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The current status and prospects of the rice processing sector in the Fogera Plain, northwestern Ethiopia: a comprehensive overview and analysis

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Ethiopia's rice production has grown steadily since the 1970s, reaching 268,224 tons in 2020/2021. The Fogera Plain, a major rice-producing region, has strong potential for rice-processing expansion but faces challenges in grain quality, competitiveness, and supply chain efficiency. Rice processing adds value, supports incomes and employment, and strengthens rural economies. This study analyzes the structure, performance, and constraints of the Fogera Plain rice-processing sector, focusing on milling technologies, market dynamics, and operational challenges. Data on machine distribution, processing capacity, technological adoption, and value-chain factors were used to assess milling efficiency and its implications for producers and processors. N90 and NX110 mills dominate the sector (42.64% and 18.60%). Between 1998 and 2023, an average of 6.15 new machines were installed annually, reflecting a 5.25% mean growth. One-pass Engelberg machines account for 75.97% of mills, followed by two-pass SB series (23.25%) and multilevel machines (0.78%). Poor maintenance and limited processing knowledge reduce efficiency, increase breakage, energy use, processing time, and costs, and lower market value. Farmers face high transport costs and limited market access, while processors often act as buyers and traders. Milling is concentrated from November–February, and maintaining optimal paddy moisture (12–16%), skilled labour, and efficient machinery is critical. The sector has strong growth potential but is constrained by outdated technology, quality control issues, and supply chain inefficiencies. Enhancing competitiveness requires policy support, strengthened cooperatives, post-harvest management, and educational programs. Premium rice production offers higher returns, but adoption may remain limited without targeted interventions.

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1. Introduction

Ethiopia's rice cultivation has expanded substantially since the 1970s [1, 2], with paddy production increasing from 170,630 tons in 2019/2020 to 268,224 tons in 2020/2021 [3]. This growth, driven by improved agronomic practices, high-yield varieties, and government support for food security [2], is most notable in Amhara, SNNPR (Southern Nations, Nationalities, and Peoples' Region), Oromia,

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Somali, Gambella, Benishangul-Gumuz, and Tigray. In 2009, Amhara led in cultivated area (44%) and production (40%), followed by SNNPR (18.7% and 18.6%, respectively) [4]. Recent decades have seen substantial increases in Amhara, Benishangul-Gumuz, Oromia, and South West Ethiopia Peoples' regional states [5].

Despite this growth, domestic production remains insufficient to meet demand, and the competitiveness of Ethiopian rice is constrained by poor paddy quality and outdated processing equipment [6, 7], leading to significant imports from India, Pakistan, and Thailand that strain foreign currency reserves [8]. The commercialization of rice has fueled the rapid expansion of milling industries, particularly in the Fogera Plain, where registered processors increased from 10 in 2009 to over 150 nationwide by 2018 [7, 8]. Over 123 small-scale processors currently operate in the Fogera Plain, with an estimated 34% annual growth rate [7, 8].

The sector relies primarily on Engelberg steel huskers (N and NX models), favoured for affordability and ease of use [7]. Powered by 5- to 20-horsepower engines and often used for custom milling, these machines are prone to grain damage and low recovery rates [9]. Obsolete and poorly maintained equipment, together with limited adoption of modern combined machines due to drying limitations and high energy consumption, exacerbate quality issues. Variability in paddy seed size further reduces milled rice quantity and quality, shifting risk from processors to producers [7].

Although Ethiopia's rice production and milling sector have expanded rapidly, particularly in the Fogera Plain, persistent challenges limit competitiveness and quality. Outdated milling technologies, poor maintenance, inconsistent paddy quality, and weak post-harvest management reduce milling efficiency and shift quality risks from processors to producers. Supply chain inefficiencies, limited market access for farmers, and concentrated milling periods further constrain sector performance. Moreover, the absence of comprehensive, empirical data on machine distribution, processing capacity, technological adoption, and operational constraints hampers evidence-based interventions.

