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Impacts of Management Training of Rice Millers on their Business Performance: Evidence from the Senegal River Valley

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Abstract

This study examines the impact of a management training program implemented by a JICA project on the performance of rice millers in the Senegal River Valley. Using panel data of 90 millers that commenced operations prior to the project, we apply a difference-in-differences approach to assess changes in equipment and facility use, paddy procurement, marketing, and business performance. Results show that trained small-scale millers were more likely to invest in graders, moisture meters, and storage facilities. In addition, they increased volumes of paddy procurement and tended to sell rice in urban markets. However, improvements in profitability were limited, which we attribute to higher procurement costs and insignificant increases in the sales price. Heterogeneity analysis reveals an inverse U-shaped relationship between initial miller size and training impact, with the strongest effects observed among medium-scale millers with milling capacities of 2–3 t/h. These findings suggest that capacity-building efforts should target medium-scale operators and include policies to promote investment in milling capacity. This study contributes to the literature on rice value chain upgrading in sub-Saharan Africa and offers practical insights for designing more effective training interventions in the rice milling sector.

Keywords: Rice milling, Management training, Rice value chain, Sub-Saharan Africa, Senegal
JEL Codes: Q12, Q13, O12, O13, O33

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1. Introduction

Countries in sub-Saharan Africa (SSA) have made significant efforts to increase domestic rice production (Arouna et al. 2021; JICA 2018; Otsuka and Larson 2016; Otsuka et al. 2024). However, rice imports have been increasing at an equally high pace, resulting in little improvement in the rice self-sufficiency rate. For example, Senegal imported 2.2 million tons of rice in 2022, accounting for 69% of the total domestic supply, and despite an average annual growth rate of 9.25% in domestic rice production since 2008, the self-sufficiency rate has remained almost unchanged at around 40%[1] (FAO 2025). One of the important reasons for this stagnation in rice self-sufficiency in SSA is that consumers, particularly in urban areas, tend to prefer imported rice due to the inferior quality of domestic rice (Demont 2013). Thus, improving the quality of domestic rice to compete with imported rice is key to improving self-sufficiency in the region (Mano, Njagi, and Otsuka 2022).

While milled rice quality is influenced by several factors—such as the farmer's choice of variety, timing of harvesting, post-harvest handling, and storage (Futakuchi, Manful, and Sakurai 2013)—another key issue is rice milling, which involves the operation of appropriate milling machinery, proper paddy storage, and the procurement of high-quality paddy. In the context of rice value chains in SSA, rice millers typically rent out machines without any regard to paddy quality. There are, however, millers who purchase paddy from farmers or middlemen, store and process it, and then sell the milled rice to retailers or consumers, as in the case of rice millers in Asia (Reardon et al. 2014). Furthermore, in some countries, rice millers provide loans to farmers and supply agricultural inputs and technical guidance (Furuya and Sakurai 2005). In this value chain, rice millers play a critical role because even when farmers produce high-quality paddy, poor milling practices can significantly reduce the quality of the milled rice (Fiamohe et al. 2018; Kapalata and Sakurai 2020; Ragasa et al. 2020). Despite this, research on rice milling technologies and their impacts on milled rice quality remains scant, with the notable exception of studies by Mano, Njagi, and Otsuka (2022), Kapalata and Sakurai (2020), and Tokida et al. (2014), which demonstrate that the adoption of quality-enhancing equipment enables rice millers to improve milled rice quality and their business performance in Eastern African countries.

In Senegal, as domestic rice production has increased rapidly since 2008, many rice millers were established in the Senegal River Valley (SRV), the major rice-producing area of the country. However, milled rice produced in the SRV is often considered inferior in quality, leading urban consumers to prefer imported rice (Demont and Rizzotto 2012; Liu et al. 2010), although empirical studies suggest that consumers' willingness to pay does not differ between SRV rice and imported rice if their quality is the same (Demont et al. 2013; Demont and Ndour 2015). This

[1] Production data are taken from FAOSTAT crops and livestock products. Import, export, and domestic supply quantities are based on FAOSTAT food balance data (2010–). The self-sufficiency ratio is calculated according to the FAO definition: Production / (Production + Imports – Exports) × 100.

suggests that rice millers in SSA cannot produce high-quality milled rice comparable to imported rice unless the overall milling performance—including both technical and managerial aspects, such as appropriate procurement and storage of paddy, the use of proper milling technologies, and effective marketing strategies—is improved.

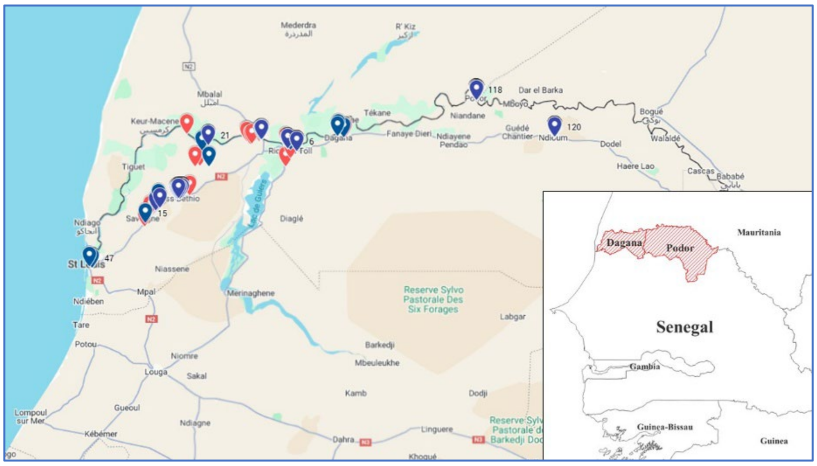
The question is whether the management efficiency of rice millers can be enhanced by a training program. Under the technical cooperation project by the Japan International Cooperation Agency (JICA), titled the Project for Improvement of Irrigated Rice Productivity in the Senegal River Valley (PAPRIZ2), a series of training programs has been offered for rice millers in the SRV. To the best of our knowledge, no studies have investigated the impact of training for rice millers on rice quality and their business performance in SSA. This study, therefore, aims to assess the impacts of training on rice millers' performance. Specifically, this research examines the impacts of training on 1) the choice of milling facilities and equipment, 2) paddy procurement methods, 3) operational efficiency, 4) marketing, and 5) millers' business performance. Furthermore, this study will investigate whether the impact of training varies based on the milling capacity of the rice millers, thereby shedding light on the optimum scale of rice millers.

This study contributes to the existing literature in three main ways. First, it provides the first empirical evidence on the effects of training for rice millers in SSA, addressing a major gap in value-chain research that has largely focused on production. Processors are crucial for upgrading and quality improvement by adopting modern equipment, complying with standards, and strengthening farmer linkages (Gereffi and Fernandez-Stark 2016; Humphrey and Schmitz 2002; Reardon et al. 2009; Trienekens 2011). Second, it extends the small- and medium-sized enterprise (SME) capacity-building literature to agro-processors. Empirical evidence on business training shows varied outcomes: McKenzie and Woodruff (2014) report modest profit effects but better practices, while Bruhn, Karlan and Schoar (2018) show large gains from intensive consulting in Mexico. In Africa, studies indicate that training can enhance managerial and technical skills and contribute to poverty reduction (Atiase, Wang, and Mahmood 2023; Baah-Mintah, Owusu-Adjei, and Koomson 2018; Bruhn and Zia 2013). This paper adds to that discussion by analyzing both technical and managerial aspects of processor performance. Third, it contributes to debates on firm size and efficiency in SSA. The existing findings are inconclusive: Biggs, Shah, and Srivastava (1995) and Söderbom and Teal (2004) highlight inefficiencies in large firms; Aggrey, Eliab, and Joseph (2010) find that an inverse U-shape with medium firms is most efficient; and Truett and Truett (2009) report a U-shaped pattern in South Africa. These contrasting results underscore the importance of examining heterogeneous effects among rice millers.

