghum varietal improvement process [67]. Previous studies have underscored the importance of extension services to learn about technologies. In our region of study, extension services are limited and mostly provided non-governmental organizations (NGOs). We hypothesize that household members who participate actively in varietal improvement activities are significantly more likely to adopt new varieties on their plot.

3.3.2. Plot Manager and Household Characteristics

The education level of famers is assumed to be positively correlated with adoption of innovation. Educated farmers are more likely in a better position to process intensive information and learn more rapidly [68]. They are more likely to be proactive in seeking solutions to their problems [69]. In Mali, previous studies (e.g., [70,71]) found that the relationship of the plot managers who are members of the household to the head of the household affects the adoption of a new technology. Here, we consider that being the spouse or son of the head of household is likely to affect adoption. Labor needs on the farm also influence adoption of technological innovations. Introduction of new technology can increase the need for labor at the farm [69]. In our study, labor supply is measured as the number of adult persons in the household per hectare of cultivated field. We also take into account the resource level of the household (assets), which indicates the capacity to acquire agricultural inputs.

3.3.3. Plot Characteristics

In order to control for biophysical characteristics linked to plots, we include the homestead location in relationship to the sorghum plot. Distant plots can discourage farmers to adopt agricultural innovations [72].

3.3.4. Market Characteristics

In the adoption literature, farmers' access to market is an important determinant [73]. We measure market access by the existence of a weekly market in the village. Although sorghum seeds are not much traded, weekly village markets can be a source of information and a place to engage in social networks, which in turn can influence attitudes toward new varieties [74].

3.3.5. Instrumental Variables

We employ the number of women participating in varietal improvement activities per household and access to credit in the village as instrumental variables. They both influence directly the intensity of participation but only affect the adoption decision indirectly.

Many studies document the important role that gender differentiation plays in the adoption of agricultural innovations. In the Sudan Savanna of Mali, better access to and higher rates of technology adoption by women have benefited the whole family, even in non-female headed households [75]. Culturally, in this region, women have a very active and vital role in rural work, including in seed testing and production activities. Yet, they do not have a say in the decision concerning adoption [76]. This led us to consider that the number of women in the farm who participated in the sorghum improvement activities does not directly affect the adoption decision but does affect the participation rate of the farm household.

It is largely recognized in the literature that limited access to credit affects the use of agricultural inputs [77]. According to Konare [78], the lack of credit to Malian farmers is one of the main challenges in the modernization and diversification of agricultural activities. In Mali, most (non-cotton) smallholder farmers do not have access to credit. Back in 1999, more than 80% of the agricultural loans were for cotton farmers [78]. Nowadays, microfinance institutions and decentralized financial services aim to provide more flexible solutions to the financial needs of individuals, such as smallholder farmers, who are often excluded from the mainstream banking system [79]. Better access to those financial services has had a positive impact on technology adoption [80]. The level of access to credit varies across crops. As pointed out by Foltz [81], the poorest farmers are very often the ones producing sorghum and millet, which require fewer resources. In the absence of governmental subsidies, these crops are often produced without fertilizers. Most of the new varieties developed by the national program with ICRISAT yield well relative to local varieties with or without fertilizer. Thus, the introduction of new sorghum varieties would allow farmers to produce more with limited resources, compared to input-demanding crops such as cotton and maize. Consequently, we consider that the adoption of a new sorghum variety on farms is not directly affected by access to credit, defined in our study as the village access to decentralized financial services. Moreover, we expect a negative effect of access to credit on participation intensity of farms in the sorghum varietal improvement activities, as those would probably be more available for cash crops or for high value-added agricultural activities.

Table 1 presents the definitions of the variables used in the econometric estimation, as well as their average (or percentage) values.

Table 1. Variables definitions and values.

Variable	Definition	Mean or %
Adoption	The currently used sorghum variety in the plot is either hybrid/improved (= 1), or local (= 0)	43.1%
Participation intensity	Participation part of the household in the village = number of participants from the household/total number of participants in the village	0.063
Plot manager characteristics		
Spouse	The plot manager is a spouse of the head of household (=1) or not (=0)	21.8%
Son	The plot manager is a son of the head of household (= 1) or not (= 0)	11.5%
Education	The plot manager received primary school education (=1) or not (=0)	15.9%
Household characteristics		
Labor supply	Number of active persons (12–55 year old) per hectare in the household	0.991
Farm assets	Value of the household assets (cattle excluded) by household member (in CFA francs)	14.0
Plot characteristics		
Location	Time to go from the homestead to the plot (in minutes)	20.5
Access to local market		
Market	There is a weekly market in the village (=1) or not (=0)	24.4%
Instrumental variables		
Financial services	The village has access to decentralized financial services (=1) or not (=0)	17.6%
Participating women	Number of women participants within the household	0.093

% for binary variables. n = 712.