To address these gaps, this study assesses the structure, performance, and constraints of the Fogera Plain rice-processing sector, focusing on milling technologies, market dynamics, operational challenges, and opportunities to enhance rice quality, competitiveness, and profitability. The analysis integrates machine-level data, supply chain assessments, and qualitative evaluations to provide actionable insights for processors, policymakers, and stakeholders. By systematically examining technology adoption, supply chain efficiency, processing practices, and market interactions, the study contributes updated knowledge on Ethiopian rice production and processing and identifies strategies for sustainable and profitable industry development.

2. Materials and methods

2.1. Study area

The Fogera Plain, located in the South Gondar Zone of the Amhara Region between 11°42'N and 12°03'N latitude and 37°25'E and 37°58'E longitude, ranges in altitude from 1,500 to 2,500 meters. It experiences annual temperatures from 10.3°C to 18.75°C and an average annual rainfall of 1,284 mm [10]. Situated 582 km from Addis Ababa, east of Lake Tana on the Bahir Dar-Gondar road, the Fogera lowlands' marshland area is rainfall-dependent. This region is the primary rice producer in Ethiopia, contributing 70% of the nation's rice grain supply [4, 11]. Rice mills in the Fogera Plain are categorized as either Custom Mills (Village Mills) or Commercial Mills (Large Mills) [7]. A survey of 81 randomly selected rice processors was conducted in the Dera, Fogera, and Libokemkim districts, specifically in the towns of Wereta, Hamusit, and Yifag, and nearby kebeles (Abua Kokit, Shina Tsyon, and Jigna). These areas have seen rapid growth in rice processing industries due to increased rice commercialization and smallholder production. The survey area is depicted in Figure 1.

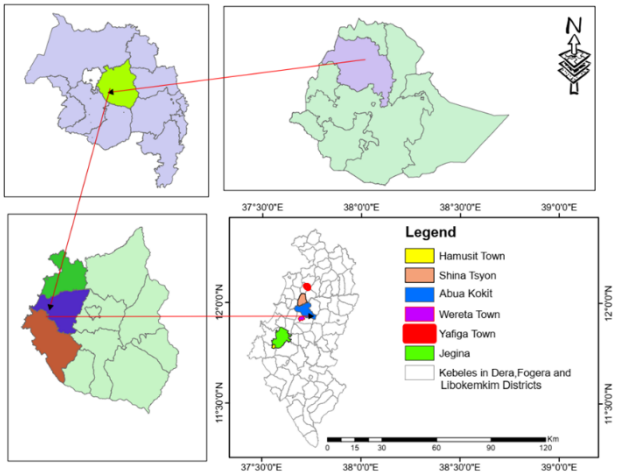

Fig. 1. Map of the survey area

2.2. Identification of target respondents

The rice processing industry in Ethiopia's Fogera Plain, especially in towns (Wereta, Hamusit, and Yifag) and Kebeles (Abua Kokit, Shina Tsyon, and Jigna), suffers from poor milled rice quality and obsolete equipment, leading to increased imports from India, Pakistan, and Thailand. A study investigated

this sector to understand its dynamics, identify key stakeholders, and address challenges related to local demand, processing trends, and market forces. Stakeholders across the rice value chain were consulted to discuss current practices, opportunities, and constraints. Primary data gathered via structured questionnaires, analyzed processors, marketing, machinery, milling quality, consumption, and gender roles. The study also examined input sources, industry obstacles, and opportunities, supplemented by secondary data on area coverage, processing trends, machinery types, and market information. Focus groups with processors, rice collectors, and government representatives further enriched the study's insights.

2.3. Sampling methods

This study examined Ethiopia's domestic rice processing sector using a mixed-methods approach, integrating quantitative and qualitative data. Data were collected through structured questionnaires and interviews with 81 randomly selected rice processors and other value chain participants, including input suppliers, development agents, government staff, and consumers. Study sites represented key regional, national, and agroecological zones for rice processing. Qualitative data from key informants complemented survey findings.

The questionnaire included closed-ended questions to collect quantitative data on processor characteristics, machine types, processing capacity, production volumes, and market participation; rating-scale (Likert-type) questions to assess perceptions of challenges, technology efficiency, and access to inputs and markets; and open-ended questions to capture managerial decisions, operational difficulties, value chain constraints, and improvement opportunities. This design enabled triangulation across stakeholders, integrating quantitative and qualitative perspectives for a comprehensive understanding of sector performance and constraints.