The organization of this article is as follows. After describing the study sites in Section 2 and data collection in Section 3, we present a descriptive analysis of rice millers' business performance in Section 4. Section 5 discusses the estimation method, followed by an examination of the estimation results in Section 6. Section 7 concludes the paper with a discussion of its policy implications.

2. Study site

This study was conducted in the Dagana and Podor departments, located along the SRV, an area with numerous irrigation schemes (Figure 1). This region produces approximately 80% of domestic rice in Senegal (USDA Foreign Agricultural Service 2015). In the SRV, rice is usually grown twice a year, and the average yield is 6.14 t/h in the dry season and 3.59 t/h in the rainy season (JICA 2021). This major rice-producing area hosts a large number of rice millers, whose numbers have increased in response to the expansion of rice production (IPAR 2019).



Note: Blue and red markers indicate the locations of small-scale millers and large-scale millers, respectively. The base map is sourced from Google Maps. The inset in the bottom-right shows a map of Senegal, with the Podor and Dagana departments highlighted in red hatching.

Figure 1: Geographic distribution of sampled rice millers in the Senegal River Valley

Rice millers in the SRV differ in their milling capacity, depending on the types of equipment they use. Most small-scale millers, with a milling capacity of less than 1 ton per hour, use only basic milling machines—such as Engelberg and Jet-pearler (one-pass) types—for husking without using quality-enhancing equipment, such as graders and destoners. These small-scale millers sometimes grow into semi-industrial millers by investing in quality-enhancing equipment and larger milling machines that can process paddy at rates between 1 and 2 tons per hour. In addition, large-scale millers with the capacity to process up to 4 tons per hour also exist. As of 2014, eight such mills were operating in the SRV (Soullier and Moustier 2018, 2021). In terms of product quality, small-scale millers generally produce low-quality rice with a high proportion of broken rice and the presence of foreign matter, leading to difficulties in competing with imported rice. Nevertheless, evidence from West Africa suggests that upgrading milling facilities is sometimes not profitable because of low capacity utilization, high depreciation costs, and harsh competition with imported rice (Soullier et al. 2020; Soullier and Moustier 2021).

JICA's support for Senegal's rice production began in 2004 with the formulation of a nationwide master plan (JICA 2006). Based on this plan, technical cooperation projects were implemented, including the "Project on Improvement of Rice Productivity for Irrigation Schemes in the Valley of Senegal" (PAPRIZ) from 2009 to 2014 and PAPRIZ2 from 2016 to 2021, whose objective was to improve rice productivity and quality in the Dagana and Podor departments through the development of rice value chains (JICA 2021). One of the key activities undertaken by PAPRIZ2 was capacity building for rice millers through training sessions for both small- and large-scale millers. Throughout the project period, twelve training sessions were held for small-scale millers and six sessions for large-scale millers. The project randomly invited millers to each session, training approximately 80 millers each year. The training covered seven key topics: 1) general information, 2) drying and cleaning of paddy, 3) use of moisture meters, 4) paddy storage techniques, 5) management of paddy storage warehouses, 6) processing of paddy by large-scale millers, and 7) processing of paddy and milled rice management by small-scale millers. The contents of the training for large- and small-scale millers were identical in topics 1 to 5, but topics 6 and 7 were specific to the two types of millers.

3. Data collection

Data collection was conducted in January and February 2024, following the completion of PAPRIZ2. Sampling was based on the membership lists of rice millers' associations in the two departments at the time of the survey. Among 163 small-scale millers, 113 were selected in proportion to the membership size of five small-scale millers' associations (UDAs: Rosso Béthio, Rosso Senegal, Richard Toll/Dagana, Podor, and Ndioum). For large-scale millers, 50 were initially targeted from the 68 operational millers of the large-scale rice millers' association (ARN). However, owing primarily to closures and partly to respondents being absent during the survey, 47 large-scale millers were ultimately surveyed. This figure is considered representative of the entire population of large-scale millers at the time of data collection.

The survey covered recall data from the five consecutive years (2018–2022), as well as for 2015—prior to the initiation of the PAPRIZ2 training program. The data were collected by trained enumerators through face-to-face interviews with miller representatives, focusing on the owner's characteristics, the history of investment in equipment and facilities, training participation, and millers' performance. After data cleaning, 90 millers (75 small-scale and 15 large-scale) were identified as having started their businesses before 2015, while the remaining millers began operations after the PAPRIZ2 intervention. The timing of participation in the training programs varied across millers. To address heterogeneity in the timing of entry and training participation, and to avoid excessively small samples, this study focuses on the 90 millers that were already operating before 2015, using data from 2015 (pre-project) and 2022 (post-project). It should be noted that this survey was conducted based on the list of association members available at the time of data collection. Consequently, rice millers that had ceased operations prior to the survey were not included in the sample.

Ideally, the sample should have been drawn at baseline; however, only recall data were collected at endline. As a result, the possibility of sample selection bias cannot be ruled out. While rice millers have come to play an increasingly important role in rice value chains, their operational efficiency continues to be hindered by several challenges, including inadequate knowledge of proper milling methods, limited access to working capital, irregular and small volume transactions, and market uncertainties. These constraints are particularly critical for large-scale millers, who are often unable to operate at full capacity (Demont and Rizzotto 2012). Indeed, the field survey revealed that several large-scale millers had closed operations between 2015 and 2022. Since there is no official membership record available from the ARN, it is difficult to directly obtain the survival rate of large-scale millers, but we estimate that the rate is about 40%.[2]

In contrast, data from an additional survey conducted in four UDAs (excluding Ndioum) revealed that the number of registered small-scale millers increased from 66 in 2015 to 121 in 2022. Moreover, only six millers were reported to have left the UDAs during this period. These figures closely align with our sample data and suggest that nearly all small-scale millers established prior to 2015 are captured in our sample. This implies that while survival bias is likely present among large-scale millers, it is minimal among small-scale ones. Therefore, the 75 small-scale millers in our sample can be considered representative of the small-scale milling sector in the SRV.

4. Descriptive analysis

4.1 Basic characteristics

Tables 1 and 2 compare the basic characteristics of rice millers and their owners at the time of the survey, by training participation status and miller size. Table 1 reports results for small-scale millers, while Table 2 reports results for large-scale millers. In both tables, the left-hand side shows millers that were operating prior to 2015, and the right-hand side presents the full sample. Among those established before 2015, the sample includes 75 small-scale millers (32 trained and 43 untrained), and 15 large-scale millers (7 trained and 8 untrained). Overall, more than 40% of these millers received training under the PAPRIZ2 program, although the timing of participation varies across millers.

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[2] According to a report from PAPRIZ, there were 28 registered millers in the ARN as of July 2013 (JICA 2014). On the other hand, our survey shows that among the 47 large-scale millers in the sample, 15 had started operations before 2015. However, among the 15 millers, only five appear in the list from the PAPRIZ report. This may indicate that some millers were established prior to 2013 but were not registered with ARN, while others were established between 2013 and 2015. Assuming that there are no unregistered surviving large-scale millers, the survival rate of large-scale millers would be 39.5% (15/ (28+15-5)).

No statistically significant differences were found in the mean values of any variables between the trained and untrained groups for both small- and large-scale millers, with one exception—rice cultivation experience in the full sample of small-scale millers. This suggests that training participation was not systematically selected, thereby mitigating concerns about selection bias. This is supported by the F-test values of joint significance, which are 0.83 for small-scale millers and 0.88 for large-scale millers when restricting the sample to those operating before 2015. While these results indicate that trained and untrained millers are broadly comparable in terms of owner and miller characteristics, they should be interpreted with caution, as the absence of statistically significant differences may partly reflect the limited sample size, which reduces the power to detect systematic differences.

