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Influencing Drivers of Agricultural Production Technology of Rice in Burundi

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The adoption of agricultural technologies has become the key to limiting imports and meeting Burundi's rice food needs. This is because rice production is generally low in the country due to the ever-increasing population. This study identified the constraints of rice production, assessed the rate and identified the determinants of the adoption of the *rutete* rice variety. Primary data was collected using the well-structured questionnaire from 524 rice farmers who were selected using a simple random sampling in the study area. Data analysis was performed using Kendall's tau coefficient for constraints, probit for adoption rate and Heckman's sample selection model for determinants. According to the results, the insufficiency or delay in the supply of fertilizers, the problem of water availability and the problem of access to agricultural credit are the major

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constraints of rice production. They also show that 29% of respondents have adopted the *rutete* rice variety. Furthermore, the results show that sex, level of education, planted area, access to extension services, membership in an association and possession of a mobile phone are the determinants of the adoption of the variety of rice *rutete*. It is therefore recommended that farmers in the study area be encouraged to adopt the *rutete* rice variety. We also recommend that the government subsidize agricultural inputs and put in place a policy of loosen the tax burden to the microfinance so that the cost of access agricultural credit for rice farmers is lowered. This will prompt an increase of production. Rice farmers who are not members in the farmer-associations should be sensitized to participate.

Keywords: Adoption; heckman sample selection; rutete rice variety.

1. INTRODUCTION

“The development of the agricultural sector plays a fundamental role in the economy of many countries on our planet, particularly in developing countries where the majority of the population depends on agriculture for its subsistance. Moreover, the progress of agriculture is one of the most powerful levers on which States must act to end extreme poverty, strengthen social prosperity and feed the 9.7 billion people on the planet. in 2050” (World Bank, 2008) .

“Rice is one of the most productive among food cereals in sub-Saharan Africa that can contribute to food problems. From 2014 to 2018, production increased by 26%, that is, 22.4 Mt in 2014, compared to 28.3 Mt in 2018. This is all the more true since its consumption has exploded since the nineties: it has exceeded 37 Mt (in milled rice equivalent) in 2017 and should be around 39 Mt in 2018, either 25% of cereals consumed” [1].

“In Burundi, following population growth, urbanization and changing consumption patterns, the demand for rice has increased sharply” [2]. “To contribute to the reduction of the rice production, the government set up the Rice System for the Development of Imbo (SRDI) to ensure the technical and financial support of rice growers and resorted to imports of rice, especially from Tanzania and Zambia. In addition, the International Rice Research Institution (IRRI) has contributed since 2008 to the promotion of the rice sector through the introduction of new rice varieties that are highly productive, resilient and adaptive to biotic and abiotic stresses for rice-growing areas” (IRRI, 2020).

Indeed, the Foreign Trade Bulletin (2018) underscores that 10,995.9 tons and 3,219.1 tons of rice were imported respectively in the third quarter of 2017 and 2018 [3], which was a reduction of imports by 70.72%. These statistics justify that the investments and efforts made by the government of Burundi to stimulate rice production have no longer led to the ultimate objective of achieving potential production and food self-sufficiency. Moreover, with a density of more than 230 inhabitants/km² [4] and an area of 23,500 km² of potentially agricultural land [5], it is unlikely to extend arable land in Burundi [6,7,8]. Furthermore, the chances of increasing rice production by bringing more land to rice cultivation are reduced. It is obvious that the adoption of new agricultural technologies at the farmer level is the best complement to all efforts made for self-sufficiency in rice production.

The adoption of in agriculture technology is defined by Zomboudre [9] as the process centered on the ability of a farmer from the first information to the adoption. The concept of adoption of innovation is used to describe the individual behavior vis-à-vis an innovation. Moreover, agricultural producers are supposed to make rational decisions on whether or not to adopt innovations based on maximizing their utility [10]. They adopt new agricultural technology which generates higher utility than old technology.

In the literature, Thanh and Singh [11] identified constraints limiting rice production and found diseases (sheath blight, borer and rot); lack of suitable varieties; low access to fertilizer, poor infrastructure; high input cost; credit problems and poor extension services. Others have determined the factors influencing adoption. For example, Abebe et al. [12] used the probit model and found that education level, family size, and household area planted have different impacts on decision-making behavior in the adoption of agricultural technologies; Issoufou et al. [13] used the logit model and found that education, access to agricultural extension and adaptability, seed productivity have significant effects on adoption; Akinola et al. [14] who applied “the Tobit regression model to examine the factors that influence technology adoption and intensity of use in the Guinea savannah of northern Nigeria”.

However, parameter estimation with binary models (probit and logit) often leads to biased estimates when we are in the presence of two groups (adopters and non-adopters) who have different characteristics in the same sample. They do not account for selection biases that arise from observable and unobservable characteristics, which can lead to an incomplete reflection of the true characteristics of technology adoption.

Heckman [15] developed “a sample selection model using an econometric framework to deal with dependent variables. The model was designed to address the problem of analyzing the determinants of adoption intensity using data collected from a population of individuals in such a way as to exclude non-adopters through self-selection. To take advantage of the merits of two-step analysis and simultaneously solve the zero-sample problem, this study used Heckman 's two-step sample selection model”. The shortcomings of the literature are that all the elements of the constraints have not been identified in the study area and that no study to our knowledge has been carried out on the analysis of the determinants of the adoption of the variety of *rutete* rice in the considered study area.