From a target population of over 150 processors across six study areas, 81 were surveyed, with a single household processor as the sampling unit. The sample size was calculated to estimate proportions within ±10% with 95% confidence, covering approximately 70% of all processors [12]:

$$n = \frac{Z^2 \times p(1-p)}{d^2} \qquad (1)$$

Where:

Z = the statistical confidence; therefore, z = 1.96 translates to 95% confidence,

p = Expected prevalence (of the rice processors of interest) with 70% of the included

d = Describes intended precision; d = 0.1 means that the estimate falls +/- 10 percentage points of true prevalence with the considered confidence.

In order to estimate rice processor population proportions in the district and towns, we require a simple random sample of 81 processors. This sample size will estimate the true proportion within 10% with 95% confidence and is expected to cover approximately 70% of all rice processors.

$$n = \frac{Z^2 \times p(1-p)}{d^2} = \frac{1.96^2 \times 0.70(1-0.70)}{0.1^2} = 80.67 \sim 81 \; sample\ rice\ processors$$

2.4. Data collection and sources

This study investigated the rice processing sector through secondary data analysis and primary research to determine its challenges, local demand, processing trends, and regional market dynamics. Stakeholders, identified through keyword searches and research databases, encompassed input suppliers, producers, extension agents, processors, traders, consumers, and NGOs. Primary data, collected via structured household surveys, evaluated processor activities (marketing, services, machinery, milling quality/loss, consumption), gender roles, input sources, opportunities, and constraints. Focus group discussions and key informant interviews complemented the survey data. Direct observation of facilities, marketing practices, and post-harvest handling validated the findings, providing a comprehensive overview of the rice industry's limitations and potential.

2.5. Data analysis

Data from group discussions, interviews, observations, and documents were analyzed thematically. Survey data from sampled households were evaluated using descriptive statistics (mean, standard deviation, frequency, and percentages). Perception-scaled responses were analyzed using a Likert scale. SPSS version 22.0 was used for data analysis, and results are presented in tables and figures. Statistical analyses were chosen based on data type and information obtained.

3. Results and discussion

3.1 Characteristics of the processors

A survey of 81 rice processors was conducted across three districts in the Fogera plain: Fogera, Libokemkim, and Dera. The sample distribution included 47 rice processors in Wereta town, 3 in Abua Kokit Kebele (Fogera district), 4 in Shina Tsyon Kebele and 15 in Yifag town (Libokemkim district), 11 in Hamusit town, and 1 in Jigna Kebele (Dera district). The survey revealed that 86.4% of rice processors were male-headed. The majority (45.7%) had an elementary education (grades 5-8), as detailed in Table 1. The average age was 36.65 years (SD = 11.45), ranging from 19 to 74 years.

Table 1. The education level of the owner of the rice processor

Education category	Education Level (%)
Irregular Education	1.2
Primary Education (Grades 1st to 4th)	8.6
Elementary Education (Grades 5th to 8th)	45.7
High School (Grade 9th to 10th)	13.1
Preparatory School (Grade 11th to 12th)	16.7
Diploma	12.3
First Degree	1.2
No Literacy	1.2

Survey data: 2024

3.2. Levels and features of the processors

Rice processing in the Fogera Plain has grown substantially since 1997, when only one processor served the region [7]. While the first milling business was established in 1998, the average establishment year is 2015. Before this, in 1990, the first rice processing service for farmers was established in Woreta town, followed by another in Yefag town, Libokemkem District [6, 7]. Currently, processors operate an average of two rice milling machines. Some processors (34.6%) use only rice processing machines, while others (65.4%) use both flour and rice processing machines. Capital and ownership details of the milling companies are shown in Table 2.