4.2 Equipment and facilities

A comparison of equipment and facilities used by trained and untrained millers in 2015 and 2022 is shown in Table 3. The milling capacity of huskers serves as a key indicator of millers' operational scale and the types of milling machines employed. Among small-scale millers in 2015, trained millers had a lower average capacity of 0.63 t/h, compared to 0.74 t/h for untrained millers. This difference is statistically significant at the 5% level. By 2022, average capacities had slightly increased to 0.71 and 0.75 t/h for trained and untrained millers, respectively, and the difference was no longer statistically significant. This suggests that some trained millers have upgraded their milling facilities to higher-capacity huskers over time. As expected, large-scale millers exhibited substantially greater milling capacities than small-scale millers.

This study focuses on the adoption of graders, moisture meters, and warehouses as essential equipment and facilities for improving the quality of milled rice. In Senegal, broken rice is in high demand and sold at high prices due to unique consumer preferences. Homogeneous grain size is important, and 100 percent pure broken rice is particularly appreciated (Mané et al. 2021). In this context, graders play a crucial role in separating broken rice from head rice to meet this demand. Moisture meters are used to measure grain moisture content at the time of procurement, which affects the milling recovery rate, storage quality, and food safety. Although their adoption remains limited, moisture meters are considered to be critical, and their use is included as a component of the PAPRIZ2 training program. Warehouses are also vital for storing paddy without compromising quality and for ensuring stable milling operations. According to experts from PAPRIZ2, the current total storage capacity in the SRV is estimated to be only about half of what is required to match production and milling volumes. This shortage forces millers to process paddy immediately after purchase, resulting in reduced product quality and seasonal fluctuations in output (JICA 2014). In addition, poor storage conditions lead to quality deterioration and, consequently, revenue loss for millers. While destoners—machines that remove stones and other impurities—are sometimes used in other African countries to improve rice quality, their adoption in Senegal remains rare, possibly due to the limited availability of such equipment.

As shown in Table 3, there were no statistically significant differences in the use of graders or moisture meters between trained and untrained small-scale millers in either year, although trained millers exhibited a general trend toward increased adoption. One notable exception was warehouse ownership: in 2015, both groups had similar ownership rates of approximately 34–35%. However, by 2022, the proportion of trained millers owning a warehouse had increased substantially to 75%, compared with 44% among untrained millers. This difference was statistically significant at the 1% level. The value of the joint F-test was 1.57 in 2015, indicating no statistical significance, but rose to 3.39 in 2022, which is significant at the 5% level. These patterns suggest that training may have encouraged investment among trained small-scale millers, particularly in storage facilities.

Among large-scale millers, all had adopted graders at the beginning of the survey period, indicating their integration as a standard component of the large-scale milling systems. The use of moisture meters and the ownership of warehouses were also higher than among small-scale millers and showed increasing trends by 2022. However, the mean differences between the trained and untrained were not statistically significant. These findings suggest that large-scale millers already had relatively high baseline levels of equipment and facility adoption, leaving limited room for further improvements resulting from training.

4.3 Paddy procurement methods

In Senegal, rice millers typically procure paddy through four main channels: bank contracts, open-market transactions, production contracts with farmers, and self-production (Soullier and Moustier 2022). Bank contracts involve arrangements in which producer groups that have obtained seasonal loans from banks deliver paddy to designated millers as repayment, after which the millers repay the banks (Soullier and Moustier 2018, 2022). Since the government sets the purchase price at a relatively low level, producers tend to deliver lower-quality paddy than in market-based transactions, where prices vary according to quality. Nevertheless, millers continue to secure paddy through bank contracts because these contracts allow them to procure large quantities of paddy without capital and to obtain loans from financial institutions to finance additional market purchases. Bank contracts are primarily utilized by large-scale millers, as financial institutions typically select larger operations.

Under production contracts, millers provide rice farmers with in-kind loans—such as fertilizers and machine services, including tractor plowing and combine harvesting—which are repaid in paddy after harvest (Soullier and Moustier 2018). Because millers provide credit under these contracts and because such channels are typically used by farmers who are excluded from formal financial institutions due to prior defaults, the purchase price of paddy under these contracts is generally low. This reflects the implicit interest charges and the risk of default borne by the miller.

Open-market transactions denote a procurement channel in which farmers sell their harvested paddy directly to millers. Payments are typically made immediately at the point of sale, based on the weight and quality of the paddy. Self-production refers to paddy cultivated on fields owned and managed by the miller. It should be noted that milling services are not always associated with paddy procurement; rather, they are often provided as a rental arrangement in which millers provide milling services and charge a milling fee (Soullier and Moustier 2022).

Table 4 presents a comparison of paddy procurement patterns. No statistically significant differences were observed in the quantity of paddy milled between trained and untrained millers for both small- and large-scale millers, although trained small-scale millers exhibited a tendency to increase their milling volumes by 2022. The composition of paddy procurement channels also showed little variation, indicating that millers maintained similar sourcing patterns over time. Among small-scale millers, open-market transactions remained the dominant procurement channel for both trained and untrained groups, accounting for more than half of their total paddy procurement, while the use of bank contracts remained marginal. In 2015, trained small-scale millers were significantly more likely to enter into production contracts, with a 6.0 percentage points difference. However, by 2022, this difference had narrowed to 1.6 percentage points and was no longer statistically significant. This indicates that trained millers procured additional paddy through more reliable and trustworthy channels rather than through production contracts.

Despite the lack of statistical significance, the quantity of paddy handled by large-scale millers consistently shows a notable difference between trained and untrained millers. Additionally, large-scale millers diversified their paddy procurement across different channels and, notably, also relied on milling services. This suggests that they sought to utilize their machinery at fuller capacity regardless of the procurement channel. This preference can be attributed to the operational requirements of large milling machines, which necessitate a stable and high volume of paddy to maintain efficient operation. In contrast, milling services often involve small quantities brought in by individual farmers, making them less compatible with large-scale operations.

4.4 Operational efficiency and marketing

Table 5 compares trained and untrained rice millers in terms of their annual capacity utilization rate, quantity of milled rice produced, market outlets, and sales price. The annual capacity utilization rate U is calculated by

$$U = \frac{W}{C}\ , \qquad (1)$$

where W is the total quantity of paddy milled annually, and C is the annual milling capacity of the husker, calculated as the daily milling capacity (based on an eight-hour day) multiplied by

300 working days. In terms of marketing strategies, milled rice in Senegal is typically sold either to traders at the miller's shop or directly to wholesalers and retailers in markets. The latter channel can be further categorized into sales to local markets and to major urban markets. Consumers in large cities tend to demand high-quality rice with uniform grain size, better whiteness, and higher cleanliness. High-quality rice also generally commands higher prices. Accordingly, this study uses the proportion of milled rice sold to major urban markets and the sales prices of both whole-grain and broken rice as proxy indicators for product quality and marketing strategy.

While trained millers demonstrated some progress in 2022 for both small- and large-scale millers, Table 5 indicates that differences in capacity utilization rates, quantities of milled rice, and market outlets remained statistically insignificant. Regarding sales prices, the overall price of milled rice declined between 2015 and 2022 for all millers, possibly due to increased competition, market saturation, or government policy interventions. It is somewhat unexpected that trained small-scale millers consistently sold both whole-grain and broken rice at significantly lower prices than untrained ones. These lower prices may be attributed to the relatively higher capacity utilization rate among trained small-scale millers, although this difference is not statistically significant. They may purchase even low-quality paddy to maintain higher capacity utilization levels. However, the price gaps narrowed over time—from 18.68 FCFA /kg to 13.31 FCFA/kg for whole grain rice, and from 23.05 FCFA/kg to 20.11 FCFA/kg for broken rice.[3]

4.5 Business performance

The business performance indicators shown in Table 6 include annual sales, variable costs, fixed costs and depreciation, and profit. These figures are standardized on a per-milling capacity basis to account for differences in scale. Annual sales, denoted as *S*, are calculated as follows:

$$S = aQ_mP_w + (1 - a)Q_mP_b + Q_sF \ , \tag{2}$$

where a is the proportion of whole-grain rice in milled rice produced. Q_m and Q_s are the annual quantities of total milled rice produced and of paddy processed by milling services, respectively. P_w and P_b are the sales prices of whole and broken rice, and F represents the milling fee per ton for milling services. Annual profit (π) is defined as:

$$\pi = S - V - D - M \, , \tag{3}$$

where V is the annual operational cost (electricity, labor, and miscellaneous expenses), D is the variable cost of purchasing paddy (quantity of paddy each source times paddy purchase price of

