ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 21 No. 4
May 2021
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Afr. J. Food Agric. Nutr. Dev. 2021; 21(4): 17931-17951 https://doi.org/10.18697/ajfand.99.20520

MODELING THE ADOPTION AND USE INTENSITY OF IMPROVED MAIZE SEEDS IN BENIN WEST-AFRICA: DOUBLE-HURDLE APPROACH

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ajfand SCHOLARLY, PEER REVIEWED
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Volume 21 No. 4
May 2021
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

ABSTRACT

Improved maize seeds are one of the main factors that can contribute to improving maize productivity. This paper was carried out with the aim of identifying the determinants of adoption and improved maize seeds' intensity use on households in all areas favourable to maize production in Benin using pooled data on 490 producers. Descriptive statistics such as mean, standard deviation, percentage, frequency distribution, t and chi-square tests were used to summarize the characteristics of the sampled producers. Cragg's Double Hurdle model was also used to categorize producers who adopted or who did not adopt improved maize seed and those who intensified the use of improved maize seed. The results showed that literacy, easy access to improved seed, specific training received on the use of improved varieties and gender, affected the adoption of improved maize seed while easy access to improved seed, maize yield, relationship with extension services, total household size, age squared, number of experience years in maize production, and distance from the producer to where the seed was purchased had a significant influence on the decision to intensify the use of improved maize seed. The fact that the variable easy access to improved seeds affected not only the adoption of improved seeds but also the intensification of their use, confirmed that access to improved seeds was an indisputable success factor for the intensification of improved seed use. Giving producers the capacity to obtain improved maize seed that was financially and geographically improved was a very important aspect to be considered by policy makers in the definition of agricultural policies. Predisposing factors for access (perception of varieties, attitudes towards the choice of new varieties, knowledge and management of these varieties) and capacity factors for access (income, availability of seeds in the environment, and seed prices) must be considered. The establishment of a wide seed distribution network through government and non-governmental organizations or private actors could, therefore, be important to reduce transaction costs and improve access to improved maize seed, and then increase the rate of adoption and continued use of improved seed.

Key words: improved seed, adoption, use intensity, Double-Hurdle Approach, Modeling

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INTRODUCTION

Improving agricultural productivity in Africa is a growing concern in view of population growth and increasing climate variability. Therefore, meeting the needs of the rapidly growing population, increasing agricultural productivity, and improving economic growth and rural welfare are becoming imperative [1]. The introduction of improved technologies and new agricultural management systems could be an important means of increasing agricultural productivity. Based on this observation, the green revolution that has emerged in Asia using new agricultural technologies, in this case high-yielding rice varieties is proving to be an inspiration for Africa in the neighboring grain sector of maize, which is looking forward to a green revolution.

Since the 2000s, early varieties that would double maize and rice production have been introduced in West Africa. This incentive has led Benin to take measures to increase agricultural productivity through the introduction of new technologies such as improved maize seeds. Maize, one of the flagship speculations of the Benin Agricultural Sector Strategic Plan (PSRSA), promotes and guarantees Benin's security and economic growth [2], as it is Benin’s leading food product far ahead of rice and sorghum [3]. In addition, maize is the subject of important internal and external transactions, which mainly justifies its importance for the national economy. The average area planted to maize from 2011 to 2015 was about 940,840 ha of which 2,339.8 ha, on average, was devoted to maize production of certified seed for an average production quantity of about 3,890,239.9 kg of improved maize seed in 2015. Between 2005 and 2014, production, mainly for human and animal consumption, increased from 3,888,639 tons to 6,287,216 tons [4]. It is imperative to intensify actions to meet the needs of producers and consumers at the national sub-regional level. This could help mitigate the potential risk of a tripling of maize imports by 2050, at an annual cost of US$30 billion, due to increased demand and declining productivity [4]. It is, therefore, essential that adequate measures be taken to anticipate this future problem, especially since Benin had a low overall growth rate in maize yield (2.9%) according to the National Human Development Report [5]. Moreover, maize yields are expected to decline in the future due to climate variability in the agricultural sector [6].

The use of improved seed adapted to the given agro-ecological zones is one of the important measures to increase maize productivity if farmers adopted and continued using them over a long period of time. To achieve this, it will be necessary to stimulate producers demand for improved maize seeds, considering aspects such as grain attributes and quality yield, which are essential to increase and improve maize production to meet human and animal needs [7]. This stimulation consists of facilitating access to improved seeds and their adoption by improving the system for making improved seeds available to producers. It is in this sense that the West African Agricultural Productivity Program (WAAPP) has initiated in Benin a strategy of packaging and labeling of improved maize seeds packages to stimulate their adoption.

