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The adoption and impacts of improved parboiling technology for rice value chain upgrading on the livelihood of women rice parboilers in Benin

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Food insecurity and child malnutrition remain persistent problems in sub-Saharan Africa. Rice is a staple food for more than half of the world's population. However, white rice is poor in micronutrients and records higher glycemic values compared to parboiled rice. An improved parboiling system called "Grain quality enhancer, Energy-efficient and durable Material" (GEM in short) allows the processing of quality rice with better physical and nutritional properties compared to traditional systems. This paper assessed the drivers and impact of the adoption of the GEM system on women's livelihoods. A total of 822 rice women parboilers were randomly sampled and interviewed in Benin, in regions where the GEM system was introduced. We employed the endogenous switching regression model (ESR) to assess the impact of the GEM system. We found evidence that adoption of the GEM system increased women parboilers' rice output rate (dehulling return), income and food security and reduced poverty. The impact of the GEM system is estimated at 14.38 kg of milled rice per 100kg of paddy (21.46%), equivalent to US$ 7.25 of additional income (17.77%). A significantly lower poverty rate of 26% was found among households due to the adoption of the GEM system. These results are supported by women's perceptions that the output rate, better nutritional value and reduction of broken rice during dehulling are major advantages of the improved parboiling system. Policy actions such as training of local fabricators and credit options are required for out-scaling and sustainability of the improved parboiling system.

KEYWORDS

quality of rice, improved parboiling system, endogenous treatment effects model, impact, Africa

1. Introduction

West Africa consumes more rice than any part of sub-Saharan Africa (SSA), as regional demand has continued to grow at almost 6% annually, driven by the growing population, changing consumption habits and urbanization (Arouna et al., 2021). However, local production has not kept pace with the increase in demand, and the gap is being filled through the importation of rice from Asia, whose characteristics are preferred by consumers (Demont et al., 2013). The low quality of local rice is mainly due to poor postharvest handling (Zohoun et al., 2018). Postharvest activities are of great importance in terms of value addition, the creation of employment opportunities, women's livelihood improvement and the reduction of food losses. Rice parboiling which is the hydrothermal treatment of paddy (rough rice) before dehulling and polishing has also been explored as a strategy to improve the physicochemical and nutritional quality of rice including its digestibility (Ndindeng et al., 2022). The most noticeable advantages of rice parboiling to the processors are increased dehulling return, higher head rice yields and longer storage shelf-life (Etoa et al., 2016; Ndindeng et al., 2021a). As in most countries in SSA, women parboilers predominantly use traditional practices of parboiling rice with low capacity (Fofana et al., 2011) and poor milled rice quality (Houssou and Amonsou, 2004). As a result, consumers prefer and are willing to pay higher prices for imported rice at the expense of parboiled rice produced using traditional methods and equipment (Houssou et al., 2013; Ndindeng et al., 2021b). Therefore, rice parboiling proves to be an important and strategic solution to improve the competitiveness of local rice (Fofana et al., 2011). To upgrade parboiled rice, an improved rice parboiling system "Grain quality enhancer, Energy-efficient, and durable Material" (GEM) with high capacity was recently introduced in West Africa (Ndindeng et al., 2015). The GEM equipment has a high capacity (up to 1,000 kg per day) compared to only 50–100 kg of the capacity of traditional equipment, reducing labor input and the quantity of firewood used. This helps slow deforestation and reduce the effects of climate change. The improved method also uses steam to parboil rice compared to traditional technology (Zohoun et al., 2018).

The GEM system is an improved model based on prototypes from the Institute of Agricultural Research for Development (Cameroon), the Food Research Institute (Ghana), and the Institut National des Recherches Agricoles du Bénin (Benin). The GEM system was introduced in Benin (in the Collines and Alibori departments) in 2015.

The technical performance of the GEM system was tested through several studies (Ndindeng et al., 2015). However, no economic study has been carried out to evaluate the impact of this new parboiling device. Previous studies have focused on the technical performance of the improved parboiling system (Houssou and Ayernor, 2002; Ndindeng et al., 2015) and the determinants of its adoption (Dandedjrohoun et al., 2012). Technical analysis focused on the characteristics of the equipment and the advantages of the GEM system to improve the quality of rice such as physicochemical and cooking properties of the parboiled rice (Ndindeng et al., 2015). In addition, technical analysis was conducted in an experiment under control. Results showed that for instance percent impurities and heat-damaged grains were lower for rice produced using the GEM system. However, no study was published to analyze the effect of the improvement of rice quality by the GEM system on the income and the livelihood of women rice parboilers. This study aim to quantify the impact of the improved GEM system for rice parboiling on the livelihood of women rice parboilers in Benin. The study addressed two research questions: can the GEM system improve rice output rate (dehulling return) of parboiled rice? What is the quantitative impact of the GEM system on income, food security and reduced poverty? By responding these questions, the contribution of this study to the literature is twofold. First, the study provided the assessment of the impact of GEM system on both income, food security and poverty reduction among women rice parboilers. Second, although there are several studies on impact of technologies in the rice value chain, Mishra et al. (2022) recently showed in their review that impact assessment of rice postharvest technologies in Africa are scanty. This study fill that gap and help providing recommendations to policy makers and extension agents on how to scale the GEM technology to improve the livelihood of women.

The rest of the paper is structured as follows. We describe the GEM system in Section "Description and dissemination of the improved GEM parboiling system in Africa" and discuss the methodology in Section "Methodology". Next, we present and discuss the results in Sections "Results" and "Discussions", respectively. Finally, we conclude the study and discuss its policy implications in Section "Conclusion and policy implications".

2. Description and dissemination of the improved GEM parboiling system in Africa

2.1. Description of the improved GEM parboiling system

GEM parboiling system is an improved parboiling technology that combines the use of a uniform steam parboiler and an improved parboiling stove (Ndindeng et al., 2015). The GEM parboiling system is not only about the equipment but also the process. The GEM parboiling system is scaled as a rice parboiling plant (complex). The main components of the complex are the parboilers (steaming tank and baskets), soaking vessels, stoves, laborsaving device, hot water siphoning system, drying surfaces and a shade that accommodates the equipment. Out-scaling is targeting mainly small processors (< 50 kg/batch; 600–800 kg/week) and medium processors (> 50–100 kg/batch; > 800 kg/week). For small-scale processors, the 20–50 kg GEM parboilers, one single 300–400 kg soaking vessel, a manual water pump and a rotational hoist are used. For medium-scale producers, the 60–100 kg GEM parboilers, several 300–400 kg soaking vessels, a manual water pump and a rail chain hoist are used. Internal and external views of the rice parboiling complex showing innovative equipment and sun-drying surfaces and are well described in the literature[1] (Ndindeng et al., 2015).