[3] The exchange rate at the time of the survey was approximately 1 USD = 606 FCFA.

each source), and *M* is the depreciation on equipment over a 10-year lifespan using the straight-line method.[4]

Among small-scale millers, significant differences were observed only in operational costs and depreciation in both years, although these costs account for a relatively small share of total costs. These differences likely reflect greater investment in equipment and facility upgrades among trained millers. Average annual sales remained relatively unchanged for both trained and untrained millers between 2015 and 2022. This implies that small-scale millers made considerable efforts to sustain their business performance despite the declining milled rice sales prices. However, trained millers experienced an increase in paddy procurement costs, resulting in a drop in annual profit from 79.5 million FCFA/t in 2015 to 52.6 million FCFA/t in 2022. A possible reason is that trained millers needed to secure sufficient paddy after upgrading their facilities. To achieve this, they might have offered marginally higher prices or accepted lower quality paddy, thereby contributing to an increase in their average procurement costs. While the F-test of joint significance in 2015 indicated statistically significant differences between the two groups ($F = 3.00, p < 0.05$), no such significance was observed in 2022 ($F = 1.64$), suggesting that training did not lead to a statistically significant divergence in overall financial performance between trained and untrained small-scale millers.

In contrast, large-scale millers exhibited more pronounced differences. At baseline, trained large-scale millers recorded higher sales and profit per unit of milling capacity, although these differences were not statistically significant, possibly due to the limited sample size. By 2022, however, the profit gap had widened to 165.9 million FCFA/t and became statistically significant at the 5% level. This change was primarily driven by a decline in profits among untrained millers, while trained millers showed relatively stable sales and cost structures over time. This observation is supported by the F-test: joint significance was not statistically significant in 2015 ($F = 1.57$), but became highly significant in 2022 ($F = 4.90, p < 0.01$). These findings suggest that training had a substantial positive impact on the business performance of large-scale millers. Nevertheless, the possibility of survival bias should be acknowledged.

5. Estimation model

This section outlines the empirical models used to estimate the impacts of training on rice millers in the SRV. The analysis employs a difference-in-differences (DID) approach using a two-period balanced panel data for 2015 (before PAPRIZ2) and 2022 (after PAPRIZ2). As noted above, because the timing of training participation differs across millers and the sample includes those who entered after the launch of the PAPRIZ2 intervention, the analysis is restricted to data from

[4] Depreciation cost (*M*) was calculated using the straight-line method, assuming a 10-year lifespan of equipment. Specifically, depreciation was computed as the total acquisition cost of equipment divided by 10 years.

2015 and 2022 for millers that had already been operating since 2015. Furthermore, as suggested by our earlier estimate, indicating that the survival rate of large-scale millers is at most 40%, survival bias is likely to be present in this group. To address this issue, the first estimation model is restricted to small-scale millers that have operated continuously since 2015, ensuring a balanced panel and mitigating the effects of survival bias. The second model extends the analysis to include large-scale millers and incorporates interaction terms with milling capacity to examine the heterogeneous effects of training.

5.1 Impact of training for small-scale millers

The impact of training participation on small-scale millers is estimated using the following model:

$$Y_{it} = a + \beta(D_i \times T_t) + \delta T_t + \mu_i + \varepsilon_{it} \ , \tag{4}$$

where Y_{it} denotes the outcome variable of interest for rice miller i in year t. The indicator T_t is a time dummy that takes the value of one for observations in 2022 and zero for the baseline year, 2015. The variable D_i is a treatment dummy equal to one if miller i received training at any point before 2022. The model includes miller fixed effects, μ_i, which control for time-invariant characteristics specific to each miller. The error term is denoted by ε_{it}. The coefficient of interest, β, represents the average treatment effect on the treated (ATT), capturing the differential change in outcomes between trained and untrained millers over time. By including miller fixed effects and year fixed effects, this specification controls for unobserved heterogeneity across millers that does not vary over time, as well as macro-level shocks that affect all millers equally.

As described in the previous section, the analysis excludes large-scale millers and small-scale millers established after 2015. This restriction serves two purposes: (1) to mitigate survival bias that may arise if only successful large-scale millers remaining in the sample by 2022 are used, and (2) to ensure a balanced panel structure that allows for consistent DID estimation. Consequently, the estimation sample for Equation (4) consists of 75 small-scale millers that were in operation in both 2015 and 2022.

5.2 Heterogeneous treatment effect by milling capacity

We hypothesize that the impact of training is limited for large-scale industrial millers due to excessively high capital intensity of production in a low-wage economy. In contrast, small- to medium-scale millers use more labor-intensive production methods and, as a result, are more likely to benefit from low labor costs. To examine whether the effect of training varies by miller size, we estimate the following model, which includes interaction terms between the training treatment and both the linear and quadratic terms of milling capacity at baseline. This specification enables us to capture potential nonlinearities in the relationship between miller size and the impact of training:

$$Y_{it} = a + \gamma_1(D_i \times T_t) + \gamma_2(D_i \times T_t \times C_i) + \gamma_3(D_i \times T_t \times C_i^2) + \delta T_t + \mu_i + \varepsilon_{it}, \qquad (5)$$

where C_i denotes the milling capacity per hour of miller i in 2015. The interaction terms $D_i \times C_i$ and $D_i \times C_i^2$ capture how the impact of training varies nonlinearly with the initial miller size. This extended model enables us to estimate heterogeneous treatment effects that vary with miller size. The turning point—the level of milling capacity at which the marginal effect of training reaches its maximum or minimum—is calculated using the standard formula for a quadratic function.[5]

This analysis helps identify the miller size at which training is most effective. This estimation draws on a pooled sample of 90 millers, including large-scale millers, that were established prior to 2015. Although survival bias, particularly among large-scale millers, cannot be completely ruled out, it is unlikely to bias the estimated training effect downward. In fact, the bias may be upward in the estimates, since the millers excluded from the sample were primarily those who were financially underperforming. As a result, the remaining sample is skewed toward relatively better-performing millers, which may lead to an overstatement of the training effect. Accordingly, this bias does not pose a serious threat to our hypothesis that training is less effective among large-scale millers. Overall, this modeling approach enables us to estimate not only the average treatment effect of training but also how this effect varies across the distribution of miller size. Identification relies on the standard parallel trends assumption. Although this cannot be tested as the panel data include only two periods, we believe that it is partially supported by the baseline covariate balance shown in Table 1 and the joint significance tests presented in earlier tables.

6. Results

6.1 Impact of training for small-scale millers

The estimation results of the first model are presented in Table 7. In this model, the analysis focuses on the average treatment effect of PAPRIZ2 training on small-scale millers. Regarding the use of equipment and facilities, training is positively and significantly associated with an increase in the milling capacity of huskers, indicating that the training contributed to the upgrading of milling facilities. It also significantly increased the adoption of graders, moisture meters, and warehouses, with particularly strong effects observed for warehouses (coefficient = 0.31, $p < 0.01$). These results suggest that rice millers that recognized the importance of these technologies through the training were more likely to invest in them.

For paddy procurement, training led to a significant increase of 330.9 tons in the annual quantity of paddy milled ($p < 0.1$). The installation of storage facilities is likely to have contributed to the increased quantity of paddy processed. However, no effects were observed on the composition of

[5] The turning point C^* is calculated as $C^* = -\gamma_2/2\gamma_3$.

paddy procurement channels. Although not statistically significant, trained millers tended to increase their reliance on bank contracts and milling services, while reducing their use of market transactions and production contracts. Bank contracts are an effective means of securing paddy without working capital, and the increase in milling services may reflect a strategic effort by trained millers to enhance capacity-utilization rates.