4. Results and Discussion

4.1. Descriptive Analysis

Our sample included 712 sorghum plots belonging to 496 households. Plots are generally no larger than 2 hectares (1 hectare for female managers, who represent 26% of the sample). The majority of plots (73%) is collectively managed by men (99%). The remainder of plots is individually managed primarily by women (94%). Among the collective plots, 72% are managed by the head of household, 14%, by his sons and 14%, by his brothers. For individual plots, spouses of the head of household manage almost 79% of them and daughters-in-law, 14%. Sorghum plots managed by women are generally cultivated in association with other crops, such as groundnuts or cowpea.

New sorghum varieties are adopted on 43% of the plots (including 7% of recently released, hybrids), while 57% of the plots are allocated to local varieties. Not surprisingly, local varieties continue to be widely grown by Malian farmers. Managers with a primary school education level, who represent

16% of the sample, tend to dedicate more plots to new varieties (60% against 40% for managers not having reached this level). The households that participate or participated in improvement activities in their village represent 11% of the sample and 13% of the plots. For those households, more than half of the plots (54%) are used for new varieties (including 13% of hybrid ones). This is a higher number than among non-participating farms, for whom 41% of the plots were allocated to new varieties (including 6% of hybrid ones).

Concerning the analysis of gender, several studies found that women (even as head of family) have a lower likelihood to adopt agricultural technologies [26,41,82]. This is coherent with past general trends in Mali, where women have had less access to agricultural inputs than men [70]. Results from the descriptive analysis shown here suggest that there is no significant statistical difference in adoption behavior between men and women, when we do not control for any other factor potentially influencing adoption. There is no significant difference between women and men concerning the share of plots dedicated to new varieties (respectively, 49% and 41%). However, the higher adoption rate observed for women may reflect a clear willingness of agricultural research centers in Mali, in particular ICRISAT, to put women at the core of their technology diffusion strategy in recent years. Recognition of the growing role of women in sorghum production in Mali has encouraged this change. This finding could reveal that, when women have the same access as men to agricultural innovation, they would tend to use it more easily.

4.2. Regressions Results

Results obtained from CMP compared to a simple probit are presented in Table 2. They differ significantly. Results from the first step (Equation (2)) indicate that the null hypothesis for exogeneity of participation intensity is rejected (Durbin and Wu-Hausman tests). As expected, results show that instrumental variables—number of participating women in the farm and access to credit—are significantly related to the "participation intensity" (endogenous) variable. The relevance of the instrumental variables is tested using Stock and Yogo [83]. This allows us to reject the null hypothesis for weak instruments with a F-statistic of 40.91 exceeding the critical value of 19.93. We have failed to reject the null hypothesis of Sargan's test, indicating that the instrumental variables are valid. These diagnostics support our choice of instrumental variables.

Results from the second step (Equation (1)) demonstrate that household members who participate actively in varietal improvement activities are significantly more likely to adopt new varieties on their plots. This confirms our hypothesis. An increase in the household participation intensity by one point is correlated with an increase of 34.5% in the probability of adopting a new sorghum variety on a plot. In other words, there is more than 1 chance in 3 that any single household in a village adopts a new variety. The effect is large and meaningful.

This participation intensity could also describe the degree of openness of the household members to entrepreneurship and innovation in comparison to the rest of the village. One plausible explanation is the emergence of market opportunities, resulting from the structural reforms. Previously, seed supply was entirely managed by the state [9,84]. This change with the creation of the Malian Agriculture Orientation Law in 2006, which gives farmers' organizations the authority to produce and commercialize certified seeds. Our results are consistent with those presented in other studies dedicated to sorghum, where the characteristics perceived by farmers, training and knowledge acquired concerning varieties, and availability of seeds influence positively the adoption of new sorghum varieties [49,85].

Results from the econometric analysis indicate that the family relationship of the plot manager to the head of household—being a spouse or a son of the head of household—affects significantly the probability of adopting new varieties on the plot. Those results do not allow us to conclude that women have a greater likelihood than men of adopting new varieties. However, we can conclude that higher family status (as indicated by proximity to the head of household) increases the probability of adopting new sorghum varieties.

Table 2. Results of the econometric estimation.