In this study, the main objective is to analyze the adoption of the *rutete* rice variety by farmers in Gihanga commune given that the study area is the most leading in rice scheme in Burundi. More specifically, the study aims at identifying the constraints of rice production, assess the rate of adoption of the *rutete* rice variety and determine the factors influencing rice farmers to adopt this variety.

The paper is answering the following three research questions: what are the constraints related to rice production in Gihanga commune? What is the adoption rate of the *rutete* rice variety? What are the factors influencing the adoption of the *rutete* rice variety?

The remaining of the paper is organized as follows: second section discusses materials and methods, third section presents results and discussions and finally conclusions and recommendation.

2. MATERIALS AND METHODS

2.1 The study area

The study was carried out in the rice fields of Gihanga commune located in the southwestern part of the province of Bubanza in the SRDI Rice Scheme.The commune of Gihanga is one of the parts of central Imbo where most of the rice is produced in Burundi. It is bounded to the north by the communes of Bubanza and Buganda (Cibitoke province), to the east by the Mpanda commune, to the south by the Mutimbuzi commune (Bujumbura province) and to the west by the Democratic Republic of Congo (DRC).

“The Gihanga irrigated perimeter was chosen as the area of interest for the study for three reasons: First, it is located in the Imbo plain where most rice is produced in Burundi. Therefore, evaluating the effect of adoption of agricultural technologies in the rice sector based on the most productive varieties sheds light and provides useful information for research, agricultural policy and practice” [16].

“Secondly, a large number of varieties from IRRI have been popularized in this commune. Thirdly, with regard to the study, the data on rice production in the Gihanga irrigated perimeter are realistic and updated to be consistent with the study”.

2.2 Sampling and Data Collection

“Buringa, Murira, Nyeshanga, Ninga and Bwiza villages. bwa Ninga of Gihanga commune having benefited from IRRI's program to disseminate different varieties of rice. The area of intervention and the various improved varieties of rice popularized by IRRI were drawn from its office located in Bujumbura. In addition, information on the variety of *rutete* rice was captured through interviews with rice farmers during the days of the pre-survey. We surveyed 105 rice farmers per village to cover the 524 adoptive and non-adoptive rice farmers of the *rutete* rice variety” [16].

The sample size was calculated from the formula of Rea and Parker [17]:

$$n = \frac{t_p^2 * p(1-p) * N}{t_p^2 * (1-p) + (N-1) * \gamma^2} \quad (1)$$

Where n = sample size; $N =$ represents the population of rice farmers in the study area, it is equal to 8224; t_p= value of the Student index at the significance level of 5%, it is therefore equal to 1.96; p = proportion of a given variable; γ= margin of error of the estimate of the main indicator.

“Among the rice farmers surveyed, many of them are members of cooperatives supervised by the SRDI. Thus, members of SRDI cooperatives and non-members were interviewed using a well-structured questionnaire. This methodology assumes to have fairly similar populations on average to be able to compare their results. In each village, rice farmers were randomly selected and all village residents had an equal probability of being sampled. The data collected are cross-sectional data and were collected following semi-structured interviews. These data grouped the demographic, socioeconomic and institutional characteristics of the households” [16]. Data was collected using KoBoCollect v1.28.0 software and analyzed with SPSS 22 and STATA 15.1 softwares.SPSS was used providing the descriptive statistics while STATA in estimating the model used in this study.

2.3 Theoretical and Conceptual Framework

2.3.1 Methods for identifying constraints in rice production

This section underscores the barriers that hinder the adoption of the technologies proposed by IRRI in the meadows of rice farmers in the study area. We evaluated through the information collected during a survey, the constraints encountered by rice farmers during the production process. The establishment of the ranks was done on the classifications according to the frequencies of each of them on the list given to the farmers. Kendall's tau-b test popularized by Kendall [18] allowed us to rank the stresses according to the degree of exposure. This is a non-parametric test for ordinal or ranked variables that takes into account links.

2.3.2 Evaluation of the rate of adoption of the rutete rice variety

The adoption rate of the *rutete* rice variety was estimated by the counterfactual approach based on the average treatment effect (ATE). This parameter was estimated after the probit model following the procedure proposed by Diagne [19]. The dependent variable that was explained here designates the adoption or non-adoption of the variety. It is a binary variable that takes the value 1 if the producer has adopted and 0 if not adopted. The estimated parameter (ATE) is the proportion of the potential adoption rate. This is the proportion of rice farmers who would have adopted the *rutete* rice variety if they were all informed of its existence.

According to Diagne and Demont, [20], the parametric estimate of the ATE is based on the assumption of conditional independence and is expressed as follows:

$$ATE(x) = E\left(\frac{y_i}{x}\right) = E\left(\frac{y}{x}, w = 1\right) \quad (2)$$

$$E\left(\frac{y}{x}, w = 1\right) = g(x, \beta) \quad (3)$$

With:

g: A function of the vectors of the covariates x;
β: A parameter that is estimated from the maximum likelihood;
w: Adoption status.