Table 2. Capital and ownership of the milling company

Variables	Mean	SD	Min	Max
Capital of Rice Processing Company (ETB)	1,829,649.12	2,851,945.43	30,000.00	12,000,000.00
Year of Establishment	2,015	5.30	1,998.00	2,023.00
Number of Branches	1.20	0.32	1.00	2.00
Number of Rice Milling Machines	2.13	1.10	1.00	7.00
Number of Flour Milling Machines	1.64	1.45	0.00	8.00
Number of Staff	4.67	3.53	1.00	30.00
Capacity of milling of paddy (Qu/hr)	7.87	4.47	1.55	20.00
Space size of milling facility (m^2)	377.69	453.97	20.00	3000.00
Warehouse for stock of paddy (Qu/hr)	2849.87	6838.15	50.00	50000.00

Survey data: 2024

Rice processing in the Fogera Plain is mainly small-scale, limited by capital, capacity, and infrastructure, especially unreliable electricity. The sector is dominated by private millers, including custom/village mills (65.4%) and commercial mills, with Engelberg machines most common (59.3%), followed by SB Series combinations (28.4%) (Figure 2). Custom Millers earn revenue from processing fees and by-products. Most processors use outdated, poorly maintained equipment, though some have acquired newer multi-level machines through cost-sharing programs. Limited drying space and high energy consumption further constrain efficiency and rice quality.

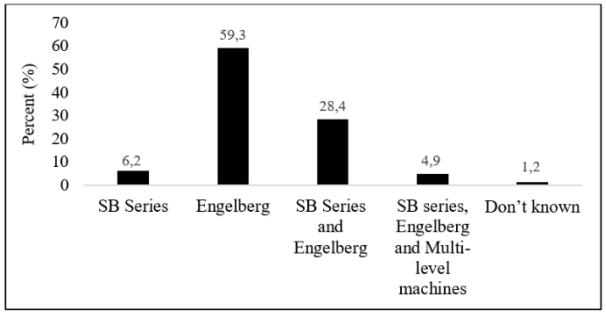

Fig. 2. Available types of rice processing machines in percent (%) in the Fogera plain

Multilevel processing machines are currently non-operational due to limitations in drying workspace, access, and electricity consumption. The N90 and NX110 rice milling machine models dominate the market with 42.64% and 18.60% shares, respectively, followed by the SB series and multilevel processing machines. N70 models are scarce and outdated in the Fogera plain. Newer Engelberg-type models (NPF-90 and NPF-110) have been introduced, but in limited quantities. While rice processing typically involves paddy drying, cleaning, de-husking, paddy separation, de-branding/whitening/polishing, grading, and color sorting to ensure quality and nutritional value, processors in the Fogera Plain primarily utilize only de-husking and polishing. Poor control over processing steps like cleaning, sorting, and storage leads to low-quality local rice that cannot compete with imported rice. Improving the quality of locally produced rice is crucial for competitiveness.

3.3. Access to the processors' improvement program

Rice processor capacity building, essential for industry advancement, is hampered by limited governmental support despite the potential of training, financial aid, and tax subsidies. Assaye and Alemu [7] highlighted inadequate government facilities and staffing as barriers to accessing capacity building. Development partners can address these issues by providing targeted training, financial assistance, and modern processing equipment, facilitated through advanced rice industries. A substantial 86.4% of rice processors surveyed reported a lack of government support. The limited assistance received originated mainly from agriculture, trade, and industry sectors, focusing on training, workspaces, and tax subsidies, but lacked a dedicated program for the rice processing industry in the study area. External donors, primarily MEDA, Agro BIG, and JICA, have supported approximately 34.6% of millers, offering training (72%) and financial assistance (18%), alongside market linkage and technical support. Machine cost-sharing, mainly through the MEDA project (2018-2024), constituted a significant portion of financial aid. Additionally, around 5% of rice millers acquired milling machines through lease financing from Waliya Leasing.

3.4. Possession and growth of rice processing

Rice processing in the Fogera Plain is predominantly small-scale due to limited capital and capacity, while large-scale processors are constrained by inadequate infrastructure, particularly unreliable electricity [7]. The sector is dominated by private millers, including custom/village mills (65.4%), which process rice without trading, and commercial mills that handle processing, buying, and selling, generating revenue from fees and by-products. Of 139 milling machines assessed, 75.97% are single-pass Engelberg types, slightly down from 84.3% previously reported. Engelberg mills are low in efficiency due to impure bran mixing with husk, increasing breakage, and reducing market income. Complete white rice production often requires two passes, as Engelberg machines lack a rice-husk separation mechanism. Millers operate an average of two machines each, ranging from one to seven (Figure 3).