2.2. Dissemination of the improved GEM parboiling system in Africa

Rice parboiling is the hydrothermal treatment of rice before dehulling and polishing to reduce grain breakages during the dehulling process, preserve nutrients and enhance cooking and eating quality. Due to the low capacity and quality of parboiled rice using the traditional system, the GEM parboiling system was developed in consultation with women processors from the Glazoué Innovation Platform (IP) in Benin to reduce drudgery, the risk of heat burns and exposure to smoke to processors, who are mostly women. The GEM parboiling system can be tailored to medium- (300–1,000 kg) and large-scale (1000–3,000 kg) processors. The cost of the technology depends on the components and the scale of operation. The equipment consists of a stainless steel (Inox 304 L) soaking tank, a stainless steel

1 http://www.ricehub.org/RT/post-harvest/gem-parboiling/out-scaling-the-gem-parboiling-technology

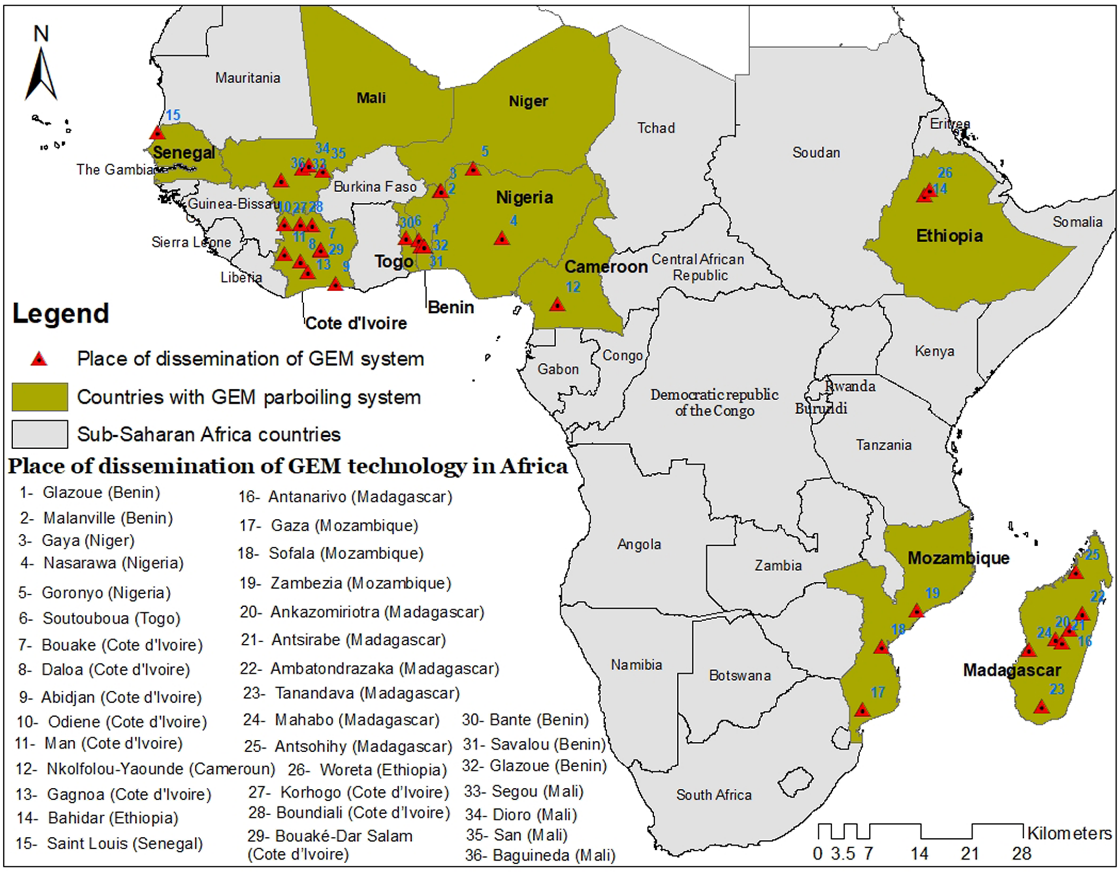

FIGURE 1
Map of Sub-Sharan Africa highlighting the place of dissemination of the GEM system in Africa by AfricaRice.

(Inox 304 L) steaming tank with a stainless steel (Inox 316 L) perforated basket that is placed on a false-bottom in the steaming tank, a hot water pump, a rail and hoist system and an improved rocket stoves constructed with fired bricks and fixed on the ground (Ndindeng et al., 2015). The system is installed under a parboiling shade with a cemented surface so that grains that drop during the parboiling process can be recovered – reduction of quantitative loss (Ndindeng et al., 2021a). Close to the parboiling shade is an improved paddy sun drying area composed of a raised concrete surface with tarpaulins places on it and fenced.

The GEM system is not only about the equipment but the process as well. The installation of the system is accompanied with training of parboilers who are predominantly women on the use of the system to produce quality parboiled. The users are trained on how to select to the most suitable variety and paddy for parboiling – varieties that are slender in shape, rough rice that is neither damaged by disease nor de-husked during threshing. They are also thought on how to clean the rice by winnowing and washing to remove all sorts of impurities, soaking at the right initial temperature (85°C for most varieties and for rough rice that is more than 3 months old), steaming time (20–25 min) and finally on drying regimes and dehulling systems that provide the best results. It is worth pointing out that parboilers using traditional equipment and methods do not consider the above-mentioned points.