Furthermore, training increased the proportion of millers selling directly to major cities at the 10 percent significance level. This pattern may reflect enhanced market access through marketing efforts by trained millers. It is also possible that their improved milling practices enabled them to meet the demand for quality rice in urban markets. However, the impacts on the capacity-utilization rate, total quantity of milled rice and sales prices were positive but not statistically significant. This may indicate that although trained millers may have improved the quality of milled rice, the change did not immediately translate into higher sales prices.

Regarding business performance, the estimation results from the first DID model show that training had no statistically significant impact on sales, profit, or cost structure. Although not statistically significant, the coefficient for annual sales per capacity is positive and very small, while that for annual profit per capacity is negative. The negative effect on profit is primarily explained by the insignificant effect on sales price and the higher costs associated with procuring paddy. These two factors are considered to be correlated as follows: trained small-scale millers increased milling capacity and invested in storage facilities; they increased total quantity of paddy processed by paying a premium to attract more clients, while keeping capacity utilization rate unchanged; probably as a result, the average cost of paddy procurement increased and the average quality of procured paddy decreased; the relatively low-quality paddy contributed to poor milling recovery and subpar milled rice quality, limiting potential gains in sales. Over time, however, marketing skills may improve, thereby increasing the profitability of improved management in the rice milling business.

6.2 Heterogeneous effects by milling capacity

The estimation results of the heterogeneous training effects are presented in Tables 8 to 11. To examine heterogeneity, each table presents: (i) a baseline model without interaction terms, (ii) a model that includes an interaction between training participation and milling capacity in 2015, and (iii) a model that further adds a squared term of milling capacity in 2015 interacted with training participation. Concerning equipment and facility usage (Table 8), most interaction terms are statistically insignificant. This is likely because large-scale millers had already achieved high adoption rates of these technologies by 2015, leaving little room for further improvement through training. However, the adoption of graders shows a negative and significant interaction with initial capacity, suggesting stronger effects among smaller millers, while the squared interaction term for moisture meters is significantly positive, implying that larger millers derive greater benefits from training in adopting moisture meters. Regarding paddy procurement outcomes shown in Table 9, the interaction terms are likewise statistically insignificant. As discussed earlier, this limited impact may reflect the training content, which primarily focused on improving technical efficiency rather than procurement strategies. Similarly, the interaction terms for annual capacity-utilization rate, the proportion of sales to major cities, and sales prices, shown in Table 10, are not statistically significant. In contrast, the regression results for total quantity of milled rice show a significantly positive interaction term with miller capacity, and a significantly negative squared interaction term, both at the 10 percent level (Table 10). This indicates an inverse U-shaped relationship with the peak at 1.96 t/h, suggesting that trained large-scale millers reduced the total quantity of milled rice. This may reflect the increased share of milling services among trained large-scale millers.

A similar nonlinear pattern emerges in the analysis of financial performance indicators shown in Table 11. With respect to annual sales per milling capacity and annual profit per milling capacity, the regression results indicate inverse U-shaped relationships with initial milling capacity. The peak is estimated at 2.61 t/h for sales—although the first-order interaction term is not significant—and at 2.59 t/h for the profit. These results suggest that the effect of training on sales and profit increases with the initial capacity among most millers except for very large-scale millers above approximately 2.6 t/h. However, this estimation shows that positive profit is obtained between 0.82 and 4.37 t/h, suggesting inefficiency among very small-scale millers. Therefore, optimal training impacts would be concentrated among millers with capacities in the 2 to 3 t/h range. As for cost components, no statistically significant heterogeneous effects are observed, except for general and administrative costs.

7. Conclusions

This study examined the impacts of the PAPRIZ2 training program for rice millers in the SRV, with a particular focus on equipment and facility usage, paddy-procurement methods, operational efficiency and marketing, and business performance. The results indicate that, among small-scale millers, training significantly promoted investment in key equipment and facilities—such as graders, moisture meters, and warehouses—increased the volume of paddy milled, and raised the proportion of rice sold to major cities. The findings suggest that the installation of warehouses facilitated increased paddy procurement, and the use of graders and appropriate storage improved the quality of milled rice, thereby enabling greater access to urban markets. It is evident that improving rice quality may not be feasible without investments in upgraded milling equipment. Although this study does not focus on how millers financed these investments, we expect that training will be more effective in promoting small- and medium-scale millers' investment in equipment if training programs are more explicitly linked to improved access to credit.

While trained millers demonstrated upward trends in both sales and capacity-utilization rates, these gains did not translate into significantly higher profits. The key constraints appear to be the high procurement costs and the insignificant price effect. To secure sufficient volumes, many millers seem to have paid higher purchase prices and/or purchased low-quality paddy, resulting in increased costs without corresponding improvements in rice quality. Over time, however, marketing skills may improve, thereby increasing profitability. Our study shows that the effects of training on paddy procurement channels were limited, likely because procurement strategies were not a focus of the training program. Therefore, training programs should incorporate this aspect more explicitly. As for sales price, even if trained millers produce improved quality rice and sell it in urban markets, it appears that they are unable to sell their products at higher prices. To compete with high-quality imported rice in urban markets, it is, in all likelihood, important to strengthen effective marketing strategies—particularly branding, as Britwum and Demont (2024) suggested.

The analysis of heterogeneous effects further reveals that the impacts of training vary by miller size, exhibiting an inverse U-shaped pattern. The positive effects of training on milled rice quantity, sales, and profit increase with the initial milling capacities up to around 2-3 t/h, and decline beyond that point. This finding suggests that investments in large-scale industrial millers equipped with highly labor-saving technologies may lead to excessive capital intensity, underutilized capacity, and ultimately unsustainable financial performance. Conversely, this finding also implies that very small-scale millers with capacities below 1 t/h are inefficient.

From a policy perspective, these results suggest that support for the rice-milling sector in Senegal should prioritize medium-scale operators. Training programs should be closely integrated with financial instruments that facilitate targeted investment in medium-sized huskers and quality-enhancing technologies. At the same time, small-scale millers continue to play an important role in rural markets, and policies that enable them to upgrade their facilities and gradually transition into medium-scale millers would also be valuable. Furthermore, greater emphasis should be placed on improving marketing, branding, and procurement strategies to enable rice millers to compete effectively in urban markets dominated by imported rice, thereby improving and maintaining sustainable profitability. A key limitation of this study is the exclusion of large-scale millers that exited from the market prior to 2022, which may introduce survival bias and potentially overestimate the training impacts for the remaining large-scale operators. Future research should examine the factors driving miller exit and assess the longer-term effects of training. Despite this limitation, the study contributes to the limited empirical literature on rice-milling technology in SSA and offers actionable insights for strengthening rice value chains in the region.

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Table 1: Comparison of basic characteristics of small-scale millers and their owners by training participation in Senegal River Valley

	Small-scale millers operating prior to 2015			All samples of small-scale millers		
	Trained (1)	Untrained (2)	Mean difference (3)	Trained (4)	Untrained (5)	Mean difference (6)
Aver. year of establishment	2008.1 (6.76)	2006.8 (8.81)	1.36	2010.8 (7.18)	2011.6 (9.49)	-0.80
Owner's sex (female=1)	0.09 (0.30)	0.19 (0.39)	-0.09	0.18 (0.39)	0.25 (0.44)	-0.07
Owner's age	49.59 (8.27)	51.14 (11.97)	-1.55	49.51 (8.97)	51.62 (11.38)	-2.11
Owner's education level (secondary/above =1)	0.13 (0.34)	0.12 (0.32)	0.01	0.18 (0.39)	0.12 (0.33)	0.06
Rice cultivation experience (=1)	0.78 (0.42)	0.61 (0.50)	0.18	0.80 (0.41)	0.63 (0.49)	0.17*
Rice trade experience (=1)	0.75 (0.44)	0.72 (0.45)	0.03	0.80 (0.41)	0.69 (0.47)	0.11
F-test of joint significance			0.83			1.07
No. of sample millers	32	43		45	68	