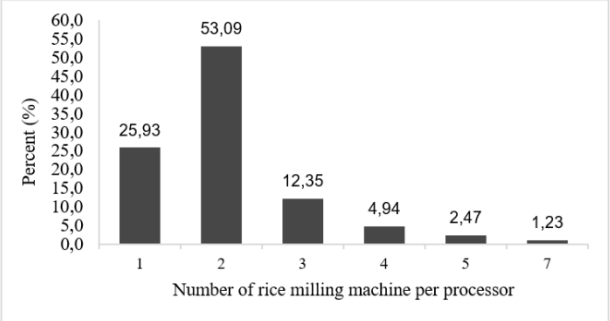

Fig. 3 Number of rice milling machines per individual miller in percent (%)

Commercial millers, often with two or more machines, supply domestically milled rice to wholesalers in cities such as Bahir Dar and Addis Ababa. Both single and multiple machine operators offer custom milling services. Paddy is processed using Engelberg mills, low-capacity machines that produce significantly broken rice during simultaneous dehusking and polishing. Engelberg milling machines suffer from low efficiency and require two passes for white rice, even with 2-3% paddy remaining due to the absence of a separation system [13]. In contrast, the SB series milling machine is a compact, single-pass, two-stage mill with a rubber roller husker and friction emery polisher. It utilizes rollers for husking, a brown rice huller system, and an air blower for husk removal [14]. The SB series offers versatility by producing

both brown and white rice, meeting varied consumer demands, and aligning with local diets and traditional food preparation. For example, *Injera* can incorporate up to 50% brown or white rice flour, favoured by urban consumers for color and farmers for cost savings. Rice is also used in traditional beverages like *Tela* and *Areki,* promoting sustainable and nutritious diets [15]. However, most processors primarily use machines for de-husking through custom millers. The N90 and NX110 models are the most common, holding 42.64% and 18.60% of the market share, respectively. Overall, 75.97% of respondents used Engelberg-type mills, including N90, NX110, NPF-90, N70, and NPF-110 models (Figure 4).

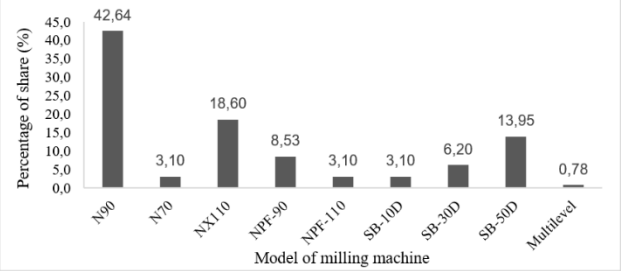

Fig. 4. Available models of milling machine (%)

The machines are mainly used for the combination operation of dehusking and polishing. It was observed that the percentages for both polishing and dehusking operations are 17.91% and 80.60%, respectively. The financial way of accessing the processor machine is from own resources (80.20%), resources from families and friends (6.20%), loans from banks/microfinance (7.4%), and cost-sharing approaches with NGOs or Lease Financing (6.10%), respectively. Cost-sharing approaches with NGOs or lease financing are from Waliya Capital Goods Finance Business S/C and MEDA for 2.5% and 3.6% respectively. The sources for the machine include a local dealer in Bahir Dar (48.1%), a dealer in Addis Ababa (29.6%), and used machines from another miller (17.3%). The survey indicated that the mean annual development of the rice milling business in the Fogera Plain from 1998 to 2023 is 5.25%, which is lower than the Assaye and Alemu [7] estimation of an average growth rate of rice processors of 34% per year between 1997 and 2018. The maximum and minimum growth rates recorded were 17.3% (2017) and 1.2% (2001 to 2007, 2011, and 2012), respectively (Figure 5).