The GEM system has been disseminated in many countries in Africa. In the first stage of the dissemination of the GEM system in Africa, training of a dozen agricultural equipment manufacturers was conducted in each country. Women parboilers from the IP in each country were trained in the use and method of rice parboiling with the GEM system. As of January 2022, the GEM system was introduced in a total of 36 areas in Africa (11 African countries): 23 areas in West Africa (Glazoue, Bante, Savalou, Glazoue, and Malanville in Benin; Gaya in Niger; Nasarawa and Goronyo in Nigeria; Soutouboua in Togo; Bouake marché de gros, Bouake Dar Salam, Abidjan, Odiene, Man, Gagnoa, Korhogo, Boundiali, and Daloa in Cote d'Ivoire; Segou, Dioro, San and Baguineda in Mali; and Saint Louis in Senegal); one area in Centrale Africa (Nkolfolou-Yaounde in Cameroon) and 12 areas in East Africa (Bahidar and Woreta in Ethiopia; Antanarivo, Antsirabe, Ambatondrazaka, Ankazomiriotra, Tanandava, Mahabo and Antsohihy in Madagascar; and Gaza, Sofala and Zambezia in Mozambique). Figure 1 highlights all 36 areas of dissemination of the GEM parboiling system in Africa.

3. Methodology

3.1. Estimation method

The impact of the GEM parboiling system on different outcomes was analyzed using the endogenous switching regression model to account for selection bias due to both observable and unobservable factors.

Endogenous switching regression can capture selection bias and the endogeneity problem and is able to provide results under different counterfactual states of adoption decisions (Lokshin and Sajaia, 2011; Khonje et al., 2015). ESR has been applied in many empirical studies (Di Falco and Veronesi, 2013; Ngombe et al., 2017). Therefore, this paper uses ESR to estimate the average situation of rice parboilers if they had not adopted the GEM parboiling system.

The adoption of the GEM system is voluntary and involves self-selection. To overcome the induced bias, the population of the treatment group (adoption group) must be similar to the population of the non-adoption group, and only the observed difference is the adoption of the GEM system. Let D_i be a dichotomous variable indicating the adoption status of a woman parboiler, with $D_1 = 1$ if she adopts the GEM system and $D_0 = 0$ otherwise. Suppose Y_{1i} and Y_{0i} are random variables of outcomes when a woman adopts and when she has not adopted, respectively. Indeed, adoption and non-adoption status cannot be observed simultaneously for an individual parboiler. ESR allows us to estimate the counterfactual situation that cannot be observed (Lokshin and Sajaia, 2011; Khonje et al., 2015). The ESR model includes two simultaneous equations and can be expressed as follows:

$$Y_{1i} = \beta_{1i} X_{1i} + \varepsilon_{1i}, \; if \quad D_1 = 1$$

$$Y_{0i} = \beta_{0i} X_{0i} + \varepsilon_{0i}, \; if \quad D_0 = 0$$

For $$D_i = 1 \quad \vartheta_i Z_i + \mu_i > 0$$

For $$D_i = 0 \quad \vartheta_i Z_i + \mu_i \leq 0,$$

where X_{1i} and X_{0i} are the explanatory variables of the adoption/nonadoption, β_{1i} and β_{0i} are the parameter vectors of the model, and $\varepsilon_{0i}, \varepsilon_{1i}$ and $\propto_i$ are the error terms assumed to be normally distributed.

The ESR model allows estimating the expected outcome (income, output rate, food security and poverty status) of the rice parboiler adopter and nonadopter in the different statuses of adoption: the outcome of an adopter who did adopt (a), the expected outcome in the counterfactual hypothetical case (in case of an adopter who did not adopt) (c), the outcome of nonadopters (b), and the expected outcomes of nonadopters if they did adopt (d). The conditional expectations of the outcomes of parboilers in the four cases are defined as follows and summarized in Table 1:

$$E\left(y_{1i} | D_i = 1\right) = \beta_{1i} X_{1i} + \sigma_{1\eta} \lambda_{1i} \qquad 1$$

$$E\left(y_{0i} | D_i = 0\right) = \beta_{0i} X_{0i} + \sigma_{0\eta} \lambda_{0i} \qquad 2$$

$$E\left(y_{0i} | D_i = 1\right) = \beta_{0i} X_{1i} + \sigma_{0\eta} \lambda_{1i} \qquad 3$$

$$E\left(y_{1i} | D_i = 0\right) = \beta_{1i} X_{0i} + \sigma_{1\eta} \lambda_{0i} \qquad 4$$

Cases (1, 2) and in the diagonal of Table 2 represent the actual and observed outcomes in the sample. Cases (3, 4) represent the counterfactual outcomes of interest (income, output rate, food security, and poverty status).

Moreover, ESR allows calculating the impact of the treatment on the treated (ATT) as the difference between Cases (1, 3) (Heckman et al., 2001). ATT represents the impact of adoption on the outcome of the parboilers who actually adopted the GEM system and is expressed as follows:

$$\begin{aligned} ATT &= E\left(y_{1i} | D_i = 1\right) - E\left(y_{0i} | D_i = 1\right) \\ &= X_{1i}\left(\beta_{1i} - \beta_{0i}\right) + \lambda_{1i}\left(\sigma_{1\eta} - \sigma_{0\eta}\right) \end{aligned}$$

Similarly, the impact of the treatment on the untreated (ATU) represents the impact that the GEM system would have on nonadopters in case they decide to adopt, and it is estimated as the difference between Cases (2, 4):

$$\begin{aligned} ATU &= E\left(y_{1i} | D_i = 0\right) - E\left(y_{0i} | D_i = 0\right) \\ &= X_{0i}\left(\beta_{1i} - \beta_{0i}\right) + \lambda_{0i}\left(\sigma_{1\eta} - \sigma_{0\eta}\right). \end{aligned}$$

The validity of the results largely depends on the quality and relevance of the instruments. Good instruments should fulfill the exclusion restriction, meaning that instruments should affect the decision to adopt but have no correlation with the outcomes (Abadie, 2003). Contact with extension services and being trained in the GEM system are selected as instrumental variables in this study. The choice of these variables is justified by the fact that contact with extension services and training in agriculture can provide information and knowledge on the GEM system and may affect the decision to adopt this technology. Only women parboilers with information on the GEM system can adopt it. However, awareness and information

TABLE 1 Conditional expectations, treatment effects, and heterogeneity.