	Simple Probit	Conditional Mixed Process (CMP)		
	Adoption	Adoption (Second Step)	Participation Intensity (First Step)	Adoption Marginal Effects (dy/dx)
Participation intensity	0.122 (0.257)	0.936 * (0.523)		0.345 * (0.188)
Spouse	0.242 ** (0.119)	0.216 * (0.120)	0.0155 (0.0148)	0.0796 * (0.0440)
Son	0.322 ** (0.155)	0.3006 * (0.156)	−0.00493 (0.0193)	0.111 * (0.0570)
Education	0.458 *** (0.132)	0.419 *** (0.134)	0.0125 (0.0164)	0.154 *** (0.0488)
Labor supply	0.220 *** (0.0736)	0.205 *** (0.0739)	0.00629 (0.00916)	0.0757 *** (0.0269)
Farm assets	0.177 *** (0.0519)	0.170 *** (0.0519)	0.00796 (0.00631)	0.0624 *** (0.0188)
Location	0.00245 (0.00257)	0.00229 (0.00256)	0.000337 (0.000322)	0.000843 (0.00942)
Market	0.00863 (0.114)	−0.0222 (0.115)	0.0321 ** (0.0141)	−0.00809 (0.0424)
Instrumental variables				
Financial services			−0.0291 * (0.0160)	
Participating women			0.194 *** (0.0117)	
Constant	−3.096 *** (0.742)	−2.996 *** (0.743)	−0.0873 (0.0898)	
LR chi2	45.82	307.76		
p-value	0.0000	0.0000		
ρ_1		−0.177 * (0.0995)		
ρ_2		−0.175 (0.965)		
Log likelihood	−463.00075	−156.25325		
Number obs.	711	711		
Tests	Coefficient	*p*-value		
Durbin	3.781	0.0519		
Wu-Hausman	3.533	0.0606		
Fisher (2, 701)	40.905	0.0000		
Sargan	0.688	0.407		

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Plot managers that received a primary school education are more likely to adopt new varieties in their plot. In addition to human capital, our results show that the labor supply and farm assets are both significantly and positively associated with the adoption of new varieties. Thus, farms that have more resources can better afford to take any risks or additional costs associated with new varieties. They can decide to cultivate new varieties even if they require more work, more fertilizer or to renew seeds regularly, in comparison with local varieties. Our results confirm the importance given by the literature to the role of resource endowments in the adoption of technologies [3,37,68].

The location of the plot it is not significantly related to the adoption of new varieties. Finally, our results show that the proximity of the household to a market or the presence of a weekly market in the village is also not a significant determinant of variety adoption. This can be explained by the fact that sorghum grain production is generally dedicated first to consumption on the farm, although it also serves to generate needed cash. Surplus grain production, if it exists, is rather sold directly to the World Food Program (WFP) through farmers' organizations. Concerning seed production, it is also put at the disposal of organizations to be sold to other farmers, to seed companies, or to NGOs. Thus the quantity of sorghum sold by individual farmers in village markets is small and occasional.

5. Conclusions

In this study, we analyzed the determinants of adoption of new sorghum varieties in Mali from a sustainability perspective. Specifically, we tested the hypothesis that the participation intensity of family farms in the varietal innovation process affected adoption. Employing a sample of 712 plots belonging to 496 households that were surveyed in 2014–2015, we applied a recursive estimation method (CMP). This approach took into account the continuous and endogenous nature of the independent interest variable (participation intensity), and the binary nature of the dependent variable (adoption).

We found that the participation intensity of households in varietal improvement activities conducted under their management on the fields of their own villages, which we consider to be a sustainable practice, was significantly and positively associated with the adoption of new sorghum varieties. Results showed that the education of the plot manager, the family relationship of the plot manager to the head of household (i.e., being a spouse or a son), the family labor supply and the assets of the household also had a significant and positive impact on the adoption probability. On the contrary, the location of the plot relative to the homestead and the presence of a weekly market in the village were not significant. Seed markets are only beginning to emerge in Mali, so this last finding does not surprise us—despite our recognition of the general role of village markets in not only trading of inputs and products, but information flows and networking.

Our results generally confirm what previous studies have identified as adoption determinants for agricultural innovations. However, this study is, to our knowledge, the only one that tested empirically the relationship between the participation intensity and adoption, despite an extensive literature on participation and adoption [14,16–18,45,86,87] and on the relationship between participation (or exposure) and adoption in West Africa [8,50,51].

Our results are aligned with the strategies of agricultural sustainability on smallholder family farms, led by several research institutions and governments in West Africa. As a matter of fact, this study draws attention to the importance of farmers' participation as a sustainable practice that can stimulate the adoption of new technologies and, in so doing, contribute to food security. It is recognized that adoption of new sorghum varieties in Mali, developed through a participatory approach, contributes to the diversity of the diets of poor families [12]. To facilitate a fairer access to agricultural inputs, we observe actions that deliberately target technologies that are accessible to women (as suggested by Doss and Morris [26]) through their participation in the innovation process.