According to the survey, an average of 6.15 new machines were bought annually between 1998 and 2023 (Figure 6). The sample machine types are Engelberg, SB series, and multilevel machines, with 99, 24, and 2 sample machines, respectively, from the period 1998 to 2023. The overall mean annual growth rate by

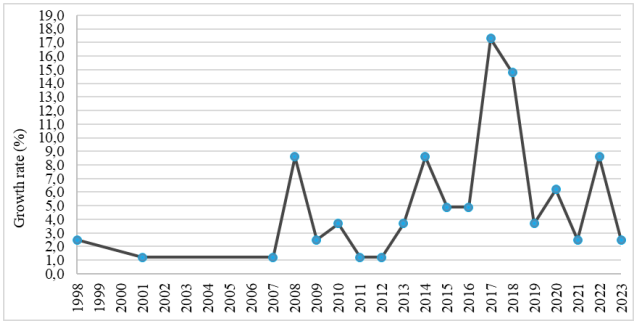

Fig. 5. Annual Growth Rate (years) of Rice Processors (%) in the Fogera Plain

machine type is 4.95, 1.1, and 0.1 machines, respectively. Figure 6 shows that the machine growth rate was calculated by dividing the recorded new machines per year by the total sample of machines and multiplying by 100. The maximum annual growth rates for various machine types from 2015 to 2023 were as follows: 3.97%, 5.56%, 14.29%, 12.70%, 10.32%, 3.97%, 4.76%, 8.73%, and 11.11%. In contrast, the minimum growth rate recorded for all machine types was 0.79% in both 1998 and 2012, as illustrated in Figure 6.

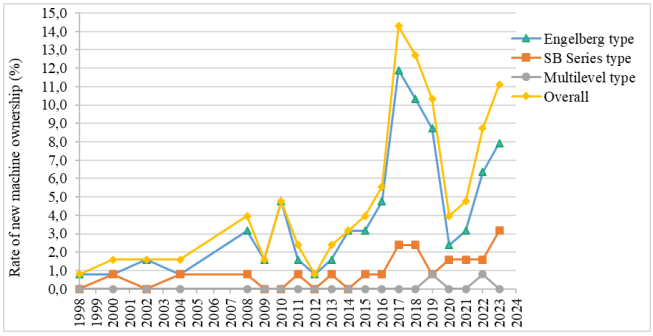

Fig. 6. The annual growth rate of the rice milling machines in the Fogera plain: 1998-2023

This study analyzed 132 rice processing machines acquired between 1998 and 2023. The N70 and N90 are older milling machines, while the SB series, introduced in the last decade, is relatively new. However, this result disproves Alemu *et al.* [15], who declare that about 52% of processors in Ethiopia reported owning old models of processing machines with limited efficiency. Additionally, 63% of processors believed that modern machines were not available in local and domestic markets. On the contrary, this assessment reveals a rapid growth in the ownership of rice milling machines in the Fogera plain, as depicted in Figure 6, indicating the presence of recent and new machines. Moreover, it aligns with [15], who declared that machinery quality and efficiency are related tothe unavailability of standard milling machines, reducing

the extent of rice breakage and the use of old and inefficient machines. Imported Chinese machines have lower efficiency than top-tier alternatives due to processor limitations [15]. Cost-sharing encourages the use of old, poorly maintained equipment. Multilevel processing machines are impractical due to high electricity consumption and limited drying space [7]. While large-scale rice processing machines can grade rice, there's no financial incentive for doing so. Consequently, processors use older machines and lack essential facilities for de-stoning, cleaning, grading, storage, and transport [7].

3.5. Perception of milling machine performance and quality

3.5.1. Quality of rice milling machine

The survey indicates that the most important investment for rice processors is processing machines and skilled manpower to operate the machines. This accounted for 75.97%, 23.25%, and 0.78% for one-pass Engelberg, two-pass SB series, and multilevel machine types, respectively. These findings align with the research conducted by Alemu *et al.* [15], which stated that about 84.3% of rice processors own a one-pass/polishing machine, followed by 38.5% owning a two-pass milling machine. All types of machines imported from China, operating on electric power with varying milling capacities, have lower efficiency levels compared to market-quality options due to limited processor capacity for higher-quality machines. Moreover, it was examined based on the perception and knowledge of processors using a 5-point Likert scale. The scale rates "very high," "high," "medium," "fair," and "low" as 1, 2, 3, 4, and 5, respectively, for machine failure frequency. Similarly, the scale rates "very poor," "poor," "fair," "good," and "very good" as 1, 2, 3, 4, and 5, respectively, for the availability of spare parts. The analysis revealed that the machine failure frequency and availability of spare parts for all sample rice milling machines (one pass, two pass, and multilevel) were rated as medium, as shown in Table 3.