2.3.3 Econometric model of the determinants of adoption

In this study, adopters are defined as rice farmers who choose to cultivate the *rutete* rice variety. Therefore, adoption is a binary dependent variable with values equal to one if rice farmers adopted the variety and zero if they did not. The first decision farmers have to make is whether or not to adopt the variety, and if they decide to adopt, the second decision is to maximize production with the right rice cultivation techniques.

The adoption decision of *rutete* rice variety by rice farmers, which estimates the probability that a rice farmer will adopt it and the intensity of adoption, can be estimated using the two-stage heckman model.

In the first stage, a selection model was used to describe the decision to adopt the *rutete* rice variety. This decision estimates the probability that a rice farmer will adopt the variety, which can be estimated using the probit model as follows:

$$Y_i = \beta X_i + u_i \quad (4)$$

Or Y_i= a binary dependent variable (1 = adoption; 0 = no adoption), β= a vector of coefficients of the explanatory variables, X_i = explanatory variables that affect the adoption of the variety, $u_i$is the error term, and$i = 1, \dots, n$.

In the second step, rice farmer yield as a proxy for adoption intensity was estimated by including an estimate of the inverse Mill's ratio (λ_j) as follows:

$$Y_j = \beta_j X_j + \lambda_j \mu + u_j \quad (5)$$

Or Y_j= yield of rice farmers as an approximation of the intensity of adoption of the *rutete* rice variety; β_j =a vector of coefficients which are to be estimated in the result equation; X_j =factors that should affect the intensity of variety adoption; λ_j = a selection bias correction factor (inverse Mill's ratio), $u_j$is the error term, and$j = 1, \dots, n$.

Heckman 's two-step approach [15] is a model that corrects for the issue of selection bias that arises when the correlation between the two terms of error is greater than zero (Hoffmann and Kassouf 2005).

According to Wooldridge [21], Heckman 's two-step approach is based on the restrictive assumption of normally distributed error terms. With this approach, the probit model is used in the first step to identify the factors that affect the decision to adopt the variety (equation 1) while in the second step, the ordinary least squares (OLS) method is applied to the factors affecting the intensity of variety adoption (equation 2).

The probit model integrated in the first step also provides the value of the IMR (λ_i), which is defined as "the ratio of the ordinate of a standard normal distribution to the tail region of the distribution" [22]:

$$\lambda_i = \frac{\theta(\rho + aX_i)}{\phi(\rho + aX_i)} \quad (6)$$

where θ = the standard normal density function and $\phi$is the standard normal distribution function.

The term IMR (λ_i) corrects the problem of selection bias and shows the influence of unobserved characteristics in the model [22]. If the term (λ_i) is not statistically significant, then sample selection bias is not an issue and unobserved characteristics are not statistically significant at adoption [15]. A statistically significant value of (λ_i) means that the selection biases that could lead to biased estimates have been removed and that there are unobserved characteristics of an individual that were not taken into account in the model but which should influence the decision to adopt.

2.3.4 Conceptual framework of the study

From the theoretical and econometric literature on the adoption of agricultural technologies and from survey data, a farmer's decision to adopt a technological innovation depends on factors such as demographic, socioeconomic and intentional characteristics.

The conceptual framework of adoption and its associated factors is illustrated in the figure below. We believe that adoption is influenced by demographic (age, gender, marital status, level of education, household size, number of household workers), socioeconomic (farm size, farming experience, possession of a mobile phone) and institutional (Credit access, extension, Membership in an association). These factors can have a positive or negative effect on the adoption and yield of rice farmers.