Beyond the adoption of improved seeds, the intensity of use of these improved seeds is an aspect that is increasingly being addressed by studies using different types of models or approaches. A study conducted in Kenya on the determinants of adoption of

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improved maize seeds showed, with the Heckman two-stage model, that fertilizer use was strongly and positively associated with the intensity of improved maize seed use [8]. In their study on the adoption and continued use of improved maize seeds in Ethiopia, probit bivariate with the sample selection model approach was used [9]. Using the Tobit model, the quantity of seed used and the number of experience' years are among other variables influencing the intensity of the use of improved maize seeds [10]. In addition to the Heckman and Tobit models, the Double-Hurdle model is increasingly being used in adoption studies and technology intensity in the agricultural sector. Some authors have used it to specifically address the adoption and intensity of use of improved maize varieties [11, 12, 13, 14]. Others have used it to analyze instead the adoption and intensity of use of agricultural production techniques and other technologies that also used the Double Hurdle approach [15, 16, 17, 18]. Some of these studies used this approach to control for endogeneity biases. Then, pooled data (two-period surveys) were used to examine how the subsidy of commercial fertilizers affected their demands with the double-hurdle model in Malawi in order to correct endogeneity biases [19].

Theoretical framework

The use of agricultural technologies by producers is marked by their perception of them. So, it is a decision that leads some farmers to adopt these technologies and others not. This process of adopting agricultural innovations is a succession of steps in which farmers move from learning about innovation, persuasion, learning for its adoption and continued use or abandonment, and readopting it over time [20]. Once the decision to adopt the technology has been made, a farmer can then decide on the level of use of the technology, considering either the benefit the farmer derives from the use of the technology or the utility it provides. Thus, the decision to adopt or reject versus the decision to adopt with or without modification of a new technology is based on a comparison of expected utilities. In addition, maximizing the expected utility makes explicit the role of information in adoption process decisions [21]. The decision to adopt and intensify the use of improved maize seeds is assumed to be derived from the utility that these seeds provide to producers. Maximizing this utility is subject to resource constraints [17, 22]. The expected utility to intensify the utilization of improved maize seeds begin when producers are sure that adoption is the best choice and then be profitable. Adoption decisions were modeled using Random utility framework [11, 17] as:

$$Z_i^* = X_i'\gamma + \mu_i \text{ with } Z_i = 1 \text{ if } Z_i^* > 0 \text{ and } Z_i = 0 \text{ otherwise} \quad (1)$$

where Z_i^* (latent variable) is the difference between utility from adopting improved maize seed (U_{ik}) and the utility from not adopting improved maize seed (U_{i0}) [$Z^* = U_{ik} - U_{i0}$]. Producers will adopt improved maize seed if the utility gained after adopting improved maize seed is greater than the utility of not adopting. X_i'explanatory variables, γ a vector of parameters to be estimated, and μ_i the error term.

A household decides to continue using improved maize seeds each year only if the use of the technology can generate a net gain [23]. The adoption of a technology and its continued use are, therefore, the result of interdependent decisions. Several authors have addressed the issue of the level of adoption or intensity of adoption. One of the studies on this concept is who defined adoption intensity as the level of adoption of a given technology (the number of hectares planted with improved seeds or the amount of fertilizer applied per hectare) [24]. Thus, before intensifying the use of agricultural technology, it should be adopted by the producer. These two decisions may be made jointly or separately, and the factors affecting them may be different.