Table 3. Likert scale rate of frequent failure and availability of spare parts of machines.

	The rate of machine failures						The Rate of availability of Spare parts					
	Score	Decision	%	N	Mean	Sd	Score	Decision	%	N	Mean	Sd
N70	2.25	High	3.28	4	1.33	0.58	2.75	Medium	3.31	4	1.33	0.58
N90	3.19	Medium	42.62	52	10.40	8.17	3.56	Fair	41.32	50	10.00	7.87
NX110	3.10	Medium	23.77	29	5.80	3.96	3.28	Medium	23.97	29	5.80	3.11
NPF-110	4.0	Fair	2.46	3	1.00	--	4.00	Fair	2.48	3	3.00	--
NPF-90	3.9	Fair	8.20	10	3.33	1.53	3.80	Fair	8.26	10	5.00	4.24
One pass	3.22	Medium	80.33	98	4.38	3.88	3.48	Medium	79.34	96	5.03	3.28
SB-10D	3.5	Fair	3.28	4	2.00	1.41	3.00	Medium	4.13	5	1.33	0.58
SB-30D	2.75	Medium	3.28	4	2.00	1.42	3.20	Medium	4.96	6	1.67	0.50
SB-50D	3.43	Fair	11.48	14	2.80	1.30	2.71	Medium	11.57	14	3.50	1.00
Two-pass	3.32	Medium	18.03	22	2.27	0.46	2.87	Medium	20.66	25	2.17	1.17
Multilevel	2.50	High	1.64	2	1.00	--	3.00	Fair	1.65	2	2.00	--
Overall	3.23	Medium	100	122	3.29	3.27	3.36	Medium	100.0	121	3.06	1.50

Survey data: 2024

Machine downtime from failures, insufficient parts and paddy stock, and labour shortages reduce milling efficiency and increase costs. Hence, the perception and knowledge of rice millers using a 5-point Likert scale, where very high, high, medium, fair, and low are rated with 1, 2, 3, 4, and 5 respectively, for the rate of machine downtime was fair from a sample of 120 rice milling machines, where the one pass, two pass, and multilevel machines were 80.0%, 18.3%, and 1.7% respectively, as shown in Table 4. Although the milling loss of a machine is also another critical parameter to evaluate the performance of a rice milling machine, it can be estimated both qualitatively and quantitatively. The survey assessed the perception regarding machine performance based on estimations by the sample rice millers' experience and knowledge of the rice milling business in the study area. It was revealed that medium, low, fair, high, and very high with 33.33%, 28.43%, 26.47%, 9.80%, and 1.96% respectively in the same order, based on the frequency of 125 sample rice milling machines, where 79.20%, 17.60%, and 3.20% are one pass, two passes, and multilevel respectively (Table 4).

Tab. 4. Likert scale score for rate of rate of machine downtime and the rate of milling loss

	The rate of machine downtime						The rate of milling loss of the machine					
	Score	**Decision**	**%**	**N**	**Mean**	**Sd**	**Score**	**Decision**	**%**	**N**	**Mean**	**Sd**
N70	3.00	Medium	3.3	4	1.33	0.58	2.50	High	3.20	4	2.00	1.41
N90	3.74	Fair	41.7	50	10.0	6.56	3.31	Medium	43.20	54	10.80	4.15
NX110	3.72	Medium	24.2	29	5.80	4.55	3.30	Medium	21.60	27	5.40	1.82
NPF-110	4.00	Fair	2.5	3	1.00	0.00	3.00	Medium	3.20	4	1.00	0.00
NPF-90	4.00	Fair	8.3	10	3.33	1.15	2.90	Medium	8.00	10	3.33	1.53
One pass	3.74	Fair	80.0	96	4.29	3.72	3.22	Medium	79.20	99	4.51	3.88
SB-10D	4.00	Fair	3.3	4	1.33	0.58	3.80	Fair	4.00	5	1.67	1.15
SB-30D	4.00	Fair	3.3	4	2.00	0.00	3.67	Fair	2.40	3	1.50	0.71
SB-50D	3.57	Fair	11.7	14	2.80	1.79	3.93	Fair	11.20	14	4.67	3.21
Two-pass	3.73	Fair	18.3	22	2.04	0.73	3.86	Fair	17.60	22	2.61	1.34
Multilevel	3.00	Medium	1.7	2	1.00	0.00	4.50	Low	3.20	4	2.00	0.00
Overall	3.73	Fair	100.0	120	3.18	2.19	3.38	Medium	100.0	125	3.59	2.79