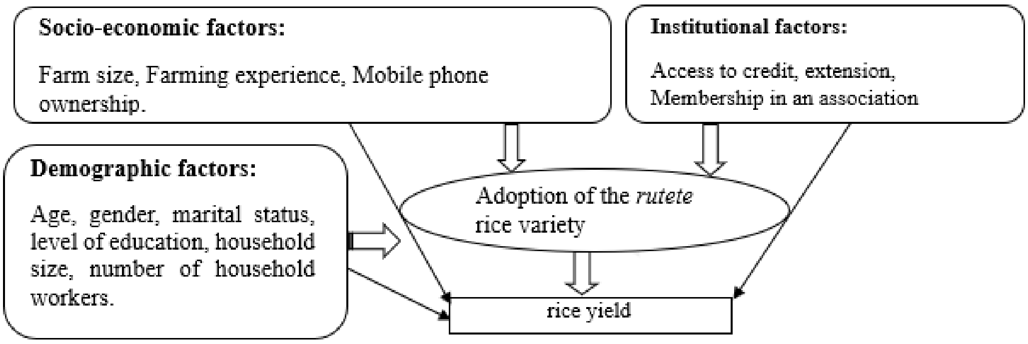

Fig. 1. Conceptual framework of the study

Table 1. Description of variables used in the study

Dependent variables	Type of variables	Description	
Adoption	Qualitative	1= if the variety of *rutete* rice is adopted and 0 if not	
Yield	Quantitative	The ratio of production and sown area of a rice farmer	
Independent variables	**Type of variables**	**Description**	**expected sign**
Age	Quantitative	Number of years of the head of operations	+
Sex	Qualitative	1 if the individual is a man and 0 if not	+ or -
status _matr	Qualitative	= 1 if the individual is married and 0 if not	+ or -
Education	Qualitative	0= no level; 1 = primary level; 2= secondary level; 3= university level	+
size _mena	Quantitative	The number of people living in the household	-
hand_men _	Quantitative	Number of farming people in the household	+
Area	Quantitative	Farm size in are	+
experience	Quantitative	Number of years of experience of a rice farmer	+
poss _tel	Qualitative	Dummy variable: 1=telephone user; 0=no	+
aparten _asso	Qualitative	Binary variable: 1=belongs to an association; 0= no	+
popularization	Qualitative	Binary variable: 1=if the farmer has access to extension services and 0=no	+
access _credit	Qualitative	Funding for the farmer from microfinance institutions.	+
access _market	Qualitative	Binary variable: 1= if the farmer has access to the market and 0 if not	+

Source: authors

In this study, the dependent variable in the model is adoption, the outcome variable is yield, and the characteristics of a farmer are independent variables. Some are quantitative and others qualitative.

3. RESULTS AND DISCUSSION

This part presents the independent variables used in our study. The results of the identified constraints that handicap the rice production of Gihanga farmers are presented. In addition, the rate of adoption and the factors that influence farmers to adopt the variety of rice *rutete* are estimated.

3.1 Descriptive Analysis of the Variables Induced in the Study

The categorization of the variables induced in the model allows us to make an overall analysis of the rice producers in the study area. It is the analysis of quantitative and qualitative variables grouped into the demographic, socioeconomic and intentional characteristics of the respondents.

3.2 Sociodemographic Characteristics

“The analysis also shows that the households surveyed are mainly headed by men with 80.15 % against 19.85% of women. Men adopting and those not adopting are respectively 24.62% and 55.53% while among women, they are respectively 4.2% and 15.65%. This situation justifies that in the study area, agricultural households are largely headed by men. There is a big gender disparity in rice production. Furthermore, marital status is an important socio-demographic factor affecting the adoption of agricultural technology. Among the rice farmers surveyed, there were more married respondents (94.85 %) than single ones (5.15 %). However, non- adopters had a higher percentage than adopters. It emerges from the analysis that the non-adoptors who are married represented 67.37 % of the sampled population while the adopters were 27.48 %. However, there were few single respondents: 3.63 % of non-adoptors and 1.53 % of adopters” [16].

“As for the level of education, the study revealed that around 35.50 % of the farmers had no level of education, 43.13 % of the farmers had a primary education, 20.23 % had a secondary education while 1.15 % of the farmers had a university education. By adoption status, the statistics revealed that the non-adopters of all education levels are respectively represented by 27.67% of rice farmers with no level, 30.15% of rice farmers with primary level, 12.98% of rice farmers with secondary level and 0.19% of rice farmers with university level while the adopters are respectively represented by 7.82% of rice farmers with no level, 12.98% of rice farmers with primary level, 7.25% with secondary level and 0.95% with university level" [16].

The results show that the entire sampled population represents the average age of 45.15458 years. It emerges from this result that the adopters of the *rutete* rice variety have an average of 45.19079 years and 45.13978 years for the non-adopters. The average household size surveyed was 8,267,176 persons per households. Statistical analysis proved an average household size of 8.197368 individuals for adopters and 8.295699 individuals for non-adopters.

Adopter and non-adoptor households have the average household size of 2.703947 and 2.680108 respectively. The gap between household size and family labor force is relatively large. This is testified by the respondents to the fact that they use much more outside labor in their rice farming system. In addition, the household heads surveyed found that men are much more responsible for rice farming while women are responsible for other agricultural activities.

3.3 Socioeconomic Characteristics

This part presents the socio-economic characteristics of rice producers, focusing mainly on the possession of a mobile phone, access to the market, the area sown for rice cultivation and the producer's experience in rice-growing activities. The distribution of respondents by phone use shows that there are many mobile phone users (74.62%) against 25.38% of non-mobile phone users. Among the adopters, only 24.62% of rice farmers own mobile phones against 4.39% who do not own mobile phones. Among the non-adopters, 50.00% of respondents are mobile phone users against 20.99% of non-users.

The statistics also show 83.78% of respondents who have access to the market against 16.22% of respondents who do not have access to the market. This justifies that the rice cultivation practice in Gihanga is largely market oriented. According to the rice growers surveyed, part of the production obtained must be sold to repay the debts contracted during the operating period. Another part is reserved for consumption. By adoption status, 25.19% of the rice farmers who have access to the market have adopted the *rutete* rice variety while 58.59% of them have not adopted it. Also 3.83% of rice farmers without market access have adopted the *rutete* rice variety against 12.40% of rice farmers without market access who have not adopted it. In addition, among the rice farmers with access to the market, 25.19% have adopted the *rutete* rice variety while 12.40% of them have not adopted it.

The results also show that the average household in the study area has an average area of 27.71565 ares. The results show us that the non-adopters have an average area of 25.9086 ares while the adopters have an average of 32.13816 ares. The average agricultural experience of rice farmers in the study area was 15.35115 years. Descriptive statistics revealed an average of 15.67105 years for the adopters while for the non-adopters the average experience was 15.22043 years.