Subsamples	Decision status		Treatment effects
	Adopt	Nonadopt	
Adopters	(a) $E\left(y_{1i} \| D_i = 1\right)$	(c) $E\left(y_{0i} \| D_i = 1\right)$	ATT
Nonadopters	(d) $E\left(y_{1i} \| D_i = 0\right)$	(b) $E\left(y_{0i} \| D_i = 0\right)$	ATU

ATT: the average treatment effect on treated; ATU: the average treatment effect on untreated.

TABLE 2 Distribution of rice parboilers surveyed in Benin.

Country	Area	Region	Frequency	Percentage
Benin	North	Malanville	400	48.66
	Centre	Bante	80	9.73
		Dassa	149	18.13
		Glazoue	48	5.84
		Ouesse	23	2.80
		Savalou	105	12.77
		Save	17	2.07
Total			822	100

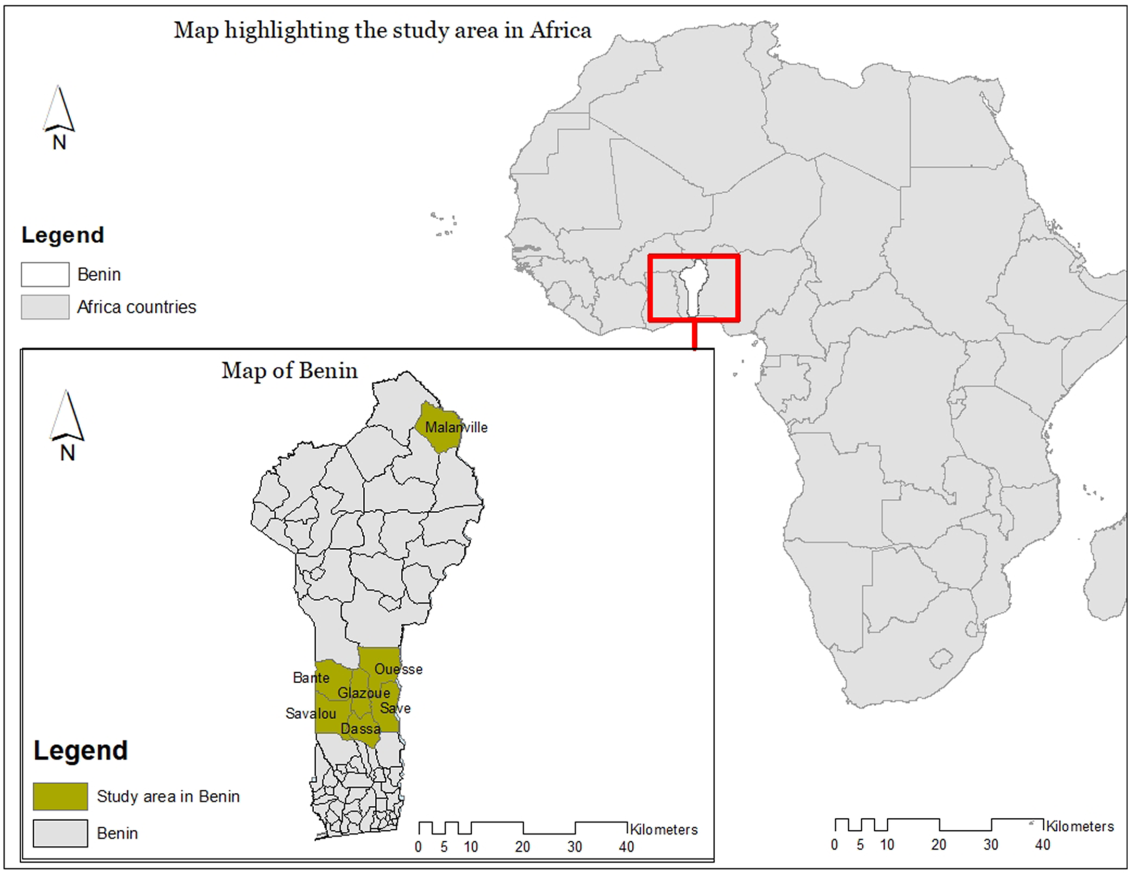

FIGURE 2
Map of Benin highlighting the study area.

cannot directly influence the outcome. In addition, we test the validity of the two instruments. Following Di Falco et al. (2011), we performed a simple falsification test: if a variable is a valid selection instrument, it will affect the technology adoption decision, but it will not affect the outcome variables. To assess the impact of the GEM system, we use the "movestay" command of STATA to estimate the endogenous switching regression model.

3.2. Sampling method and data collection

The study was conducted in seven districts of the Republic of Benin, including Malanville in the northern part of the country, Bantè, Savalou, Dassa-Zounme, Glazoué, Savè, and Ouèssè and the central part of the country (Figure 2). These regions were selected purposively for two main reasons: their major rice production areas are in Benin (Arouna and Aboudou, 2020), and the GEM system was first introduced in these areas through training and demonstration.

A two-stage random sampling technique was used to select the households of the parboilers in the study area. In the first stage, villages were randomly selected from the list of villages where parboiling activities were conducted and from where women were trained in GEM parboiling. The number of villages per district was proportional to the total number of eligible villages per district. From each selected village, the list of all rice-parboiler households was developed, and the women parboilers were randomly selected. The number of women parboilers per village was proportional to the total number of women parboilers in the village. In total, 822 women were randomly selected. This resulted in the number of parboilers to investigate in each village (Table 2).

Data were collected by enumerators selected based on their experience and trained in the use of the CSPro application on tablets. Computerized data collection has avoided many of the biases associated with paper questionnaires, such as errors in recording responses, changing variable values, and recording test responses for numeric variables. Data collection was conducted between January and February 2019. Four main categories of data were collected: socioeconomic and demographic characteristics, type of systems used for rice parboiling, perception of women of different parboiling systems and quantity and price of inputs and outputs in paddy parboiling activity.