Note: Standard deviations in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

Table 2: Comparison of basic characteristics of large-scale millers and their owners by training participation in Senegal River Valley

	Large-scale millers operating prior to 2015			All samples of small-scale millers		
	Trained (1)	Untrained (2)	Mean difference (3)	Trained (4)	Untrained (5)	Mean difference (6)
Aver. year of establishment	2005.3 (8.67)	2003.9 (9.72)	1.41	2012.5 (8.82)	2013.5 (8.99)	-1.05
Owner's sex (female=1)	0.43 (0.54)	0.25 (0.46)	0.18	0.44 (0.51)	0.45 (0.51)	-0.01
Owner's age	57.00 (13.27)	56.00 (6.89)	1.00	54.13 (10.74)	57.52 (7.74)	-3.39
Owner's education level (secondary/above =1)	0.71 (0.49)	0.38 (0.52)	0.34	0.63 (0.50)	0.58 (0.50)	0.04
Rice cultivation experience (=1)	0.86 (0.38)	0.63 (0.52)	0.23	0.69 (0.48)	0.74 (0.45)	-0.05
Rice trade experience (=1)	0.71 (0.49)	0.75 (0.46)	-0.04	0.81 (0.40)	0.87 (0.34)	-0.06
F-test of joint significance			0.88			0.31
No. of sample millers	7	8		16	31	

Note: Standard deviations in parentheses.

Table 3: Comparison of equipment and facility usage between trained and untrained millers by miller association in 2015 and 2022

		Small-scale millers			Large-scale millers		
		Trained (1)	Untrained (2)	Mean difference (3)	Trained (4)	Untrained (5)	Mean difference (6)
Milling capacity of husker (t/h)	2015	0.63	0.74	-0.12**	3.06	2.28	0.78
		(0.28)	(0.14)		(1.80)	(1.94)	
	2022	0.71	0.75	-0.04	3.06	2.62	0.44
		(0.21)	(0.15)		(1.80)	(1.70)	
Use of grader (=1)	2015	0.16	0.14	0.02	1.00	1.00	0.00
		(0.37)	(0.35)		(0.00)	(0.00)	
	2022	0.44	0.26	0.18	1.00	1.00	0.00
		(0.50)	(0.44)		(0.00)	(0.00)	
Use of moisture meter (=1)	2015	0.00	0.02	-0.02	0.43	0.63	-0.20
		(0.00)	(0.15)		(0.54)	(0.52)	
	2022	0.09	0.02	0.07	0.57	0.63	-0.05
		(0.30)	(0.15)		(0.54)	(0.52)	
Ownership of warehouse (=1)	2015	0.34	0.35	-0.01	0.71	0.50	0.21
		(0.48)	(0.48)		(0.49)	(0.54)	
	2022	0.75	0.44	0.31***	1.00	0.75	0.25
		(0.44)	(0.50)		(0.00)	(0.46)	
F-test of joint significance	2015			1.57			0.62
	2022			3.39**			0.71
No. of sample millers		32	43		7	8	

Note: Standard deviations in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

Table 4: Comparison of paddy procurement channels between trained and untrained millers by miller association in 2015 and 2022

		Small-scale millers			Large-scale millers		
		Trained (1)	Untrained (2)	Mean difference (3)	Trained (4)	Untrained (5)	Mean difference (6)
Total quantity of paddy milled (t/year)	2015	568.1 (596.1)	628.5 (850.0)	-60.4	6944.6 (9885.4)	3120.3 (3880.2)	3824.3
	2022	878.5 (978.5)	608.0 (829.1)	270.5	7001.4 (10942.6)	2070.8 (4526.1)	4930.7
Proportion of paddy milled from bank contract (%)	2015	0.51 (2.22)	2.51 (14.21)	-2.0	14.96 (30.47)	18.06 (26.19)	-3.1
	2022	4.88 (17.71)	1.87 (6.26)	3.0	11.58 (28.06)	34.40 (33.62)	-22.8
Proportion of paddy milled from market (%)	2015	57.04 (25.54)	51.03 (34.61)	6.0	26.45 (20.61)	25.93 (24.40)	0.5
	2022	55.37 (24.10)	53.25 (29.84)	2.1	21.87 (18.48)	31.13 (25.12)	-9.3
Proportion of paddy milled from production contract (%)	2015	7.64 (19.96)	1.68 (6.49)	6.0*	22.67 (22.39)	14.58 (13.91)	8.1
	2022	4.42 (8.66)	2.79 (8.64)	1.6	25.61 (38.43)	21.33 (16.96)	4.3
Proportion of paddy milled from own production (%)	2015	9.19 (10.24)	8.00 (17.77)	1.2	28.10 (26.43)	17.30 (32.03)	10.8
	2022	11.73 (15.04)	10.40 (21.44)	1.3	21.73 (24.30)	9.56 (8.29)	12.2
Proportion of paddy milled from milling service (%)	2015	25.62 (21.96)	36.78 (34.22)	-11.2	7.82 (13.83)	24.14 (39.92)	-16.3
	2022	23.60 (23.55)	31.69 (29.50)	-8.1	19.21 (32.30)	3.58 (7.16)	15.6
F-test of joint significance	2015			1.16			0.42
	2022			0.61			0.84
No. of sample millers		32	43		7	8	

Note: Standard deviations in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

Proportions for each procurement channel are based on 72 small-scale and 12 large-scale millers, excluding those who did not procure paddy in the survey year.

Table 5: Comparison of operational efficiency and marketing between trained and untrained millers by miller association in 2015 and 2022

		Small-scale millers			Large-scale millers		
		Trained	Untrained	Mean difference	Trained	Untrained	Mean difference
		(1)	(2)	(3)	(4)	(5)	(6)
Annual capacity utilization rate (%)	2015	44.11	36.15	7.95	75.75	68.28	7.46
		(41.01)	(48.79)		(93.14)	(106.55)	
	2022	52.37	34.02	18.35	80.17	27.06	53.10
		(53.87)	(43.84)		(95.74)	(48.49)	
Total quantity of milled rice (t/year)	2015	344.6	398.9	-54.3	4720.1	1364.4	3355.8
		(368.1)	(649.4)		(6196.2)	(1400.1)	
	2022	506.1	408.0	98.2	4470.7	993.4	3477.3
		(494.7)	(607.2)		(6542.4)	(2043.5)	
Proportion of milled rice sold to major cities (%)	2015	10.31	12.79	-2.48	12.14	21.25	-9.11
		(27.91)	(31.02)		(32.13)	(40.16)	
	2022	15.00	11.28	3.72	26.43	10.00	16.43
		(31.55)	(26.75)		(45.34)	(28.28)	
Sales price of whole grain rice (FCFA/kg)	2015	270.2	288.9	-18.68**	292.5	278.3	14.17
		(24.7)	(39.5)		(44.5)	(34.9)	
	2022	249.1	262.4	-13.31*	274.2	251.7	22.50
		(24.6)	(34.8)		(49.0)	(29.9)	
Sales price of broken rice (FCFA/kg)	2015	256.7	279.7	-23.05**	276.5	277.7	-1.24
		(20.0)	(43.4)		(19.0)	(25.6)	
	2022	236.2	256.3	-20.11**	266.6	248.8	17.77
		(23.9)	(38.9)		(23.9)	(20.0)	
Milling fee (FCFA/kg)	2015	10.7	10.7	0.04	12.5	11.5	0.97
		(2.3)	(2.2)		(0.4)	(5.9)	
	2022	9.7	9.8	-0.11	13.0	12.4	0.61
		(2.5)	(2.6)		(2.0)	(2.1)	
F-test of joint significance	2015			1.58			1.29
	2022			1.71			1.81
No. of sample millers		32	43		7	8	

Note: Standard deviations in parentheses. * p<0.1, ** p<0.05, *** p<0.01. All prices are in real terms, deflated by the GDP deflator (base year = 2015). Sales prices of whole grain, broken rice and milling fees are reported only for millers that sell whole grain or broken rice; averages are not based on full sample. Sales price of whole-grain rice refers to the price at which rice is sold as whole grain by millers, although the product may not contain 100% whole grains.