3.4 Institutional Characteristics

In the population surveyed, farmers obtain agricultural credit through SRDI cooperatives, local lenders, and micro-finance institutions. Credits from the SRDI are often seeds and pesticides. These the latter are supposed to be repaid after the harvest. The rice farmers complain that the price recorded by the SRDI on the royalty payment is so low (1300Fbu) compared to that of the local market (2200Fbu). Also, local lenders demand loan repayments at a high rate that rice farmers are unable to pay. However, we based ourselves on credit in monetary terms.

In this study, information on access to credit was collected. Table 2 shows the number of respondents who requested agricultural credit during the last season of the year 2022 and others who did not request it. In the population surveyed, 61.26 % of farmers had access to credit against 38.74 % of farmers who did not have access to credit.

Among the adopters, 19.27% of the adopting rice farmers had access to agricultural credit against 9.73% of the rice farmers who did not have access to agricultural credit. However, 41.98% of non- adopters had access to agricultural credit against 29.01% of rice farmers who did not have access to agricultural credit.

Table 2. Ranking of rice production constraints

Constraints	average rank	Frequency	Percentage	Overall Rank
Lack of and/or delay in fertilizers	4.91	437	83%	1st –
Water availability problem	4.75	408	78%	2 nd
Lack of extension services	2.73	57	11%	5th –
Damage caused by insects, diseases and pests	2.85	136	26%	4th –
Small areas	2.66	49	9%	6th –
Lack of access to agricultural credit	3.1	164	31%	3 rd

Source: author based on survey data with SPSS software, 2023

As for membership in an organization, the statistics showed 71.56% of the respondents who belong to a rice farmers' association and 28.44% of the respondents who do not belong to any rice farmers' association. By adoption status, 23.09% of adopters belong to an association against 5.92% of adopters who do not belong. In addition, 48.47% of non-adoptors belong to an association against 22.52% of non-adoptors who do not belong to any association.

An extension service to rice farmers is an incentive for the adoption of improved rice varieties. In the study area, 48.47% declared that they did not benefit from these services from the extension agents while in the counterpart, the number who benefited from at least one extension agent was only 51.53%. By adoption status we noticed 18.89% of adopters who received at least one extension worker against 10.11% of adopters who did not. On the side of non-adopters, 32.63% benefited from extension services while 38.36% answered that they never benefit from them. These services are supposed to be provided by SRDI agents as revealed by farmers. The lack of extension services has been linked to inefficient production in agriculture sector.

Since the aftermath of the civil war in Burundi, the delivery of extension services has declined due to the declining number of extension workers and lack of budget allocated to the extension service of the ministry of environment, agriculture and livestock.

3.5 Rice Production Constraints

The constraints in irrigated rice in Gihanga are seriously hampering the production and here we rank them form the most important to the less using a statistical tool.

This study in progress on the constraints related to rice production highlights the insufficiency of chemical fertilizers or the delay of the latter as the main constraint that slows down rice production in the study area. Chemical fertilizers are purchased by SRDI from private companies and distributed to rice farmers in Gihanga at a certain price set by the same company (ie SRDI). According to the rice farmers surveyed, the SRDI distributes them through their cooperatives. These fertilizers often come late, which disrupts the development of rice plants. These are given on credit which is recovered when buying rice from the same farmers. This also shows that non-SRDI rice farmers do not have access to inputs on credit. This considerably affects their production because of their low financial capacity which does not allow them to obtain fertilizers. The distribution is equitable in proportion to the areas of the rice growers. As the land has been overexploited for a long time, fertilizers from the SRDI are insufficient for the development of rice plants. The doses of fertilizers used are below the needs of the crop due to the lack of fertilizers. MASA [23] estimates the average doses at 69 kg/ha for NPK and 28 kg/ha for urea.

However, this is inaccessible for most low-income producers who practice subsistence farming with the use of low amounts of fertilizer [24]. This shortage may be due to the high prices of the latter, which do not allow rice growers to obtain the quantity necessary for their land. It is obvious that if the cost of fertilizers is very high or if they come late in the period planned for the rice cultivation practice, this can have a negative effect on the expected production of the farmers. Therefore, it is considered a great source of disincentive for agricultural production. This result confirms that of Gomgnimbou et al. [25] who revealed that the lack of fertilizers is a brake on agricultural production. This allows us to conclude that rice production for farmers unable to obtain fertilizer from elsewhere in the SRDI is low given the potential of the varieties used in the region.

In addition, the low availability of water limits rice production. The rice cultivation practiced in Gihanga is irrigated, which requires a large quantity of water throughout the operating period. *Pamard* [26] showed that irrigated rice growing needs more than 12,000 m^3/ha of water for the duration of the vegetative cycle, which lasts from 130 to 200 days. According to the rice farmers surveyed, irrigation canals are rare, which causes a shortage of water in the event of a lack of rain. However, misuse or non-use of canal irrigation and drainage negatively affects rice yield [27]. Water management of poorly drained soils in rainfed lands is one of the major constraints [28,29]. It has been found that about one-third of the total rice grown in the eastern states is rainfed and grown in areas with low topography, a problem of drainage in depressed rice fields [30].