3.3. Description of outcome variables and data

The first outcome variable of interest is the output rate. In the context of this study, we defined the output rate (dehulling return) as the quantity of dehulled rice obtained from a bag of 100 kg of paddy rice after parboiling and dehulling. It is expressed in kilograms per

100 kg of paddy. Second, we expressed the impact of adoption of the GEM system on income defined as income per 100 kg of paddy rice parboiled and milled. Income was calculated by multiplying the output rate per 100 kg of paddy by the average unit price of 1 kg of parboiled and milled rice in the data (in US$) (Income = Output rate *Price). To assess the impact of the GEM system on food security, we used two complementary indicators: the food consumption score (FCS) and *per capita* food expenditure. The FCS is a composite indicator developed by the World Food Programme (WFP, 2009), which reflects food availability, access to food and food consumption at the household level. The FCS is, therefore, a good indicator to evaluate the food security of parboiler households. However, the food consumption score may not capture all the actual household food consumption costs. Therefore, we added food consumption expenditure, which includes both the parboilers' own production and purchased food for consumption at the household level. Finally, the poverty line was calculated from the monthly mean adult-equivalent household expenditure (MAHE)[2] of the sample household. Two-thirds of the MAHE for sample households was used as the poverty line for the study. This approach has already been used in several research studies (World Bank, 1996; Amaza et al., 2009; Abass et al., 2017).

Table 3 describes the characteristics of the surveyed women parboiler households. Mean difference tests showed that the hypothesis of no difference between adopters and nonadopters of the GEM system is rejected for most characteristics. These results underscored the presence of selection into adoption, and heterogeneity between adopters and nonadopters must be considered in the impact assessment of the GEM system. Specifically, descriptive statistics showed a difference in the rice output rate between adopters and nonadopters. On average, the overall paddy output rate obtained by a parboiler is approximately 58 kg per 100 kg of paddy rice, with 50.39 kg for nonadopters and 65 kg for adopters. The average income of parboilers is also different based on adoption status. After parboiling and dehulling a bag of 100 kg of paddy, parboiler income is generally approximately US$ 36. The food consumption score and food consumption expenditure were also significantly different between adopters and nonadopters. The poverty headcount ratio is significantly different, at 0.39 and 0.24 for nonadopters and adopters of the GEM system, respectively. This means that 24% of the adopters are poor, while 39% of the nonadopters of the GEM parboiling system are poor. However, this difference between adopters and non-adopters should not be considered as an impact of the GEM system. Indeed, because of heterogeneity between adopters and non-adopters and self-selection into the adoption of the GEM system, other factors apart from adoption of GEM system may explain the difference between the two groups. The ESR method used in this study helps to account for other factors in the estimation of the impact of GEM technology.

The results showed that adopters and nonadopters of the GEM system are also distinguishable in terms of household characteristics. Evidence from Table 3 shows that the mean age of the parboilers was 43 years old, and they were mainly women. This highlights the fact that the stakeholders in parboiling activity in Benin were women. Approximately 93% of respondents were married, a sign of independence and maturity as cultural norms in Benin villages. The mean household size of the sample surveyed is 6 people. Furthermore, approximately 61% of respondents received training on the GEM system, with 96% being adopters and 26% being nonadopters. The fact that 26% of women received the training on the GEM system but they did not adopt can be explained by other factors that also affect the decision of women parboilers to adopt the GEM system. These factors are analyzed in the results section. Approximately 34% of the women parboilers had formal education. Only 8% of the respondents reported that they had recently obtained credit for rice processing. Moreover, 55% of parboilers were engaged in rice parboiling activities as their main occupation, and 36% of parboilers were also rice producers. In addition, all parboilers were members of parboiler associations. Finally, approximately 78% of respondents had contact with agricultural extension agents.

For a robustness check, we tested the properness of the two instruments (contact with extension service and training in agriculture) used. The results showed that contact with extension services and training in agriculture are jointly statistically significant in explaining the adoption of the GEM system but not in the outcomes (Table A1). To further check the robustness of the instruments, we also performed weak instrument and overidentification tests (Staiger et al., 1997). We rejected the null hypothesis that the instruments are weak [$F = 385.16$ ($p = 0.00$)] (Table A1). However, the instruments affected all five outcomes. Furthermore, we performed the overidentification test (Table A1). Therefore, simple falsification, weak instruments and overidentification tests confirm the validity of the two instruments (contact with extension services and training on the GEM) used in this study.

4. Results

We started this section with an analysis of the perception of women parboilers. This is followed by the analysis of drivers of the adoption of the GEM parboiling system. Finally, we present the impact of the adoption of the GEM parboiling system on different outcomes (income, output rate, food security and poverty headcount ratio) of women rice parboilers.

4.1. Perception of rice parboilers on parboiling activity in Benin

4.1.1. General constraints of rice parboiling activities

Rice parboilers in Benin face several processing constraints that contribute to making the local industry noncompetitive. Following an extensive review of the literature and talking to experts in the sector, a list of constraints was identified (Table 4), and parboilers were then asked to rank these constraints based on their experience and operations. The mean rank for each constraint was then calculated, and the rank was determined using Kendall's coefficient of concordance.

2 The living standard of households was measured based on the expenditure of the households. *Per capita* expenditure was derived by dividing the household expenditure with the number of members in the parboilers' household and standardized to adult equivalent based on the equivalency scales of Martin (2017).

TABLE 3 Socioeconomic characteristics of respondents.