Table 6: Comparison of millers' financial performance between trained and untrained millers by miller association in 2015 and 2022

		Small-scale millers			Large-scale millers		
		Trained (1)	Untrained (2)	Mean difference (3)	Trained (4)	Untrained (5)	Mean difference (6)
Annual sales per milling capacity (million FCFA/t)	2015	182.0 (255.4)	138.3 (210.5)	43.72	349.2 (394.9)	232.8 (459.0)	116.4
	2022	182.2 (177.6)	135.4 (202.4)	46.80	334.3 (378.7)	88.4 (149.3)	245.95
Annual paddy procurement cost per milling capacity (million FCFA/t)	2015	94.7 (137.6)	75.5 (126.3)	19.20	155.0 (197.3)	157.8 (291.6)	-2.78
	2022	120.7 (159.0)	72.3 (120.0)	48.37	153.8 (195.8)	70.9 (132.2)	82.91
Annual transport cost per milling capacity (million FCFA/t)	2015	0.21 (1.17)	0.97 (5.34)	-0.76	0.14 (0.38)	0.00 (0.00)	0.14
	2022	0.34 (1.06)	0.20 (1.27)	0.13	0.11 (0.28)	0.03 (0.09)	0.07
Annual general and administrative cost per milling capacity (million FCFA/t)	2015	6.70 (7.09)	3.77 (2.97)	2.93**	6.17 (6.63)	8.86 (11.09)	-2.69
	2022	5.18 (2.52)	3.79 (2.80)	1.40**	5.73 (7.41)	6.95 (14.62)	-1.21
Depreciation expense of equipment per milling capacity (million FCFA/t)	2015	0.72 (1.06)	0.33 (0.32)	0.40**	3.52 (5.81)	3.76 (3.26)	-0.24
	2022	0.76 (0.92)	0.41 (0.55)	0.35**	5.73 (7.41)	6.95 (14.62)	-1.21
Annual profit per milling capacity (million FCFA/t)	2015	79.5 (132.2)	57.8 (165.9)	21.7	184.3 (228.6)	62.4 (179.2)	121.9
	2022	52.6 (116.5)	58.7 (102.4)	-6.0	179.2 (182.1)	13.3 (32.8)	165.9**
F-test of joint significance	2015			3.00**			1.57
	2022			1.64			4.90***
No. of sample millers		32	43		7	8	

Note: Standard deviations in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

All prices are in real terms, deflated by the GDP deflator (base year = 2015).

Table 7: Estimation results of determinants for small-scale millers operating since 2015

Variables	ATT	SE
Milling capacity of husker (t/h)	0.08**	0.04
Use of grader (=1)	0.16*	0.09
Use of moisture meter (=1)	0.09*	0.05
Ownership of warehouse (=1)	0.31***	0.1
Total quantity of paddy milled (t/year)	330.91*	184.53
Proportion of paddy milled from bank contract (%)	5.57	4.22
Proportion of paddy milled from market (%)	-3.85	5.1
Proportion of paddy milled from production contract (%)	-3.84	3.86
Proportion of paddy milled from self-produced (%)	-2.41	2.82
Proportion of paddy milled from milling service (%)	4.53	3.66
Annual capacity utilization rate (%)	10.40	11.74
Total quantity of milled rice (t/year)	152.49	96.75
Proportion of milled rice sold to major cities (%)	6.20*	3.66
Sales price of whole grain rice (FCFA/kg)	6.34	4.61
Sales price of broken rice (FCFA/kg)	5.15	4.87
Milling fee (FCFA/kg)	0.02	0.32
Annual sales per milling capacity (million FCFA/t)	3.08	45.35
Annual paddy procurement cost per milling capacity (million FCFA/t)	29.17	33.66
Annual transport cost per milling capacity (million FCFA/t)	0.90	0.65
Annual general and administrative cost per milling capacity (million FCFA/t)	-1.53	1.25
Depreciation expense of equipment per milling capacity (million FCFA/t)	-0.04	0.09
Annual profit per milling capacity (million FCFA/t)	-25.41	30.91

Note: *p<0.1 **p<0.05 ***p<0.01

Table 8: Estimation results of the determinants of equipment and facility usage for all millers operating since 2015

	Use of grader (=1)			Use of moisture meter (=1)			Ownership of warehouse (=1)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Training (=1) x Year dummy (=2022)	0.13	0.19**	0.19	0.10**	0.02	0.12**	0.27***	0.32***	0.21
	(0.08)	(0.10)	(0.13)	(0.05)	(0.07)	(0.05)	(0.09)	(0.11)	(0.17)
Training (=1) x Year dummy (=2022)		-0.06**	-0.04		0.08	-0.09		-0.05	0.13
x Milling capacity in 2015		(0.02)	(0.14)		(0.06)	(0.08)		(0.04)	(0.22)
Training (=1) x Year dummy (=2022)			-0.00			0.03*			-0.03
x Milling capacity in 2015^2			(0.02)			(0.02)			(0.03)
Other control variables	No	No	No	No	No	No	No	No	No
Year dummy (=2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Miller fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.29***	0.29***	0.29***	0.10***	0.10***	0.10***	0.39***	0.39***	0.39***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
Peak milling capacity (t/h)			-8.72			1.48**			1.98
			(106.31)			(0.65)			(1.35)
No. of sample millers	180	180	180	180	180	180	180	180	180

Note: Standard errors clustered at the miller level are in parentheses. *p<0.1 **p<0.05 ***p<0.01

Table 9: Estimation results of the determinants of paddy procurement channels for all millers operating since 2015

	Total quantity of paddy milled (t/year)			Proportion of paddy milled from bank contract (%)			Proportion of paddy milled from market (%)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Training (=1) x Year dummy (=2022)	446.81	655.61	27.82	5.36	6.67	11.08	-4.35	-3.60	1.71
	(328.26)	(461.74)	(429.69)	(3.77)	(4.92)	(8.61)	(4.83)	(5.38)	(7.63)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015		-196.22	854.62		-1.21	-8.64		-0.69	-9.62
		(463.81)	(534.06)		(1.46)	(8.76)		(1.51)	(10.66)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015^2			-191.75			1.33			1.60
			(127.88)			(1.35)			(1.72)
Other control variables	No	No	No	No	No	No	No	No	No
Year dummy (=2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Miller fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1319.8***	1319.8***	1319.8***	4.23***	4.23***	4.25***	49.47***	49.47***	49.49***
	(85.30)	(85.14)	(84.32)	(0.93)	(0.94)	(0.93)	(1.19)	(1.19)	(1.20)
Peak milling capacity (t/h)			2.23**			3.25***			3.01***
			(0.85)			(0.409)			(0.513)
No. of sample millers	180	180	180	168	168	168	168	168	168

Note: Standard errors clustered at the miller level are in parentheses. *p<0.1 **p<0.05 ***p<0.01

Table 9: Estimation results of the determinants of paddy procurement channels for all millers operating since 2015 (continued)

	Proportion of paddy milled from production contract (%)			Proportion of paddy milled from self-produced (%)			Proportion of paddy milled from milling service (%)		
	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Training (=1) x Year dummy (=2022)	-2.19	-3.89	-10.41	-2.81	-2.55	-3.35	3.99	3.38	0.97
	(3.65)	(4.16)	(6.39)	(2.55)	(2.74)	(2.67)	(3.35)	(3.65)	(4.47)
Training (=1) x Year dummy (=2022)		1.58	12.54		-0.24	1.11		0.57	4.61
x Milling capacity in 2015		(1.55)	(9.87)		(0.59)	(1.78)		(0.61)	(3.50)
Training (=1) x Year dummy (=2022)			-1.96			-0.24			-0.72
x Milling capacity in 2015^2			(1.59)			(0.34)			(0.55)
Other control variables	No	No	No	No	No	No	No	No	No
Year dummy (=2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Miller fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.20***	6.20***	6.17***	10.73***	10.73***	10.72***	29.38***	29.38***	29.37***
	(0.86)	(0.86)	(0.86)	(0.66)	(0.66)	(0.66)	(0.87)	(0.88)	(0.88)
Peak milling capacity (t/h)			3.20***			2.29*			3.19***
			(0.267)			(2.16)			(0.189)
No. of sample millers	168	168	168	168	168	168	168	168	168