An important consequence of our results for political decision-makers and agricultural innovation practitioners is related to the level of involvement of farmers (men and women) in the sorghum varietal innovation process. Farmer involvement should be encouraged, and the engagement of women and youth in the production of new sorghum seed varieties should be emphasized. It is essential to promote the processing of sorghum into market-attractive derivatives, in order to increase adoption rates and to increase the economic opportunity for women and youth to produce seeds.

We are aware of certain methodological limitations in this study. First, it would have been interesting to have access to data allowing to distinguish between various types of participation (in problem identification, in varietal tests, in seed production) in order to evaluate more precisely the adoption behavior following participation intensity in the different phases of the innovation process. It would also have been interesting to measure the participation intensity at the individual level, if the data would have permitted. In this study, we have examined adoption at a given time (2014 agricultural survey). It would be interesting, in future analyses, to examine adoption in the context of a longitudinal study. Future research could also consider the impact of factors as communication channels from farmers' organizations.

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References

1. Rogers, E. *Diffusion of Innovations*, 3rd ed.; The Free Press: New York, NY, USA, 1983.
2. Chi, T.T.N.; Yamada, R. Factors affecting farmers' adoption of technologies in farming system: A case study in Omon district, Can Tho province, Mekong Delta. *Omonrice* **2002**, *10*, 94–100.
3. Feder, G.; Just, R.E.; Zilberman, D. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Econ. Dev. Cult. Chang.* **1985**, *33*, 255–298. [CrossRef]
4. Feder, G.; Umali, D.L. The adoption of agricultural innovations: A review. *Technol. Forecast. Soc. Chang.* **1993**, *43*, 215–239. [CrossRef]
5. Bazile, D. State-farmer partnerships for seed diversity in Mali. *Gatekeeper Ser.* **2006**, *127*, 22.
6. Matlon, P.J. *Improving Productivity in Sorghum and Pearl Millet in Semi-Arid Africa*; Working Paper; Food Research Institute Studies, Stanford University: Stanford, CA, USA, 1990; pp. 1–43.
7. Rattunde, H.F.W.; Weltzien, E.; Diallo, B.; Diallo, A.G.; Sidibe, M.; Touré, A.O.; Rathore, A.; Das, R.R.; Leiser, W.L.; Touré, A. Yield of Photoperiod-sensitive Sorghum Hybrids Based on Guinea-race Germplasm under Farmers' Field Conditions in Mali. *Crop Sci.* **2013**, *53*, 2454–2461. [CrossRef]
8. Abakemal, D.; Hussein, S.; Derera, J.; Laing, M. Farmers' Perceptions of Maize Production Systems and Breeding Priorities, and Their Implications for the Adoption of New Varieties in Selected Areas of the Highland Agro-Ecology of Ethiopia. *J. Agric. Sci.* **2013**, *5*, 159–172. [CrossRef]
9. Coulibaly, H.; Bazile, D.; Sidibe, A. Modelling Seed System Networks in Mali to Improve Farmers Seed Supply. *Sustain. Agric. Res.* **2014**, *3*, 18–32. [CrossRef]
10. FAO; ICRISAT. L'économie Mondiale du Sorgho et du Mil: Faits, Tendances et Perspectives. Available online: http://www.fao.org/3/W1808F/W1808F00.htm (accessed on 4 October 2016).
11. Kergna, A.; Smale, M.; Assima, A.; Diallo, A.; Weltzien, E.; Rattunde, F. The potential economic impact of Guinea-race sorghum hybrids in Mali: A comparison of research and development paradigms. *Afr. J. Agric. Resour. Econ.* **2017**, *12*, 17–34.
12. Smale, M.; Assima, A.; Kergna, A.; Theriault, V.; Weltzien, E. Farm family effects of adopting improved and hybrid sorghum seed in the Sudan Savanna of West Africa. *Food Policy* **2018**, *74*, 162–171. [CrossRef]
13. Yapi, A.; Kergna, A.; Debrah, S.; Sidibe, A.; Sanogo, O. *Analysis of the Economic Impact of Sorghum and Millet Research in Mali*; International Crops Research Institute for the Semi-Arid Tropics: Andhra Pradesh, India, 2000; p. 60.
14. Ashby, J.A.; Lilja, N. Participatory Research: Does it Work? Evidence from Participatory Plant Breeding. In Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 26 September–1 October 2004.
15. Chiffoleau, Y.; Desclaux, D. Participatory plant breeding: The best way to breed for sustainable agriculture? *Int. J. Agric. Sustain.* **2006**, *4*, 119–130. [CrossRef]
16. Rhoades, R.; Booth, R. Farmer-Back-To-Farmer: A Model for Generating Acceptable Agricultural Technology. *Agric. Adm.* **1982**, *11*, 127–137. [CrossRef]
17. Weltzien, R.; Eva, S.; Margaret, E.; Meitzner, L.S.; Sperling, L. *Technical and Institutional Issues in Participatory Plant Breeding-from the Perspective of Formal Plant Breeding: A Global Analysis of Issues, Results, and Current Experience*; Participatory Research and Gender Analysis Program (PRGA): Cali, CO, USA, 2003; p. 208.
18. Witcombe, J.R.; Joshi, A.; Joshi, K.D.; Sthapit, B.R. Farmer Participatory Crop Improvement. I. Varietal Selection and Breeding Methods and Their Impact on Biodiversity. *Exp. Agric.* **1996**, *32*, 445–460. [CrossRef]
19. Zeweld, W.; Van Huylenbroeck, G.; Tesfay, G.; Speelman, S. Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *J. Environ. Manag.* **2017**, *187*, 71–81. [CrossRef] [PubMed]