A Tobit model, often used in some cases to assess both adoption and intensity [25], is restrictive for modeling a two-stage process because it assumes that the decision to adopt improved seeds and the quantity of seed to purchase are determined by the same process, and therefore at the same time. Thus, the vector of coefficient estimates on the decision to adopt improved maize seeds and the quantity of such seeds to be purchased is assumed to be the same. In this study, we assumed that the adoption processes were made in two separate decisions [26] and were treated separately. In these cases, the decision to adopt a technology and the quantity of use of that technology were taken separately, the DH model was then appropriate [27]. Thus, the DH model, which is a parameterized Tobit model, appeared more flexible than the Tobit model, as it was possible that the factors influencing the decision to use improved seeds and the factors influencing the decision to purchase the quantity of improved seeds may be different [25]. Studies have been conducted giving preference to the DH model over the Tobit model. The DH model is based on a binary probability model that investigates whether a counting variable has a zero or positive value. The hurdle is overcome if the value is positive and the conditional distribution of positive values is governed by a truncated zero-count model. The DH model reflects a two-step decision-making process, with each party modeling a decision. The DH model is preferred to the Tobit model in this research because its combined equations by incorporating the characteristics of the farmer and his/her circumstances or environment. This research made two contributions. It revealed the different sets of factors that influenced adoption and the intensity of use of improved maize seeds decisions. It, therefore, made a thematic contribution to the choice of the estimation technique of the Tobit model and the DH model. In addition, the use of these models was the contribution of this research since few studies in Benin have used these models and more specifically improved seeds. By identifying the factors influencing the intensity of adoption of improved maize seed, the study also contributed to improving the effectiveness of agricultural research and extension by acting on these factors to define the technological packages to be provided to producers. This study, which analyzed factors influencing adoption and intensity of use of improved maize seed in Benin, was one of the few papers to use pooled data (baseline and endline) applied to the DH model to assess adoption and intensification decisions of improved maize seed use to correct for endogeneity bias. The study would help policy makers to choose the best policy options to improve the adoption rate of improved seeds and intensify their use. The maximum likelihood estimator (ML) of the DH model, due to the independent operation of the two parts of the model, can be obtained by maximizing the two likelihood terms, one for zeros and the other for positives.

Model Specification

Adoption and intensity of use decisions were modeled in a process of two separate decisions. In the first step, the farmers made a dichotomous choice to decide to adopt or not the improved maize seed. In the second step, farmers made a continuous choice to extend adoption or proportion of the area under the improved maize seed adopted. The factors that affect these two steps may differ. According to Ghimire and Huang [11], Bokusheva *et al.* [28], Langyintuo and Mungoma[29] and Aramyan *et al*. [30], some observations of the farmer's status adoption could be zero because all farmers cannot adopt at the same time. Then Cragg's DH model is appropriate and performs better than standard OLS (Ordinary Least Squares). Furthermore, in a process of adoption and intensification of use where decisions are supposed to be taken separately, it is recommended to use the DH approach [31].

The first step of DH uses a probit model (to determine the probability of adopting improved maize seed by farmers) with dependent variable which takes 0 when decision to use improved maize seed is no, and 1 when decision to use improved maize seed is yes. The second step of DH uses a truncated normal model (to determine the intensity of adoption) to show the explanatory factors of the intensity of adoption only for farmers who adopt [32].

The model specification is:

$$Z_{i1}^{*} = \alpha A_i' + \mu_i \text{ adoption} \tag{2}$$

$$Z_{i2}^{*} = \beta X_i' + \mu_i \text{ intensification of adoption} \tag{3}$$

$$Z_i = \beta X_i' + \mu_i \text{ if } \begin{cases} Z_{i1}^{*} > 0, \text{ and} \\ Z_{i2}^{*} > 0 \end{cases} \tag{4}$$

where Z_{i1}^{*} (latent variable) the probability of famers' decisions to adopt improved maize seed, Z_{i2}^{*} the intensification of adoption of improved maize seed which is the area of improved maize cultivated, Z_i a dependent variable (proportion of maize area planted to improved maize seed), A_i' and X_i' are vectors of variables explaining the adoption decision and intensification of adoption, α and β are the parameters to be estimated, and μ_i are the respective error terms.

Hypothesis testing of the DH model against the Tobit model has been done. The test is done by separately estimating three regression models (Tobit Model, Probit Model and Truncated Regression) and using the maximum likelihood ratio test. This test checks the hypothesis that the Tobit model is better than the DH model in our study by comparing the values of the maximized likelihood functions. The LR test was done to compare the log-likelihood values of the Tobit and DH models to determine if they were significantly different from each other [33]. The same explanatory variables were used in the two models and estimating the LR statistic using:

$$\lambda = -2\,(X_A - X_B - X_{AC}) \tag{5}$$

where X_A , X_B , and X_{AC} were the log-likelihood function values for the Tobit, probit and truncated models, respectively.

The statistical value LR (λ) is estimated under the null hypothesis that the Tobit model is superior to the DH model. If the LR test rejects the Tobit null hypothesis, then the DH model is preferred, and producers make decisions adopt improved maize seeds in a sequential two-step process. However, if the null hypothesis is not rejected, producers make their adoption decision simultaneously and the Tobit is a better representation of the data.

Variables included in the models
The table 1 summarizes the variables to be used in the models. These are the dependent variables of adoption of improved maize seeds and the proportion of the area devoted to production with improved maize seeds, and the explanatory variables of adopters and non-adopters of improved maize seeds. A review of several studies on adoption provides a long list of factors that may influence the adoption of agricultural technologies.