Variables	Overall (n=822)	Nonadopters (n=412)	Adopters (n=410)	Mean difference
Outcome variables				
Income for 100 kg of paddy ($USD)	35.94 (7.46)	31.03 (5.12)	40.89 (6.05)	−9.852***
Output rate for 100 kg of paddy (kg)	57.68 (8.26)	50.39 (5.08)	65.02 (1.90)	−14.63***
Food consumption score (unite)	75.63 (14.24)	67.27 (11.84)	84.03 (11.18)	−16.77***
Food consumption expenditure ($USD/Year)	868.59 (427.97)	777.84 (491.13)	959.79 (329.62)	−181.96***
Poverty headcount ratio (%)	0.31 (0.46)	0.39 (0.48)	0.24 (0.43)	0.15***
Household characteristics				
Age of rice parboiler (year)	43.51 (10.01)	44.04 (9.05)	42.98 (10.88)	1.06
=1 if age is ≥40	0.64 (0.47)	0.68 (0.47)	0.60 (0.48)	0.077**
Household size (Number)	6.84 (3.36)	6.30 (3.44)	7.39 (3.19)	−1.09***
Number of children (Number)	2.56 (1.80)	2.17 (1.57)	2.95 (1.93)	−0.78***
=1 if female (%)	0.99 (0.07)	0.99 (0.06)	0.99 (0.06)	0.00
=1 if married (%)	0.93 (0.25)	0.93 (0.26)	0.93 (0.25)	−0.01
=1 if parboiler has a formal education (%)	0.34 (0.47)	0.37 (0.48)	0.30 (0.45)	0.07**
=1 if parboiling is main activity (%)	0.55 (0.49)	0.51 (0.50)	0.59 (0.49)	−0.08**
=1 if production is second activity (%)	0.36 (0.48)	0.34 (0.47)	0.39 (0.48)	−0.05
=1 if parboiler is rice producer (%)	0.73 (0.44)	0.58 (0.49)	0.89 (0.31)	−0.31***
=1 if parboiler is Muslim (%)	0.59 (0.49)	0.27 (0.44)	0.91 (0.29)	−0.64***
=1 if Dendi ethnic group	0.53 (0.49)	0.18 (0.38)	0.88 (0.32)	−0.70***
=1 if Idaasha ethnic group	0.14 (0.35)	0.25 (0.43)	0.04 (0.18)	0.21***
=1 if Mahi ethnic group	0.21 (0.41)	0.38 (0.48)	0.04 (0.19)	0.34***
=1 if living in north region (%)	0.49 (0.50)	0.17 (0.37)	0.81 (0.39)	−0.65***
Institutional characteristics				
Distance to extension agent (km)	7.94 (4.48)	7.28 (4.07)	8.59 (4.78)	−1.31***
Distance to market (km)	3.30 (3.25)	3.39 (2.87)	3.20 (3.60)	0.19
Distance to town (km)	7.86 (5.17)	7.35 (5.03)	8.37 (5.26)	−1.03***
=1 if trained in GEM (%)	0.61 (0.48)	0.26 (0.43)	0.96 (0.19)	−0.70***
=1 if trained in parboiling activities	0.92 (0.27)	0.85 (0.36)	0.99 (0.12)	−0.14***
=1 if knowledge of GEM	0.77 (0.42)	0.55 (0.49)	1.00 (0.04)	−0.45***
=1 if contact with extension (%)	0.78 (0.41)	0.68 (0.46)	0.89 (0.31)	−0.21***
=1 if member of farm association (%)	1.00 (0)	1.00 (0)	1.00 (0)	0
=1 if has access to market information	0.97 (0.17)	0.97 (0.16)	0.96 (0.18)	0.01
=1 if has access to new varieties of rice	0.99 (0.12)	0.98 (0.13)	0.99 (0.09)	−0.01
=1 if has access to credit (%)	0.08 (0.26)	0.09 (0.29)	0.06 (0.23)	0.03*

***Significant at 1%, **Significant at 5%, *Significant at 10%, () standard deviation.

The findings showed that the lack of credit is the major constraint among rice parboilers in Benin. This constraint is seconded by the low availability of funds for the purchase of rice paddy. Many other constraints, such as the unavailability of areas for drying, the lack of training on improved techniques of parboiling, and the low storage capacity for parboiled rice were also seen to hinder parboilers from performing their work properly. Some constraints of less importance, such as the lack of knowledge of the price of rice and the unavailability of labor for sorting, were also mentioned.

4.1.2. Advantages of rice parboiling

Among the various advantages mentioned of parboiling rice, Kendall's test revealed that improving the quality of rice is the first and most important advantage according to the women parboilers (Table 5). Obtaining better nutritional value, reducing the volume of broken rice and attenuating the effect of bad drying (cracking) are also some key advantages identified as related to the parboiling of rice (Table 5). However, advantages such as better and longer storage, more resistance against insect attacks and avoiding the absorption of environmental humidity are also present in parboiling rice advantages.

TABLE 4 General constraints of rice parboiling activities.

Constraints	Mean rank	Rank
Lack of credit	3.68	1
Low availability of funds for the purchase of paddy	4.03	2
Unavailability of areas for drying	5.81	3
Lack of training on improved techniques of parboiling	6.39	4
Low storage capacity for parboiled rice	6.93	5
Low storage capacity for parboiled rice	7.54	6
Low physical quality of processed rice	7.69	7
Difficulty in obtaining packaging materials for parboiled rice	7.70	8
Problem of selling in the market	7.84	9
Mixing of rice varieties	8.13	10
Presence of foreign materials in the parboiled rice	8.20	11
No knowledge of paddy rice prices	8.43	12
No availability of labor for sorting	8.63	13
The Kendall's ranking test		
N	822	
Df	12	
Kendall's W	0.24	
Chi-square	2359.55***	

***Significant at 1%.

TABLE 5 Advantages of rice parboiling.

Parboiling advantages	Mean rank	Rank
Improve the quality of rice	3.03	1
Produce better nutritional value	3.21	2
Reduce the rate of brokenness of rice in milling	3.34	3
Attenuate the effect of bad drying (cracking)	3.92	4
Achieve better and lengthy storage	4.53	5
More resistance to insects' attack	4.94	6
Avoid the absorption of humidity of the environment	5.02	7
The Kendall's ranking test		
N	822	
Df	6	
Kendall's W	0.247	
Chi-square	1219.46***	

***Significant at 1%.

4.2. Determinant of adoption of the GEM parboiling system

We analyzed the drivers of the adoption of the GEM parboiling system, and the results are presented in Table 6. The model is globally significant at the 1% level, and 56% of the variation in the dependent variables is explained by the variation in the explanatory variables. The results showed that eight variables significantly drove the adoption of the GEM parboiling system. Knowledge and information indicators such as contact with extension agents, receiving training on the GEM parboiling system and having access to market information are positively associated with adopting the GEM parboiling system. This suggests that the likelihood of adopting the GEM parboiling system is higher for households that had access to information and knowledge than for those that did not. Furthermore, the distance to the extension agent is positively associated with the probability of adopting the GEM parboiling system.

The positive effect of contact with extension could be explained by the fact that most of the extension agents work in collaboration with AfricaRice for the training and dissemination of the improved GEM parboiling system. Thus, all women parboilers using the GEM system were in contact with extension agents who gave them training.