The results showed the high incidence of diseases and pests as the constraint of rice production. Some identified diseases are pycuraliose and yellow mottle. Authors [31,32] have shown that blast leads to yield losses ranging from 11 to 30% per year, which represents a loss of approximately 157 million tons in global production. In Burundi, it can lead to yield losses of more than 10% per year (MINAGRIE, 2016). ISABU research also shows that the yellow mottle (Rice Yellow Mottle Virus, RYMV) which was detected from 2011 in irrigated rice cultivation in the Imbo plain and the Moso depressions is gaining more and more high-altitude marshes [33,34]. These results corroborate with those found by Ndimanya and Ndatitwayeko [35] in their survey on the level of adoption of agricultural technologies in Burundi. According to Ekeleme et al*.* [36], major rice pests and diseases in Borno State could be production-related constraints that attack crops from seedling to maturity.

Yet the seriousness of diseases and pests could be caused by the lack of access to agricultural credit allowing farmers to buy pesticides to fight against them. Furthermore, most poor smallholders are often unable to invest in new technologies or in acquiring inputs such as fertilizer, wage labor, etc. on their own [37]. According to assouto and houngbeme [38], credit allows producers to have the necessary resources to meet the financing needs induced by the production cycle. This cycle is particularly long in agriculture due to the time lag between sowing time and harvest time. The availability of credit is supposed to enable both the consumption and use of purchased inputs, which increases farmers' production and therefore their income.

In addition, technical constraints are faced with the lack of access to extension services. Therefore, the identification and use of communication channels is important (Onasanyat, 2006). Lack of access to information and extension services by farmers would hinder the loss of agricultural production [39]. These results invalidate the first hypothesis according to which the technical constraints identified do not affect the production of rice farmers.

3.6 Evaluation of the Rate of Adoption of the Rutete Rice Variety

The result shows that the potential adoption rate (ATE) is 29% indicating that a rice farmer taken at random from the population has a probability of 29% to adopt the *rutete* rice variety. As a reminder, adoption is here defined as having used the *rutete* rice variety in the last season of the year 2022. This result shows that this variety is poorly adopted in Gihanga and is similar to that of Ouédraogo and Dakouo [40]. The low adoption rate could therefore express the lack of information about the variety in terms of its high yield for adopters. This situation can be explained by the fact that rice farmers in Gihanga know other varieties (kazosi, mugwiza, gwizumwimbu, komboka and hybrid) which compete with the *rutete* rice variety.

In addition, to better understand this adoption rate, the adopting rice farmers were asked about the reasons for adopting this variety. Their responses are shown in the figure below.

Rutete rice variety is linked to several intrinsic reasons. It appears from the analysis that five main reasons are given by rice farmers to justify the adoption of the *rutete* rice variety. It is used by some producers who testified to the latter.

Testified by 91% of the adopters of our sample "the high yields", is the main reason to adopt this variety. Rice being the food crop par excellence, higher yields improve the food security of agricultural households. In addition, they allow them to access opportunities for other prospects to improve family conditions.

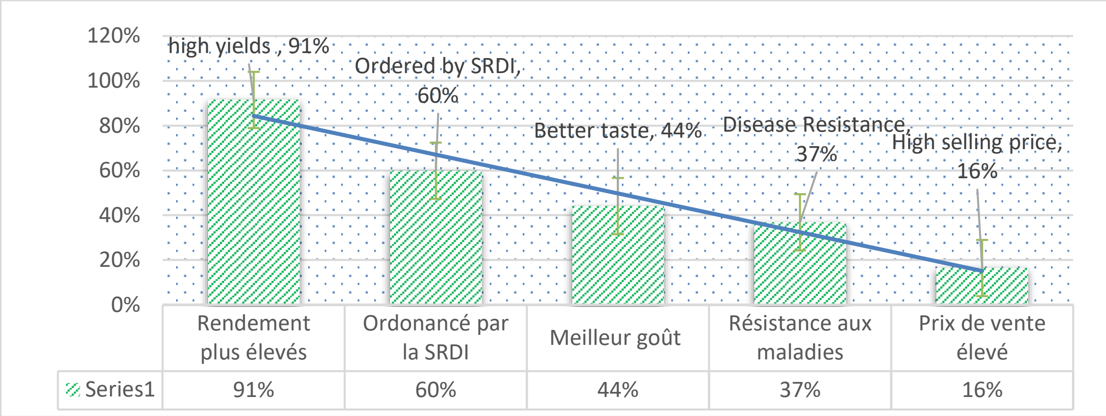

Fig. 2. Challenges for adopting the rutete rice variety
Source: authors based on survey data, 2023

Table 3. Parameter estimates for factors affecting variety adoption improved *rutete* rice