Moreover, in general, farmers' decisions to use improved agricultural technologies and the intensity of their use over a period of time are assumed to be influenced by a combined effect of several factors such as household characteristics and the farmer's socio-economic and physical environment. Based on past studies on the adoption of improved agricultural technologies, especially cereal crops, the following variables were hypothesized to influence the adoption and intensity of adoption of the improved maize seed.

Variables dependent on the Probit, Truncated and Tobit regression models: the Probit model dependent variable takes the dichotomous values depending on whether the producer's decision is to adopt (Y=1) or not to adopt (Y=0) improved maize seeds. Adopters are producers who use at least one of the thirteen varieties of improved maize seeds spread over the eight agro-ecological zones. Non-adopters are farmers who did not use any of these varieties during the farming campaigns. Furthermore, the Truncated and Tobit regression models used a continuous variable that is the proportion of the area per hectare allocated to improved maize seeds.

Data
Study area and survey design
This research was conducted nationally in 49 (seed-producing towns) of the 77 towns. It took into account all agro-ecological zones, especially regions with natural conditions favorable to maize production in Benin. Three types of surveys were conducted. A qualitative survey as an exploratory study, and two quantitative surveys (baseline and endline). The first phase was carried out in order to have a better knowledge of the Beninese seed system through interviews with key actors of the system. The second phase was followed by the phase of collecting quantitative baseline data in order to gather the necessary socio-economic and demographic characteristics of maize producers to ensure similarity between control and treatment groups. The third

https://doi.org/10.18697/ajfand.99.20520

and final phase consisted of setting up the experimental design. A qualitative survey was conducted in eight maize producing towns in Benin (Ouinhi, Zogbodomey, Covè, Kétou, Djougou, Matéri, Banikoara and Kalalé). The choices of these municipalities are guided by three main criteria: the production capacity of the improved maize seeds multipliers, the extension system implemented in the municipalities (Regional Agricultural Centers for Rural Development "CARDER", Advice for Agricultural Exploitation "CEF", Multistakeholder Platform "PMA") and the agro-ecological zone to which the municipality belongs. Focus groups were conducted in these villages with certified seed multipliers and consumption maize producers. The quantitative survey was mainly based on two important criteria of the exploratory phase: the towns (place of residence of the multipliers of improved maize seeds) and the extension system. At the town level, the survey villages were randomly selected from the villages where the multipliers of improved maize seeds reside. A categorization of the selected villages was made according to the knowledge of the introduction of the platforms (extension system). Other villages with similar characteristics (knowledge of the Territorial Agency for Agricultural Development "ATDA" (old name CARDER) intervention) to previous villages were randomly selected from the maize production areas.

Data

A complete census of producers was carried out in each town based on data from two surveys. This allowed to randomly select 490 producers for 2015 (first survey) and 456 producers for 2016 (second survey with about 7% of the farmers interviewed in 2015 dying or having left their village) who were considered for this study. The exploratory survey took place in December 2014 and the data collection for the first phase with the questionnaire was done from January to February, 2015, after considering corrections and modifications of the questionnaires. After the administration of the treatment, the last phase of the survey took place in February 2016 with the same questionnaire from the same producers. These data are used in this study to analyze the factors influencing the adoption and intensity of use of improved maize seed. Then, the two dependent variables in this study (adoption and intensification of use of improved maize seed) use pooled data (2015 and 2016). The explanatory (lagged) variables in this study were taken from the baseline survey (2015). Socio-economic and production data were collected.

Descriptive Statistics

The results in Table 2 showed that the overall average age of producers was 43 years. The amount of experience, years in maize production, which was an important element in the economic activities of the producer was 15.6 for adopters and 17.6 for non-adopters. This variable had a positive relationship with both groups (adopters and non-adopters) with a level of significance of 5%. The share of annual income from maize production in 10 percent of the annual income was a measure of the importance that the producer attached to maize speculation in his/her household or farm. This share out of 10 was about 5 for adopters and non-adopters, which confirmed the importance of that speculation for household food security. Household size was an important factor in family farms due to the scarcity of labor. This size is 5.06 for adopters and 4.80 for non-adopters. It is approximately equal to 5 for adopters and non-adopters and is not far from the reference value for household size in Benin, which is 5.6 contained in the document summarizing the analyses on households and housing conditions [3]. Maize yield, which is one of the criteria for assessing the performance of a farm, was 3736.2 kg / ha for adopters and 2677.1 kg / ha for non-adopters. These obtained yields confirm the importance of using improved seeds as one of the main factors to improve the productivity of a farm. Moreover, most producers surveyed were male (97%) (75% adopters and 21% non-adopters) compared to only 3% female.