Note: Standard errors clustered at the miller level are in parentheses. *p<0.1 **p<0.05 ***p<0.01

Table 10: Estimation results of the determinants of operational efficiency and market outlets for all millers operating since 2015

	Annual capacity utilization rate (%)			Total quantity of milled rice (t/year)			Proportion of milled rice sold to major cities (%)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Training (=1) x Year dummy (=2022)	15.84	16.34	2.64	138.34	439.98	-158.63	9.45**	7.34*	-4.22
	(11.22)	(14.11)	(20.61)	(184.34)	(318.55)	(280.88)	(4.36)	(4.16)	(8.15)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015		-0.47	22.46		-283.46	718.54*		1.98	21.34
		(5.13)	(20.39)		(383.78)	(408.76)		(2.91)	(15.12)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015^2			-4.18			-182.84*			-3.53
			(3.18)			(100.77)			(2.40)
Other control variables	No	No	No	No	No	No	No	No	No
Year dummy (=2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Miller fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	44.92***	44.92***	44.92***	801.48***	801.48***	801.48***	12.61***	12.61***	12.61***
	(2.79)	(2.80)	(2.79)	(44.35)	(42.85)	(41.02)	(1.03)	(1.03)	(1.00)
Peak milling capacity (t/h)			2.68***			1.96***			3.02***
			(0.53)			(0.66)			(0.22)
No. of sample millers	180	180	180	180	180	180	180	180	180

Note: Standard errors clustered at the miller level are in the parentheses. *p<0.1 **p<0.05 ***p<0.01

All prices are in real terms, deflated by the GDP deflator (base year = 2015).

Table 10: Estimation results of the determinants of operational efficiency and market outlets for all millers operating since 2015 (continued)

	Sales price of whole grain rice (FCFA/kg)			Sales price of broken rice (FCFA/kg)			Milling fee (FCFA/kg)		
	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Training (=1) x Year dummy (=2022)	6.04	3.52	-6.42	6.94	4.44	-9.30	-0.16	-0.29	-1.16
	(5.41)	(5.57)	(10.22)	(5.71)	(5.81)	(10.36)	(0.50)	(0.59)	(1.04)
Training (=1) x Year dummy (=2022)		2.31	19.04		2.28	25.51		0.14	1.71
x Milling capacity in 2015		(2.59)	(16.58)		(2.92)	(16.99)		(0.39)	(1.47)
Training (=1) x Year dummy (=2022)			-2.99			-4.16			-0.33
x Milling capacity in 2015^2			(2.60)			(2.66)			(0.26)
Other control variables	No	No	No	No	No	No	No	No	No
Year dummy (=2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Miller fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	283.68***	283.69***	283.64***	270.99***	271.00***	270.84***	10.81***	10.81***	10.79***
	(1.40)	(1.39)	(1.39)	(1.47)	(1.47)	(1.47)	(0.12)	(0.12)	(0.12)
Peak milling capacity (t/h)			3.18***			3.07***			2.61***
			(0.22)			(0.18)			(0.18)
No. of sample millers	156	156	156	153	153	153	133	133	133

Note: Standard errors clustered at the miller level are in the parentheses. *p<0.1 **p<0.05 ***p<0.01

All prices are in real terms, deflated by the GDP deflator (base year = 2015).

Table 11: Estimation results of the determinants of business performance for all millers operating since 2015

	Annual sales per milling capacity (million FCFA/t)			Annual paddy procurement cost per milling capacity (million FCFA/t)			Annual transport cost per milling capacity (million FCFA/t)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Training (=1) x Year dummy (=2022)	22.59	30.87	-64.18	22.59	30.87	-64.18	22.59	30.87	-64.18
	(44.32)	(60.95)	(101.63)	(44.32)	(60.95)	(101.63)	(44.32)	(60.95)	(101.63)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015		-7.78	151.32		-7.78	151.32		-7.78	151.32
		(27.04)	(104.14)		(27.04)	(104.14)		(27.04)	(104.14)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015^2			-29.03*			-29.03*			-29.03*
			(15.92)			(15.92)			(15.92)
Other control variables	No	No	No	No	No	No	No	No	No
Year dummy (=2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Miller fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	178.64***	178.64***	178.64***	178.64***	178.64***	178.64***	178.64***	178.64***	178.64***
	(10.86)	(10.89)	(10.73)	(10.86)	(10.89)	(10.73)	(10.86)	(10.89)	(10.73)
Peak milling capacity (t/h)			2.61***			2.61***			2.61***
			(0.40)			(0.40)			(0.40)
No. of sample millers	180	180	180	180	180	180	180	180	180

Note: Standard errors clustered at the miller level are in parentheses. *p<0.1 **p<0.05 ***p<0.01

All prices are in real terms, deflated by the GDP deflator (base year = 2015).

Table 11: Estimation results of the determinants of business performance for all millers operating since 2015 (continued)

	Annual general and administrative cost per milling capacity (million FCFA/t)			Depreciation expense of equipment per milling capacity (million FCFA/t)			Annual profit per milling capacity (million FCFA/t)		
	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Training (=1) x Year dummy (=2022)	-1.04	-1.19	-2.81*	0.15	0.16	0.13	-14.68	-7.24	-85.16
	(1.17)	(1.41)	(1.63)	(0.14)	(0.15)	(0.29)	(27.33)	(35.17)	(51.70)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015		0.14	2.85*		-0.01	0.03		-7.00	123.44**
		(0.40)	(1.47)		(0.07)	(0.41)		(14.64)	(51.41)
Training (=1) x Year dummy (=2022) x Milling capacity in 2015^2			-0.49**			-0.01			-23.80***
			(0.24)			(0.06)			(7.99)
Other control variables	No	No	No	No	No	No	No	No	No
Year dummy (=2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Miller fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	5.45***	5.45***	5.45***	1.02***	1.02***	1.02***	75.83***	75.83***	75.83***
	(0.28)	(0.28)	(0.28)	(0.04)	(0.04)	(0.04)	(6.75)	(6.76)	(6.57)
Peak milling capacity (t/h)			2.88***			1.98			2.59***
			(0.34)			(11.83)			(0.24)
No. of sample millers	180	180	180	180	180	180	180	180	180

Note: Standard errors clustered at the miller level are in parentheses. *p<0.1 **p<0.05 ***p<0.01

All prices are in real terms, deflated by the GDP deflator (base year = 2015).

Abstract (in Japanese)

要　　約

本研究の目的は、セネガル川流域において JICA 技術協力プロジェクトが実施した精米業者向け研修の効果を検証することである。プロジェクト開始前から操業していた 90 精米業者のパネルデータを用い、差分の差法により設備投資、籾調達先、販売活動、経営成果の変化を分析した。その結果、研修を受けた小規模業者は選別機や水分計、貯蔵施設への投資を増加し、籾取扱量の拡大や都市市場での販売増加が確認された。他方、収益性の改善は少なくとも短期的には限定的で、調達費の上昇や販売価格の停滞が要因と考えられる。さらに異質性分析では、初期規模と研修効果に逆 U 字型の関係が確認され、特に精米能力 2〜3 トン/時の中規模業者に顕著な研修効果が見られた。これらの結果は、アフリカのコメバリューチェーン強化において、中規模精米業者を重点対象とし、設備投資を促す政策と組み合わせることの有効性を示唆する。

キーワード：　精米、経営研修、コメバリューチェーン、サブサハラアフリカ、セネガル

JEL コード：　Q12、Q13、O12、O13、O33