20. Christinck, A.; Rattunde, F.; Mulinge, W.; Weltzien, E. *Identifying Options for the Development of Sustainable Seed Systems: Insights from Kenya and Mali*; ZEF Working Paper Series No. 165; University of Bonn: Bonn, Germany, 2018.
21. Weltzien, E.; Sidibe, M.; Diallo, B.; Traore, Y.; Coulibaly, M.; vom Brocke, K.; Jones, K.; Ehret, M.; Niccoleau, A.; Somé, H.; et al. *Seed Systems II: Sustaining Farmer Managed Seed Initiatives for Sorghum and Pearl Millet in Mali, Niger, and Burkina Faso*; Project Report; ICRISAT: Patancheru, India, 2010.
22. Barro-Kondombo, C.P.; Vom Brocke, K.; Chantereau, J.; Sagnard, F.; Zongo, J.-D. Variabilité phénotypique des sorghos locaux de deux régions du Burkina Faso: La Boucle du Mouhoun et le Centre-Ouest. *Cah. Agric.* **2008**, *17*, 107–113. [CrossRef]
23. Haussmann, B.I.G.; Fred Rattunde, H.; Weltzien-Rattunde, E.; Traoré, P.S.C.; vom Brocke, K.; Parzies, H.K. Breeding Strategies for Adaptation of Pearl Millet and Sorghum to Climate Variability and Change in West Africa. *J. Agron. Crop Sci.* **2012**, *198*, 327–339. [CrossRef]
24. Touré, A.; Traoré, K.; Bengaly, A.; Scheuring, J.; Rosenow, D.; Rooney, L. The potential of local cultivars in sorghum improvement in Mali. *Afr. Crop Sci. J.* **1998**, *6*, 1–7. [CrossRef]
25. Folkertsma, R.T.; Rattunde, H.F.W.; Chandra, S.; Raju, G.S.; Hash, C.T. The pattern of genetic diversity of Guinea-race *Sorghum bicolor* (L.) Moench landraces as revealed with SSR markers. *Theor. Appl. Genet.* **2005**, *111*, 399–409. [CrossRef]
26. Doss, C.R.; Morris, M.L. How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana. *Agric. Econ.* **2001**, *25*, 27–39. [CrossRef]
27. Nuijten, H.; Temudo, M.; Richards, P.; Okry, F.; Teeken, B.; Mokuwa, G.; Struik, P. Towards a new approach for understanding interactions of technology with environment and society in small-scale rice farming. In *Realizing Africa's Rice Promise*; CABI: Wallingford, UK, 2013; pp. 355–366.
28. Smale, M.; Just, R.; Leathers, H. Land allocation in HYV adoption models: An investigation of alternative explanations. *Am. J. Agric. Econ.* **1994**, *76*, 534–546. [CrossRef]
29. Camara, Y.; Bantilan, M.; Ndjeunga, J. Impacts of sorghum and millet research in West and Central Africa (WCA): A synthesis and lessons learnt. *J. SAT Agric. Res.* **2006**, *2*, 1–39.
30. Sanogo, O.; Teme, B. Impact Assessment of On-farm Trials Conducted at the Cinzana Research Station. In Proceedings of the Partners in Impact Assessment: Summary Proceedings of the ICRISAT/NARS Workshop on Methods and Joint Impact Targets in Western and Central Africa, Samanko, Mali, 11–12 May 1995.
31. Ndjeunga, J.; Mausch, K.; Simtowe, F. Assessing the Effectiveness of Agricultural R&D for Groundnut, Pearl Millet, Pigeonpea, and Sorghum in West and Central Africa and Eastern and Southern Africa. In *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*; Walker, T.S., Alwang, J., Eds.; CABI: Wallingford, UK, 2015.
32. Ndjeunga, J.; Bantilan, M.C.S. Uptake of Improved Technologies in the Semi-arid Tropics of West Africa: Why is Agricultural Transformation Lagging Behind? *eJADE* **2005**, *2*, 85–102.
33. Bandiera, O.; Rasul, I. Social Networks and Technology Adoption in Northern Mozambique. *Econ. J.* **2006**, *116*, 869–902. [CrossRef]
34. Besley, T.; Case, A. *Diffusion as a Learning Process: Evidence from HYV Cotton*; Working Paper No. 174; Research Program in Development Studies; Woodrow Wilson School, Princeton University: Princeton, NJ, USA, 1994.
35. Conley, T.G.; Udry, C.R. Learning about a New Technology: Pineapple in Ghana. *Am. Econ. Rev.* **2010**, *100*, 35–69. [CrossRef]
36. Munshi, K. Social learning in a heterogeneous population: Technology diffusion in the Indian Green Revolution. *J. Dev. Econ.* **2004**, *73*, 185–213. [CrossRef]
37. D'Souza, A.; Mishra, A.K. Adoption and Abandonment of Partial Conservation Technologies in Developing Economies: The Case of South Asia. *Land Use Policy* **2018**, *70*, 212–223. [CrossRef]
38. Alademerin, E.A. Rural Innovations and knowledge systems development and dissemination among cassava cooperative farmers in Southern Nigeria. In *Science, Technology and Innovation: For Sustainable Future in the Global South*; Muchie, M., Desta, A., Mengesha, M., Eds.; Africa World Press: Trenton, NJ, USA, 2016; pp. 27–47.
39. Arslan, A.; Belotti, F.; Lipper, L. Smallholder productivity and weather shocks: Adoption and impact of widely promoted agricultural practices in Tanzania. *Food Policy* **2017**, *69*, 68–81. [CrossRef]
40. Walisinghe, B.; Ratnasiri, S.; Rohde, N.; Guest, R. Does agricultural extension promote technology adoption in Sri Lanka. *Int. J. Soc. Econ.* **2017**, *44*, 2173–2186. [CrossRef]