RESULTS AND DISCUSSION

Model performance

For the comparison between the Tobit and DH models, this research conducted a comparison using statistical values such as the Akaike Information Criterion (AIC), Chi- Square Test values, and the LR Statistical Test. The result of the statistical LR rejected the null hypothesis that the Tobit model was appropriate and indicated while the DH model was preferred. The result of statistical tests of log likelihood is equal to 100.43. This result rejects the use of simultaneous decision (Tobit Model) and shows that there are two separate steps in the decision process for adopting improved maize seeds using the DH model [25]. The AIC value of the Tobit model (332.205) was higher not only than those of the truncated regression model (-12.204) and the Probit model (251.803), but also for the DH model (truncated and probit), which confirmed the LR test result.

Factors affecting the adoption of improved maize seeds

From the analysis in Table 3, it appeared that four of the fourteen variables of the first hurdle (probit model) had a positive and significant influence on the decision to adopt improved maize seeds. Among these variables, literacy, easy access to improved seeds and specific training received on the use of improved maize varieties were significant at ($p<0.01$), while the producer's gender variable was significant at ($p<0.05$).

The gender of the producer was positively and significantly ($p<0.01$) associated with the probability of the decision to adopt improved maize seeds. Thus, male-headed households were more likely to adopt improved maize seeds than female-headed households. This was believed to be because female-headed households had low agricultural incomes, less family labor, limited access to factors of production (especially land), and less access to information on improved maize seeds. The result was consistent with studies of Mangisoni *etal.*[34], Nambiro *et al.* [35] and Hailemariam [36].

The estimate for the *literacy* variable showed a positive coefficient, which reflected a positive influence on the probability of adoption of improved maize seeds. This result implied that farmers who had been literate were the most likely to adopt improved maize seeds, while maintaining the effect of other constant variables. This was supported by the statistically significant coefficient obtained at less than ($p<0.1$) of the probability level, which confirmed the logical link between the production of improved maize seeds and the literacy level of producers. In addition, receiving an education (formal or non-formal) increased the likelihood of having access to, and therefore, adopting, improved maize seeds. The result was conformed with the work that showed

https://doi.org/10.18697/ajfand.99.20520

ajfand SCHOLARLY, PEER REVIEWED AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT Volume 21 No. 4 May 2021 PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST ISSN 1684 5374

that literacy was a factor favoring the adoption of the shea mill in northern Benin because it helped to understand the importance of this technology [37].

As expected, *easy access to improved maize seeds*, which expressed the accessibility of producers to improved seeds, significantly and positively influenced the probability of the decision to adopt them. This implied that producers who had lifted the constraint on access to seeds adopted them more easily, which would increase the demand for maize seeds. This could be explained by the fact that producers were in contact with extension structures, that seeds were available to them in their immediate environments, and that they travelled a short distance to obtain its seeds.

The specific training variable received on the use of improved seeds was highly significant at the ($p<0.01$) threshold. The training received on the use of improved maize seeds positively influenced the probability of their adoption. This would be explained by the fact that the training received provided: the necessary information to producers to judge the usefulness of the technology and, therefore, its adoption or not.

Factors determining the intensity of use of improved maize seeds

Analysis of the results in Table 3 showed that seven of the fourteen variables in the second hurdle (truncated regression) influenced the intensity of use of improved maize seeds. Between the seven variables, four (easy access to improved seeds, maize yield, relationship with extension structures, and total household size) positively influenced the intensity of use of improved maize seeds, while three other (age squared, number of experience' years in maize production, and distance from the producer to the place of supply) had a negative influence.

Easy access to improved maize seed had a positive and significant influence on the decision to adopt and intensify the use of improved seeds. This access was reflected in the likelihood of adoption and intensification of use of improved maize seeds by smallholder farmers if these improved seeds were available in their immediate environment (example shop). This was due not only to the fact that very few stores or shops were expanding their seed distribution networks in outlying areas where the vast majority of small producers in developing countries reside, but also to the transaction costs (especially transport costs) that small producers were not prepared to pay addition to the price of improved seeds. Even if these networks were extended in these areas, the reliability of the source of origin of these seeds remained a problem. Moreover, if these networks existed in these peripheral areas, the barrier to access the seeds could remain given the low-income level of small producers. To achieve a high adoption rate followed by an intensification of seed use by small producers, the question of the availability of seeds from credible sources (seed distribution network in peripheral areas) accompanied by an income improvement policy for small producers would ensure the accessibility of improved seeds and, in turn, their adoption and intensification of use in order to increase yields. This option would work well if the state delegated more responsibilities to the private sector, which was already the case in the Benin seed policy document, but its operationalization was not yet really effective. Similar findings confirmed this result [11, 29, 38].