TABLE 6 Determinant of adoption of the GEM parboiling system.

Variables	Coefficients	Standard error
=1 if Dendi ethnic group	0.92***	0.26
=1 if parboiling is main activity (%)	−0.09	0.17
=1 if production is second activity (%)	0.00	0.17
=1 if belong to parboilers association	0.09	0.46
=1 if have contact with extension (%)	0.57***	0.16
=1 if trained in GEM (%)	1.76***	0.19
=1 if access to market information	0.66**	0.31
=1 if access to new varieties of paddy	0.73	0.45
Age of rice parboiler (year)	−0.01	0.01
Household size (Number)	0.01	0.02
=1 if female (%)	0.07	0.67
=1 if married (%)	−0.52**	0.25
=1 if parboiler has a formal education (%)	−0.05	0.13
=1 if parboiler is rice producer (%)	0.44**	0.17
Distance to extension agent (km)	0.04***	0.02
Distance to town (km)	0.02	0.01
Distance to market (km)	−0.08***	0.02
=1 if living in north region (%)	0.27	0.25
_ Constant	−3.55***	1.01
Number of observations	822	
Log of likelihood	−253.11	
Wald Chi-square	633.31***	
McFadden Pseudo R^2	0.56	

***Significant at 1%, **Significant at 5%.

The positive correlation between "participation in the GEM training" and adoption of the GEM system showed that in addition to making them aware of the technology, it enabled women to improve their skills in its use and increase the probability of adoption. The results also revealed that the coefficient of the variable representing "being married" and "distance to market" have a significant and negative influence on the use of the GEM system.

4.3. Impact of the GEM system on income, food security, and poverty reduction

This subsection presents the results from the endogenous switching regression model on the five main outcomes (income, output rate *per capita* food consumption expenditure, food consumption score, and poverty headcount ratio). Table A2 presents the estimated coefficients of the selection model on adopting the improved GEM system or nonadopters for different outcomes. The estimated coefficients of the selection terms are significantly different from zero, suggesting that both observed and unobserved factors influence the decision to adopt modern technology and welfare outcomes given the adoption decision. The result of the selection equation reveals that many variables are positively and significantly related to the adoption of the GEM system.

Table 7 shows the results of the impact of the adoption of the GEM parboiling system on the output rate. The expected quantity of milled rice per 100 kg of a bag of paddy under actual and counterfactual conditions is presented. We found evidence that the expected quantity of milled rice produced per bag of 100 kg of paddy by parboilers who adopted GEM technology is approximately 66.51 kg of milled rice.

In the counterfactual case (a), parboilers who actually adopted would have produced approximately 14.38 kg of milled rice per 100 kg (approximately 21.46%) less than if they did not adopt the GEM system for rice parboiling. Similarly, in the counterfactual case (b) that parboilers who did not adopt, they would have produced approximately 15.41 kg of milled rice (approximately 23.24%) more if they had adopted the GEM system. These results implied that the adoption of the GEM system significantly increases the rice output rate.

The impact of the adoption of the GEM parboiling system on income was also assessed (Table 8). The expected income per 100 kg of bag of paddy under actual and counterfactual conditions are presented. The results showed that the expected income per bag of 100 kg of paddy rice by parboilers who adopted the GEM system was approximately US$ 40.80.

In the counterfactual case (a), parboilers who actually adopted would have gained approximately US$ 7.25 per 100 kg of paddy (that is, approximately 17.77%) less if they did not adopt the GEM system

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TABLE 7 Impact of the GEM parboiling system on output rate using the ESR method.

Treatment effect	Treatment type		Treatment effect	Change (%)
	Without adoption	With adoption		
Output rate of 100 kg of paddy (kg)				
Parboiler who adopted GEM system	(a) 52.24	(c) 66.51	ATT = 14.38***	21.46
	(0.08)	(0.02)	(0.07)	
Parboiler who did not adopt GEM system	(d) 50.91	(b) 66.32	ATUT = 15.41***	23.24
	(0.09)	(0.01)	(0.08)	

***Significant at 1%; () standard error.

TABLE 8 Impact of the GEM parboiling system on income using the ESR method.

Treatment effect	Treatment type		Treatment effect	Change (%)
	Without adoption	With adoption		
Income for 100 kg of paddy (US$)				
Parboiler who adopted GEM system	(a) 33.55	(c) 40.80	ATT = 7.25***	17.77
	(0. 08)	(0.13)	(0.10)	
Parboiler who did not adopt GEM system	(d) 30.93	(b) 35.73	ATUT = 4.81***	13.46
	(0.11)	(0.18)	(0.12)	

***Significant at 1%; () standard error.

TABLE 9 Impact of the GEM parboiling system on the food consumption score using the ESR method.

Treatment effect	Treatment type		Treatment effect	Change (%)
	Without adoption	With adoption		
Food consumption score (unit)				
Parboiler who adopted GEM system	(a) 70.62	(c) 84.03	ATT = 13.41***	15.96
	(0.17)	(0.18)	(0.28)	
Parboiler who did not adopt GEM system	(d) 67.26	(b) 86.28	ATUT = 19.02***	22.04
	(0.21)	(0.19)	(0.35)	

***Significant at 1%; () standard error.

for rice parboiling. Finally, in the counterfactual case (b) that parboilers did not adopt, they would have gained approximately US$ 4.81 (approximately 13.46%) more if they had adopted the GEM system. These results imply that adoption of the GEM system significantly increases women's parboiler income.

To assess the impact of the adoption of the GEM system on food security, we used two complementary indicators. We used the food expenditure and food consumption score (FCS). Table 9 presents the results of the impact of the adoption of the GEM parboiling system on the food consumption score.

We find evidence that in the counterfactual case (a), parboilers who actually adopted would have improved FCS in their household by approximately 13 points (approximately 15.96%) less if they did not adopt the GEM system for rice parboiling. Similarly, parboilers who did not adopt the GEM would have gained approximately 19 points (approximately 22.04%) more. These results imply that adoption of the GEM system significantly increases the food consumption score of women parboilers.