41. Theriault, V.; Smale, M.; Haider, H. How Does Gender Affect Sustainable Intensification of Cereal Production in the West African Sahel? Evidence from Burkina Faso. *World Dev.* **2017**, *92*, 177–191. [CrossRef]
42. Katungi, E.; Edmeades, S.; Smale, M. Gender, social capital and information exchange in rural Uganda. *J. Int. Dev.* **2008**, *20*, 35–52. [CrossRef]
43. Angarawai, I.I.; Bukar, B.; Olabanji, O.G.; Iro, N.; Haussmann, B.G.; Weltzien, E.V.; Gwadi, K.W.; Gubio, T.; Yahaya, Y. Farmer participatory varietal selection in pearl millet: Experience across some states of Northern Nigeria. *Afr. J. Agric. Res.* **2016**, *11*, 1421–1425. [CrossRef]
44. Almekinders, C.J.M.; Thiele, G.; Danial, D.L. Can cultivars from participatory plant breeding improve seed provision to small-scale farmers? *Euphytica* **2007**, *153*, 363–372. [CrossRef]
45. Weltzien, E.; Kanouté, M.; Toure, A.; Rattunde, F.; Diallo, B.; Sissoko, I.; Sangare, A.; Siart, S. Sélection participative des variétés de sorgho à l'aide d'essais multilocaux dans deux zones cibles. *Cah. Agric.* **2008**, *17*, 134–139. [CrossRef]
46. Chiulele, R.; Mwangi, G.; Tongoona, P.; Ehlers, J.; Ndeve, A. Assessment of farmers' perceptions and preferences of cowpea in Mozambique. In Proceedings of the 10th African Crop Science Conference Proceedings, Maputo, Mozambique, 10–13 October 2011; pp. 311–318.
47. Haugerud, A.; Collinson, M.P. Plants, Genes and People: Improving the Relevance of Plant Breeding in Africa. *Exp. Agric.* **1990**, *26*, 341–362. [CrossRef]
48. Amane, M.; Dias, D.; Chirwa, R.; Rubyogo, J.; Tembo, F. Using innovative approaches in selecting and disseminating bean varieties in Mozambique: Lessons learnt. In Proceedings of the 10th African Crop Science Conference Proceedings, Maputo, Mozambique, 10–13 October 2011; pp. 283–286.
49. Adesina, A.A.; Baidu-Forson, J. Farmers' Perceptions and Adoption of New Agricultural Technology: Evidence from Analysis in Burkina Faso and Guinea, West Africa. *Agric. Econ.* **1995**, *13*, 1–9. [CrossRef]
50. Diagne, A. Diffusion and Adoption of Nerica Rice Varieties in Côte D'ivoire. *Dev. Econ.* **2006**, *44*, 208–231. [CrossRef]
51. Kiiza, B.; Kisembo, L.G.; Mwanga, R.O.M. Participatory plant breeding and selection impact on adoption of improved sweetpotato varieties in Uganda. *J. Agric. Sci. Technol.* **2012**, *A2*, 673–681.
52. Umar, S.; Musa, M.W.; Kamsang, L. Determinants of Adoption of Improved Maize Varieties among Resource-Poor Households in Kano and Katsina States, Nigeria. *J. Agric. Ext.* **2014**, *18*, 115–124. [CrossRef]
53. Röling, N. Pathways for impact: scientists' different perspectives on agricultural innovation. *Int. J. Agric. Sustain.* **2009**, *7*, 83–94. [CrossRef]
54. Shaw, A.; Kristjanson, P. A Catalyst toward Sustainability? Exploring Social Learning and Social Differentiation Approaches with the Agricultural Poor. *Sustainability* **2014**, *6*, 2685–2717. [CrossRef]
55. Ashby, J.A. The impact of participatory plant breeding. In *Plant Breeding and Farmer Participation*; Ceccarelli, S., Guimaraes, E.P., Weltzien, E., Eds.; FAO: Rome, Italy, 2009; pp. 649–671.
56. Soleri, D.; Cleveland, D.A. Breeding for quantitative variables. Part 1: Farmers' and scientists' knowledge and practice in variety choice and plant selection. In *Plant Breeding and Farmer Participation*; Ceccarelli, S., Guimaraes, E.P., Weltzien, E., Eds.; FAO: Rome, Italy, 2009; pp. 323–366.
57. vom Brocke, K.; Trouche, G.; Weltzien, E.; Barro-Kondombo, C.P.; Gozé, E.; Chantereau, J. Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria. *Field Crop. Res.* **2010**, *119*, 183–194. [CrossRef]
58. Ceccarelli, S.; Grando, S. Decentralized-participatory plant breeding: An example of demand driven research. *Euphytica* **2007**, *155*, 349–360. [CrossRef]
59. Paris, T.R.; Singh, A.; Cueno, A.D.; Singh, V.N. Assessing the Impact of Participatory Research in Rice Breeding on Women Farmers: A Case Study in Eastern Uttar Pradesh, India. *Exp. Agric.* **2008**, *44*, 97–112. [CrossRef]
60. Lee, D.R. Agricultural Sustainability and Technology Adoption: Issues and Policies for Developing Countries. *Am. J. Agric. Econ.* **2005**, *87*, 1325–1334. [CrossRef]
61. Angrist, J.D.; Imbens, G.W.; Rubin, D.B. Identification of Causal Effects Using Instrumental Variables. *J. Am. Stat. Assoc.* **1996**, *91*, 444–455. [CrossRef]
62. Wooldridge, J.M. *Econometric Analysis of Cross Section and Panel Data*; MIT Press: Cambridge, MA, USA, 2002; p. 752.
63. Roodman, D. Fitting Fully Observed Recursive Mixed-Process Models with CMP. *Stata J.* **2011**, *11*, 159–206. [CrossRef]