https://doi.org/10.18697/ajfand.99.20520

The expectation of producers that *yields* obtained with improved maize seeds should be better than yields obtained with local seeds influenced very highly ($p<0.01$) the intensity of use of these seeds. The fact that improved seed yields were higher than local seed yields was, therefore, a very important factor in increasing the use of certified improved seeds. Yield was, therefore, an essential attribute for the continued and increased use of improved seeds. Thus, improved maize seeds that had great potential for increased production had a high probability of continued use by producers. In addition, producers who were aware of the increase in their yield will seek to intensify the use of improved maize seeds to boost their production and ensure their household's food security. These results were similar with other work [39, 40].

The relationship with extension structures had a positive relationship with the intensity of use of improved maize seeds. These structures provided producers with a reliable source of information on improved seeds (newly developed varieties) but also on the entire technological package that would enable seeds to express their true potential. The fact of being in contact with these structures, therefore, gave a certain guarantee to producers of any changes that may have occurred on the technical itinerary over time that could release the full genetic potential of the seeds. This meant that producers in contact with extension agents were more sensitive to the increased use of improved seeds. As information was one of the important elements in the process of adopting and, therefore, intensifying the use of improved seeds after a technology came into contact with each other, the role of extension structures became essential and indispensable, as these structures strongly contributed to increasing adoption and intensification of use through the facilitation and promotion of technologies. Then, it was preferable to have to be informed by extension workers than by colleagues [41]in order to have the information unfiltered. This was consistent with other work [11, 42, 43].

The total size of the household, expressed as the number of people potentially able in the household to contribute to agricultural activities, had a significant and positive relationship with the intensity of use of improved maize seeds. This human capital, which constituted a potential labor force for the household, allowed households not only to avoid depending entirely on the wage labor force, which was becoming scarcer and more expensive from one year to the next, but also on agricultural mechanization, which was not yet a reality in all developing countries, in this case Benin. In addition, the use of improved seeds was more demanding in terms of maintenance than local varieties (example higher number of weeding). This work was consistent with Danso-Abbeam *et al.* [44] and Sodjinou *et al.* [45], who found that household size was positively and significantly related to the intensity of use of improved maize varieties in Ghana and the adoption of organic cotton in Benin, respectively. Similarly, some authors found in their study of agricultural conservation techniques in Zimbabwe that the availability of family labor had a positive impact on the adoption and intensity of use of these techniques [16].

Age square had a negative quadratic relationship with the intensity of use of improved maize seeds. This meant that the amount of seed that smallholders were willing to use in the intensification process increased with age until it reached an inflection point

ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 21 No. 4
May 2021
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

(inverted U shape) where it decreased sharply as the trend changed. This was in line with the work of Chiwaula *et al.* [15] and Zongo *et al*. [46].

The number of years of experience was expected to have a positive impact with the intensity of use of improved maize seeds. The opposite sign obtained in this study meant that as the years of experience increased, producers had less enthusiasm for increasing seed use. Older people would no longer find it useful to allocate more land for improved seeds. As the future of the latter is supposed to be behind them, they no longer had any motivation or would prefer to be satisfied with the use of improved seeds. Also, with age, some producers already allocated plots to their children, which made the availability of land to sow in the household scarce. Young people were, therefore, more valid and more favorable to the intensification of the use of improved maize seeds. The policy of intensified seed use should, therefore, be more focused on young people.

The distance from the producer to the place of purchase of improved maize seeds had a negative relationship with the intensification of use, which was in line with our expectations. Farmers with improved seed supply sites in their immediate environment were more likely to use those seeds than those living in areas far from the supply site. That meant that the greater the distance between the farmers' place of residence and the place of supply, the lower the probability of more intensive use of improved varieties. Hence, the further away from the place of supply, the less producers intensified the use of improved seeds. Thus, this distance generated not only additional costs for the acquisition of improved seeds, but also time. This was in line with other work [44].