Variables	Selection equation (1)			Result Equation (2)		
	Coeff.	S.E	P>z	Coeff.	S. _ E	P>z
Gender (Female)	-0.2821	0.1588867	0.076	-1.0176	60.73204	0.987
Age	-0.0029	0.006869	0.671	0.20678	0.986883	0.834
status _matr	-0.1553	0.3057202	0.611	26.9053	39.7046	0.498
Education	0.27074	0.0820379	0.001	-7.3319	54.17958	0.892
size _mena	-0.0508	0.0425923	0.233	0.25517	10.83448	0.981
labor _men	0.05863	0.0518458	0.258	-2.9654	12.19416	0.808
Area	0.00368	0.0018141	0.043	0.0012	0.750761	0.999
Experience	0.00182	0.0072629	0.802	-0.8205	0.878469	0.350
access _credit	0.08732	0.1272223	0.493	-14.422	21.98304	0.512
access _market	0.13976	0.1756463	0.426	-46.116	34.68929	0.184
popularization	0.26374	0.1406628	0.061	17.6998	56.02347	0.752
aparten _asso	0.51131	0.1242551	0.000	7.34304	105.6446	0.945
poss _tel	0.50717	0.1525827	0.001	25.7837	108.1911	0.812
_cons	-1.3801	0.4803533	0.004	76.8851	522.4071	0.883
Rho				**0.2912**		
Sigma				68.3814		
Inverse Mill's ratio				**19.9124**	287.2037	**0.945**

Source: authors

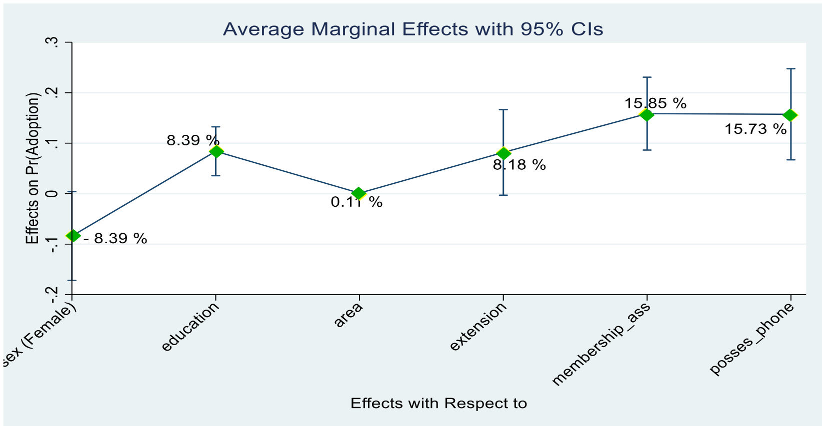

Fig. 3. Estimation of marginal effects
Source: authors

Confirmed by 60% of adopting rice farmers, “Ordered by SRDI” comes second in the reasons for adopting the *rutete* rice variety. It comes in this position because the SRDI is responsible for supervising the rice growers grouped into cooperatives. As a result, during the growing season, it orders each time the variety worthy of being exploited by village according to the varieties present in the region. However, this does not prevent some rice farmers from deciding to cultivate another variety of their choice according to their preferences.

The taste after husking the rice comes third in the reasons for adopting the *rutete* rice variety (44%). Taste, specializing in food appreciation and determination, enables rice farmers to adopt a variety of the most preferable rice in consumption. Testified by 37% of the sampled rice farmers, disease resistance comes fourth as a reason for adopting the *rutete* rice variety. As seen previously that diseases in rice handicap production, rice farmers prefer varieties that are much more resistant to diseases in order to produce a satisfactory quantity.

The high selling price comes last with 16% of the rice farmers who testified it as a reason for adopting the *rutete* rice variety. This result confirms that the rice cultivation practiced in Gihanga is market-oriented. For this, the rice farmers adopt the varieties with the high selling price on the market to earn more money allowing them to satisfy other family needs.

3.7 Factors Affecting Adoption of Improved Rutete Rice Variety

Heckman model which facilitates the unbiased estimation of the adoption probability for the rice farmers who decided to adopt the improved rice variety *rutete*.

The estimated results have been presented in the table. The coefficient of the ratio of “Inverse Mill's ratio *(*19.9124)” is positive but it is statistically insignificant. This indicates that the unobserved characteristics that are not taken into account in the model have a positive but non-significant influence on the adoption of the *rutete* rice variety. In addition, it indicates the absence of self- selection result biases that may lead to biased estimates. This justifies that no unobserved characteristics are noted as a result of the determinants of adoption.

Moreover, the positive sign of the *Rho* coefficient (0.2912) suggests that rice farmers' unobservable factors, which lead to the adoption of rice variety *rutete*, may also be positively associated with rice farmers' yields. But their contribution is not statistically significant because the value of the coefficient is closer to 0. This therefore justifies the use of Heckman 's two-step regression model to determine the factors influencing the decision to adopt the variety of *rutete* rice.

The variables gender, level of education, area sown, access to extension services, membership in an association and possession of a telephone are statistically significant and are taken as determinants of the adoption of the *rutete* rice variety. Some variables like gender, access to extension services are statistically significant at 10% each and area planted is statistically significant at 5%. Thus, the level of education, membership in an association and possession of the telephone are statistically significant at 1% each. The variable coefficients indicate the direction (either positive or negative) in which the explanatory variable is related to the dependent variable in the selection equation. Additionally, marginal effects were estimated to measure the change in the probability of adopting the *rutete* rice variety.

Female-headed households are less likely to adopt the *rutete* rice variety than male-headed households. This means that when the head of the household is a woman, all other things being equal, the probability of adopting the *rutete* rice variety decreases by 0.0838773 (8.39%). The conclusion of Chirwa [41] in Malawi indicates that the presence of a woman at the head of the household negatively influences decisions to adopt new technologies in agriculture. Indeed, in Malawi, female-headed households tend to be poorer and more constrained in available resources [42], which reduces their ability to adopt new agricultural technology.