64. Chowdhury, M.; Amin, S.; Farah, T. *Access to Microcredit and Women's Entrepreneurship: Evidence from Bangladesh*; PEP Working Paper Series No. 13; Partnership Economic Policy: Nairobi, Kenya, 2016.
65. Leathers, H.D.; Smale, M. A Bayesian Approach to Explaining Sequential Adoption of Components of a Technological Package. *Am. J. Agric. Econ.* **1991**, *73*, 734–742. [CrossRef]
66. Ghadim, A.K.A.; Pannell, D.J.; Burton, M.P. Risk, uncertainty, and learning in adoption of a crop innovation. *Agric. Econ.* **2005**, *33*, 1–9. [CrossRef]
67. Sissoko, M. Vers une Agriculture Durable au Mali à Travers L'innovation. Ph.D. Thesis, Université de Namur, Namur, Belgique. 2019, in progress.
68. Foster, A.D.; Rosenzweig, M.R. *Microeconomics of Technology Adoption*; Working Paper No. 984; Economic Growth Center, Yale University: New Haven, CT, USA, 2010.
69. Mignouna, D.; Manyong, V.; Rusike, J.; Mutabazi, K.; Senkondo, E. Determinants of adopting imazapyr-resistant maize technologies and its impact on household income in Western Kenya. *AgBioforum* **2011**, *14*, 158–163.
70. De Groote, H.; Coulibaly, N.G. Gender and generation: An intra-household analysis on access to resources in southern Mali. *Afr. Crop Sci. J.* **1998**, *6*, 79–96. [CrossRef]
71. Smale, M.; Kergna, A.; Thériault, V.; Assima, A.; Keita, N. *Gender, Generation and Agricultural Intensification: A Case of Two Cereals in the Sudanian Savanna of Mali*; Working Paper No. 26; Feed the Future Innovation Lab for Food Security Policy, Michigan State University: East Lansing, MI, USA, 2016.
72. Aryal, J.P.; Jat, M.L.; Sapkota, T.B.; Khatri-Chhetri, A.; Kassie, M.; Rahut, D.B.; Maharjan, S. Adoption of multiple climate-smart agricultural practices in the Gangetic plains of Bihar, India. *Int. J. Clim. Chang. Strateg. Manag.* **2018**, *10*, 407–427. [CrossRef]
73. Hailu, B.; Abrha, B.; Weldegiorgis, K. Adoption and impact of agricultural technologies on farm income: Evidence from Southern Tigray, Northern Ethiopia. *Int. J. Food Agric. Econ.* **2014**, *2*, 91–106.
74. Smale, M.; Diakite, L.; Grum, M. When grain markets supply seed: Village markets for millet and sorghum in the Malian Sahel. In *Seed Trade in Rural Markets: Implications for Crop Diversity and Agricultural Development*; Lipper, L., Anderson, C.L., Dalton, T.J., Eds.; Earthscan: London, UK, 2010.
75. Van den Broek, E. *Gender in Development: The Case Study of ICRISAT's Development Initiatives for Female Sorghum Producers in Mali*; Wageningen University: Wageningen, The Netherlands, 2009.