The results also showed that adoption of the GEM system reduced the food consumption expenditure of parboilers who adopted it by approximately US$ 72.63 (7.42%) (Table 10). Additionally, in the counterfactual case (b) of the parboilers who did not adopt, they would have increased their food consumption expenditure by approximately US$ 40.53 (approximately 4.99%) if they had adopted the GEM system.

Finally, the impact of the adoption of the GEM system on the poverty headcount ratio was assessed. We found evidence that in the counterfactual case (a), parboilers who actually adopted would have reduced the poverty headcount ratio in their household by approximately 5% more if they did not adopt the GEM system for rice parboiling (Table 11). In the counterfactual case (b) of parboilers who did not adopt, they would have been reduced by approximately 23% if they had adopted the GEM system. This is mainly because the adoption of the GEM system reduces the probability of poverty by nearly 5% for the average adopter, and the average untreated parboilers would have experienced a decrease in the poverty rate of approximately 23% by adopting the GEM system (Table 11). These results imply that the adoption of the GEM system significantly reduced the poverty headcount ratio in women's household parboilers.

TABLE 10 Impact of the GEM parboiling system on food consumption expenditures using the ESR method.

Treatment effect	Treatment type		Treatment effect	Change (%)
	Without adoption	With adoption		
Food consumption expenditure (US$/Year)				
Parboiler who adopted GEM system	(a) 1033.48	(c) 960.85	ATT = −72.63***	−7.56
	(9.66)	(4.88)	(7.42)	
Parboiler who did not adopt GEM system	(d) 770.98	(b) 811.51	ATUT = 40.53***	4.99
	(9.90)	(4.83)	(7.62)	

***Significant at 1%; () standard error.

TABLE 11 Impact of the GEM parboiling system on the poverty headcount ratio using the ESR method.

Treatment effect	Treatment type		Treatment effect	Change (%)
	Without adoption	With adoption		
Poverty headcount ratio (%)				
Parboiler who adopted GEM system	(a) 29	(c) 23	ATT = −5***	−26.09
	(11)	(13)	(1)	
Parboiler who did not adopt GEM system	(d) 39	(b) 15	ATUT = −23***	−61.54
	(10)	(14)	(1)	

***Significant at 1%; () standard error.

5. Discussion

To improve the physicochemical and nutritional value of the paddy rice produced in sub-Sahara Africa, AfricaRice has introduced the GEM system in many countries in the region. The objective of this study was to assess the drivers of adoption and impacts of the improved GEM parboiling system on the income, output rate, food security and poverty headcount ratio of women rice parboilers in Benin. The results showed that knowledge and information indicators such as contact with extension agents, being trained in the GEM parboiling system and having access to market information were positively associated with the probability of adopting the GEM parboiling system. Training in the GEM parboiling system and contact with extension agents have been found to positively impact the use of improved parboiling technology in Benin. This result is in line with the determinants of video technology adoption (Dandedjrohoun et al., 2012). Contact with agricultural extension services is supposed to facilitate better awareness, access to agricultural technologies and adoption (Jaleta et al., 2018). Membership in associations such as cooperatives enhances adoption by reducing information, credit, labor, and insurance market imperfections (Wossen et al., 2015). These results are in line with those of Zossou et al. (2009) who highlighted the importance of video screening in stimulating the adoption of improved technology in triggering local innovation. The results are also in line with the research from Zossou et al. (2022), who discussed the impact of information on technology adoption.

On average, the income of a random person selected among adopters of the GEM system increased by US$ 7.25 and the output rate increased by 14.38 kg per 100 kg of paddy rice after parboiling and dehulling. Adoption of the GEM system improves the food consumption score by 13.41 units in the population of adopters. Adoption of the GEM system increased the food consumption diversity in the household and decreased the food consumption expenditure in the population of adopters. This can be explained by the fact that the GEM system mainly aims to improve the physicochemical and nutritional quality, and all training and recent publications on the GEM system highlighted the nutrition aspect in rural areas (Ndindeng et al., 2015, 2022; Etoa et al., 2016; Zossou et al., 2022).

A lower poverty rate of 26% was found among households using the GEM system. The results were supported by women's perceptions that the output rate, quality of milled rice, better nutritional value and reduction of grain breakages during dehulling were major advantages of parboiling rice with the GEM system. These findings are in line with other previous research on parboiling activities. As reported by Ahiakpor et al. (2017), good appearance, good packaging and freedom from contaminants were the key traits that influenced consumers' choice of local rice in the Upper East Region. Ensuring better quality is necessary to obtain higher prices. As noted by Fofana et al. (2011), the use of traditional equipment and methods in parboiling results in high (90%) heat-damaged grains compared with the use of improved methods (17%). However, meeting the cost of improved processing vessels remains a challenge for most women parboilers. Training local fabricators in GEM systems of small, medium and large sizes should be promoted.

6. Conclusion and policy implications

This study assessed the impact of the improved GEM parboiling system on the livelihoods of women rice parboilers and the factors affecting the adoption of the GEM system and estimated its impact on income, output rate and food security in Benin. The improved GEM parboiling system has greater capacity than the traditional system. However, the high cost of the equipment limited its individual acquisition by women parboilers. In addition, different factors are positively and negatively correlated with the adoption of the GEM parboiling system, including "receiving training on GEM," "having contact with extension agents," "distance to extension agents," and "having access to market information." The GEM parboiling system adopters were found to have a lower rate of poverty (24%). This result suggests that the GEM parboiling system should be promoted among parboilers, as households with adopters of the GEM system suffer lower levels of poverty. In general, the findings indicate that the support and promotion of women parboilers training in GEM and having contact with extension agents is a means to increase technology uptake and access and subsequently improve their livelihoods. However, policy actions such as the training of local fabricators and credit options are required for the out-scale and sustainability of industrialization in Africa. Promotion of an innovation platform (IP) is a strategy to put all rice value chain actors together to work and have a common vision and defend their interest. Emerging opportunities in the rice sector that women and youth could take advantage of for better livelihoods and welfare could include sales to institutions, packaging, and government input subsidy programs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AA conceptualized the survey, design the data collection tools, contributed to the data analysis, and write the manuscript. RA contributed to the design of the data collection tools, data analysis, and contributed to write the manuscript. SA contributed to the survey design and review the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1066418/full#supplementary-material

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