The level of education of the household head positively influences the likelihood that a rice farmer will adopt the *rutete* rice variety. This means that when the number of years of education of the household head increases by one year, all other things being equal, the probability that a rice farmer adopts the *rutete* rice variety increases by 0.0839548 (8.39 %). Education, as noted by Onyeneke [43], has positive effects on farmers' likelihood of adopting improved rice varieties. This observation is consistent with the conclusions of other authors [44], Bezu et al*.* [45], and Ghimire et al*.* [46] who found a significant and positive relationship between education and the adoption of new rice technologies.

rutete rice variety. This means that when the area increases by one are, all other things being equal, the probability that a rice farmer adopts the *rutete* rice variety increases by 0.0011397 (0.11%). That is, farmers who are able to put additional farmland into rice production, are more likely to try the recommended practices and subsequently adopt them Onyeneke [43]. This conclusion is consistent with that of Mustapha et al. [47] who reported that ownership of cropland significantly and positively affects the decision to adopt improved production practices as an option for adaptation to climate change and variability by smallholder farmers in northern Ghana.

Access to extension services positively influences the likelihood of adopting the *rutete* rice variety. This means that when a farmer receives an additional visit from an extension agent, all other things being equal, the probability that a rice farmer will adopt the rice variety *rutete* increases by 0.0817853 (8.18%). This is rational, as the mission of agricultural extension officers is to provide technical advice and training to farmers on how to use, maintain and the importance of using higher yielding varieties. This confirms Kudi 's findings et al. [48]. The provision of extension services is an important source of information on improving production technologies [43].

Belonging to an association positively influences the probability of adopting the *rutete* rice variety. This means that when a rice farmer decides to belong to a rice farmers' association, all other things being equal, the probability that a rice farmer adopts the *rutete* rice variety increases by 0.1585551 (15.85%). This reflects that households whose heads belong to a rice farmers' association are likely to adopt high-yielding varieties. To be served by the SRDI, rice producers must come together in an association. In this form, the distribution and follow-up of agricultural credits becomes easier than if the farmers are helped each other. Moreover, farmers learn from each other. The participation in an association, as pointed out by Prasanna et al. [49], Mbonimpa and Ndikubayo [50], determined adoption of the technology and influence accessibility of the resources agricultural.

Owning a mobile phone positively influences the probability of adopting the *rutete* rice variety. This means that when a rice farmer has a mobile phone, all other things being equal, the probability of adopting the *rutete* rice variety increases by 0.1572733(15.73%). A similar result was found by Afolami et al. [51]. The results imply that farmers receive information on input markets through mobile phone communication. It creates awareness and thus increases the likelihood of adoption of improved rice varieties. The results highlight the importance of information in the process of adopting a technology, suggesting that information and communication technologies (ICT) are among the main channels for the diffusion of technology. In most developing countries, a high proportion of households own at least one telephone, which is one of the fastest ways to communicate agricultural information [52]. It is therefore clear that mobile phones contribute to the adoption of varieties that generate higher yields [53].

The other variables have an influence on the adoption of the *rutete* rice variety but they are not statistically significant. Therefore, the determining factors for the adoption of the *rutete* rice variety are those found to be significant [54-56].

Finally, the direction of variation in the determinants of the adoption of an innovation introduced in rural areas therefore depends on the context of the study and the assumptions made by the author during his analyses. In addition, it should be noted that most of the results of this study corroborate those of previous work carried out on the determinants of the adoption of agricultural technologies. Therefore, the results found testify to an influence of demographic, socioeconomic and institutional characteristics on the decision to adopt the *rutete* rice variety.

4. CONCLUSIONS AND RECOMMENDATIONS

In this article, we were motivated to find out the constraints of rice production and the factors that influence rice farmers to adopt high yielding rice variety (*rutete* rice variety). For this, a global sample of 524 rice farmers was used. Descriptive statistics showed that men outnumbered women in the survey and that several households were headed by men. The analysis of the identification of production constraints by Kendall's tau-b test, highlighted that the insufficiency and / or delay of fertilizers; Problem of water availability; Lack of access to agricultural credit; Damage caused by insects, diseases and pests; Lack of extension services and Small acreage, were the ones that rice production policy makers should pay attention to. Furthermore, the two-stage Heckman model revealed that demographic, socio-economic and institutional factors such as gender, level of education, area planted, access to extension services, association membership and mobile phone ownership had an effect on the adoption of the *rutete* rice variety.

In view of these results, we suggest here that policymakers and private promoters of rice production in Burundi subsidize agricultural inputs to rice farmers and help them access agricultural credit at low interest rates. In this area, the focus should be on fertilizers, seeds and pesticides. In addition, improving the capacity of rice farmers' organizations could encourage non-member rice farmers to join, allow them to have more information on varieties that produce higher yields and provide motivation to adopt technologies. improved rice fields.

After identifying the constraints of rice production, evaluating the adoption rate and identifying the determinants of the adoption of the *rutete* rice variety, we see that similar additional research is needed in all rice areas to have a general view of the country and could influence political decision-makers and rice research institutions in decision-making for the development of the rice sector in Burundi.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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