76. ICRISAT. *Sustaining Farmer-Managed Seed Initiatives for Sorghum and Pearl Millet in Mali, Niger, and Burkina Faso*; Project Report; ICRISAT: Hyderabad, India, 2011.
77. Udry, C. The Economics of Agriculture in Africa: Notes toward a Research Program. *Afr. J. Agric. Resour. Econ.* **2010**, *5*, 284–299.
78. Konare, K. Challenges to Agricultural Financing in Mali. Master's Thesis, Michigan State University, East Lansing, MI, USA, 2001.
79. Nguyen, G.; Wampfler, B.; Benoit-Cattin, M.; Savadogo, K. Characteristics of household demand for financial services in highly uncertain economies: A review of evidence from Burkina Faso. In *The Triangle of Microfinance*; Zeller, M., Sharma, M., Eds.; The Johns Hopkins University Press: Baltimore, MD, USA, 2002; pp. 46–68.
80. Abate, G.T.; Rashid, S.; Borzaga, C.; Getnet, K. Rural Finance and Agricultural Technology Adoption in Ethiopia: Does the Institutional Design of Lending Organizations Matter? *World Dev.* **2016**, *84*, 235–253. [CrossRef]
81. Foltz, J.D. *Opportunities and Investment Strategies to Improve Food Security and Reduce Poverty in Mali through the Diffusion of Improved Agricultural Technologies*; Working Paper No. 97141; Department of Agricultural, Food, and Resource Economics, Michigan State University: East Lansing, MI, USA, 2010.
82. Smale, M.; Kaunda, Z.; Makina, H.; Mkandawire, M.; Msowoya, M.; Mwale, D.; Heisey, P. *Chimanga Cha Makolo, Hybrids and Composites: An Analysis of Farmers' Adoption of Maize Technology in Malawi, 1989–1991*; CIMMYT Economics Working Paper No. 91/04; CIMMYT: Mexico City, Mexico, 1991.
83. Stock, J.; Yogo, M. Testing for Weak Instruments in Linear IV Regression. In *Identification and Inference for Econometric Models*; Andrews, D.W.K., Ed.; Cambridge University Press: New York, NY, USA, 2005; pp. 80–108.
84. Haggblade, S.; Diallo, B.; Smale, M.; Diakité, L.; Témé, B. *Revue du Système Semencier au Mali*; Working Paper No. Mali-2015-3; Feed the Future Innovation Lab for Food Security, Michigan State University: East Lansing, MI, USA, 2015.

85. Elsheikh, S.E. Factors Affecting Adoption of Improved Varieties of Sorghum, Millet, Groundnut and Sesame in North Kordofan State. *Agric. Res. Technol. Open Access J.* **2018**, *13*. [CrossRef]
86. Mangione, D.; Senni, S.; Puccioni, M.; Grando, S.; Ceccarelli, S. The cost of participatory barley breeding. *Euphytica* **2006**, *150*, 289–306. [CrossRef]
87. Morris, M.; Bellon, M. Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. *Euphytica* **2004**, *136*, 21–35. [CrossRef]