CONCLUSION

This study was designed to identify factors affecting the probability of adoption of improved maize seeds and the intensity of use of those seeds in Benin. The use of the DH model showed that producers' decisions on adoption and intensity of use of improved maize seeds were made separately. The results of the DH econometric model showed that out of 14 explanatory variables used in regression analyses, literacy, easy access to improved seeds, specific training received on the use of improved varieties and gender affected adoption of improved maize seed when easy access to improved seeds, maize yield, relationship with extension structures, total household size, age squared, number of experience' years in maize production, and distance from the producer to the place of supply significantly influenced the decision of intensity of use of improved maize seeds. Based on these results, the following policy and research implications could be considered in future intervention strategies to further promote the use of improved maize seeds. The training received on the use of improved seeds and literacy, considered as a form of education, significantly influenced the adoption decision and the intensity of use of improved maize seeds. More emphasis should be placed on farmers' practical knowledge through improved extension approaches to stimulate the use of improved maize seeds in all Territorial Agricultural Development Agencies (ATDAs). The fact that easy access to improved maize seeds maintained a positive and significant relationship with the adoption and intensity of use of improved seeds suggested that smallholder producers should have continuous and permanent access to improved seeds. This continuous access could be a reality if the extension structures were revitalized (involvement of the public and private sector). As distance from the place of supply was crucial to intensify the use of improved seeds, it would be interesting to initiate improved seed production by strengthening the capacities of seed producers living in the producers' immediate environments or to stimulate seed production by other producers. This initiative, which would require additional efforts from the departments in charge of the certification process, would reduce or even eliminate transaction costs. By more effective targeting actions to facilitate access to improved seeds with a particular focus on young people, adoption and adoption intensity would increase. This action should be accompanied by the strengthening of decentralized institutions and, as far as possible, address seed market failures. Also, the value chain of improved maize seeds should be analyzed to identify the links on which to focus much more to facilitate farmers' access to improved seeds. Moreover, the organization of the actors including producers of improved seeds could facilitate accessibility. Improving the intensity of use of improved maize seeds must be done by addressing much more effectively the resource and information constraints of male-headed households. The other producer factors required by the use of improved seeds must be made available to producers in order to increase maize yield and improve farm income from maize. It is, therefore, urgent to pay attention to access to seeds and cropland taking these variables into account.

ACKNOWLEDGEMENTS
We acknowledge the financial and technical support from the Benin section of West African Agricultural Productivity Program (WAAPP), Cotonou, Benin, through the proposal on "Impact of seed supply strategies on the adoption of improved maize varieties in Benin."

ajfand SCHOLARLY, PEER REVIEWED AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT Volume 21 No. 4 May 2021 PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST ISSN 1684 5374

Table 1: Summary definition of variables and their expected signs

Variable definitions	Nature and unit of measurement of variables	Expected sign	
		Decision to adopt	Intensity of use
Dependent variables			
Adoption of improved maize seeds	Dummy (1=Yes ; 0= otherwise)		
Proportion of land area allocated to improved maize seeds	Continue		
Independent variables			
Age	Continue	+/-	+/-
Age squared	Continue	-	-
Gender	0 = Female, 1 = Male	+ / -	+ / -
Formal education	Dummy (1=Yes ; 0= otherwise)	+	+
Literacy	Dummy (1=Yes ; 0= otherwise)	+	+
Number of years of experience	Continue	+	+
Distance from the producer to the place of supply	1 = Small; 2 = medium; 3= long	-	-
Access to credit	Dummy (1=Yes ; 0= otherwise)	+	+
Share of annual farm income in 10	Continue	+	+
Agro-ecological zones	1= Extreme North Benin zone; 2= North Benin cotton zone; 3 = South Borgou food zone; 4 = West Atacora zone of Benin; 5 = Central Benin cottonzone;6=BarrierLandszone;7 = Benin depression zone; 8 = Benin fisheries zone	-	-
Household size	Continuous/Number of family members	+ / -	+ / -
Maize yield	Continue	+	+
Easy access to improved seeds	Dummy (1=Yes ; 0= otherwise)	+	+
Specific training received on the use of varieties	Dummy (1=Yes ; 0= otherwise)	+	+
Relationship with extension structures	Dummy (1=Yes ; 0= otherwise)	+	+

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Volume 21 No. 4
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Table 2: Descriptive statistics of continuous and dummy variables according to adoption status

Variables	Adopters (Y= 1)			Non-adopters (Y = 0)			Test t
	Obs	Average	Std.Dev	Obs	Average	Std.Dev	
Continuous variables							
Age	352	42.47	9.15	106	44.06	11.32	0.84
Age squared	352	1904.50	965.11	106	1888.76	1049.13	0.88
Number of experience' years in maize production	352	15.60	8.50	106	17.63	10.45	2.04**
Share of 10 of annual agricultural income from maize production	352	5.22	2.77	106	5.11	1.87	- 0.38
Total household size	352	5.06	3.49	106	4.80	3.64	-0.67
Maize yield	352	3736.19	2555.67	106	2677.08	1649.83	2.68***

Dummy variables	Categories	Adopters (y=1)	Non-adopters (y=0)	Total size	Chi2
Gender	Male	75 (345)	21 (97)	97 (442)	10.22***
	Female	2 (7)	2 (9)	3 (16)	
Formaleducation	No	35 (160)	14 (62)	48 (222)	5.54**
	Yes	42 (192)	10 (44)	52 (236)	
Literacy	No	42 (191)	16 (72)	57 (263)	6.22**
	Yes	35 (161)	7 (34)	43 (195)	
Distance from the producer to the place of supply	Short	20 (80)	10 (40)	30 (120)	6.79**
	Medium	25 (100)	7 (28)	32 (128)	
	Long	30 (117)	8 (30)	38 (147)	
Access to credit	No	61 (272)	20 (89)	80 (361)	2.30
	Yes	17 (73)	3 (15)	20 (88)	
Agro-ecological zones	zone 1	2 (7)	1 (2)	3 (9)	16.47**
	zone 2	6 (22)	2 (6)	8 (28)	
	zone 3	7 (27)	5 (19)	12 (46)	
	zone 4	17 (64)	3 (12)	20 (76)	
	zone 5	20 (77)	3 (12)	23 (89)	
	zone 6	18 (67)	6 (24)	24 (91)	
	zone 7	2 (7)	1 (2)	3 (9)	
	zone 8	6 (23)	2 (8)	8 (31)	
Easy access to improved seeds	No	24 (106)	17 (78)	41 (184)	73.62***
	Yes	54 (245)	5 (22)	59 (267)	
Specific training received on the use of varieties	No	32 (148)	18 (83)	50 (231)	42.84***
	Yes	45 (204)	5 (23)	50 (227)	
Relationship with extension structures	No	15 (70)	11 (51)	26 (121)	33.39***
	Yes	62 (282)	12 (55)	74 (337)	

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ISSN 1684 5374

Table 3: MLE (Maximun Likelihood Estimation) estimates of the Double Hurdle and Tobit models

	Double Hurdle Method		Tobit
Variables	**Probit (first hurdle)**	**Truncated (second hurdle)**	
Age	0.02 (0.06)	-0.02 (0.01)	0.01 (0.01)
Age Squared	-0.001 (0.001)	-0.001 (0.001) **	0.001 (0.001)
Gender	1.13 (0.49) **	-0.07 (0.09)	0.03 (0.13)
Number of experience' years in corn production	-0.02 (0.01))	-0.001 (0.001) *	- 0.01(0.001)**
Agro-ecological zone	0.01 (0.07)	-0.02 (0.01)	-0.06 (0.02)***
Share of annual farm income in 10	-0.00 (0.03)	-0.00 (0.00)	0.01 (0.01)
Total household size	-0.01 (0.03)	0.01 (0.00)***	-0.01 (0.01)*
Formal education	-0.07 (0.22)	0.01 (0.03)	0.02 (0.05)
Literacy	0.71 (0.23)***	0.04 (0.03)	0.10 (0.05)**
Access to credit	-0.07 (0.27)	0.05 (0.04)	0.15 (0.05)***
Distance from the producer to the place of supply	0.06 (0.12)	-0.04 (0.02)**	-0.04 (0.03)
Specific training received on the use of improved maize varieties	0.78 (0.29) ***	-0.04 (0.03)	0.11 (0.05)**
Relationship with extension structures	0.29 (0.22)	0.07 (0.04)*	0.03 (0.06)
Natural logarithm of maize yield	-0.27 (0.18)	0.41 (0.05)***	-0.33 (0.05)***
Easy access to improved seeds	1.23 (0.21)***	0.15 (0.03)***	0.44 (0.05)***
_cons	-0.02 (2.08)	4.91 (0.44)***	3.24 (0.5)***
	LR Chi2 (15) = 111.72***	Wald Chi2 (15) = 137.28***	LR Chi2 (15) = 168***
Log likelihood	-109.902	23.972	-149.10233
AIC (−2 logL̃+ 2k)	251.803	-12.204	332.205
LR test (p=0)	χ^2 (16)= 126.35***		
Number of observations (N)	306	252	302

*=P < 0.1, **=P < 0.05, and ***=P < 0.01; Note: Standard errors are in parentheses.

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