Survey data: 2024

The Likert scale score for the rate of operation quality of the machine was also examined. The options for rating were very poor, poor, fair, good, and very good, which were assigned scores of 1, 2, 3, 4, and 5, respectively. This examination was conducted on a sample of 113 rice milling machines, where 78.76% were rated as one pass, 19.47% as two pass, and 1.77% as Multilevel. The overall rating for the rate of operation quality of the machine was determined to be fair, as shown in Table 5. The overall situation of the milling machine regarding the frequency of Failures, availability of spare parts, machine downtime, milling loss, and operation quality were assessed. It was revealed that the situation was either "fair" or "medium," indicating that predictive maintenance and real-time monitoring are required effective strategies for reducing the risk of machine failure and improving milling operation quality. It is crucial to understand the root causes of machine failure to implement long-term solutions and improve the reliability of equipment, the availability of spare parts, and the machine downtime.

Table 5. Likert scale score for the rate of operation quality of the machine

	N70	**N90**	**NX110**	**NPF-110**	**NPF-90**	**One pass**	**SB-10D**	**SB-30D**	**SB-50D**	**Two-pass**	**Multilevel**	**Overall**
Score	4.00	3.79	3.96	3.50	3.78	3.84	4.25	3.50	3.79	4.05	4.00	3.88
Decision	Fair	Fair	Fair	Fair	Fair	Fair	Low	Fair	Fair	Fair	Fair	Fair
%	3.54	42.48	23.01	1.77	7.96	78.76	3.54	3.54	12.39	19.47	1.77	100
N	4	48	26	2	9	89	4	4	14	22	2	113
Mean	1.33	9.60	8.67	1.00	4.50	5.93	1.33	2.00	4.67	2.75	1.00	4.52
Sd	0.58	7.13	2.08	0.00	3.54	2.66	0.58	0.00	1.53	0.70	0.00	1.71

Survey data: 2024

3.5.2. Milling performance of the machine

The study evaluated rice processors' perceptions of quantity and quality losses from SB series, Engelberg, and multilevel rice milling machines. The assessment focused on milling performance, recovery rate, and by-product generation. The capacity of the assessed machines (Table 6) was lower than reported by Assaye and Alemu [7] and machine manufacturers. The report revealed the machine types with the following capacities: N90 (800-1300), N70 (900-1500), NX110 (1000-1200), Sb30 (1000-1500), Sb50 (1800-2300), and Multi-level processors (2500 kg/hr) [7]. However, the mean milling capacity reported by respondents is significantly lower than both the manufacturer's recommendation and related research findings ($p < 0.01$). This suggests rice millers in the study area are underutilizing their milling machines' potential capacity (Table 6).

Table 6. Model of rice milling machine and mean milling capacity (kg/hr)

Model of Machine	Milling Capacity (kg/hr)						
	Mean	SD	N	Minimum	Maximum	Machine Type	Mean
Multilevel	1750.00** (144.34)	250.00	2	1500.00	2000.00	Multiple-pass mill	1750.00
SB-10D	772.22** (118.76)	205.71	4	600.00	1000.00	SB-Series (two-pass mill)	699.40
SB-50D	640.00** (20.82)	36.06	17	600.00	670.00		
SB-30D	638.10** (30.95)	53.61	7	607.14	700.00		
N90	601.52** (64.71)	78.74	55	479.55	625.00	Engelberg (One-pass mill)	521.10
NPF-90	598.06** (15.71)	67.74	11	566.67	700.00		
NX110	540.45** (38.22)	166.14	32	470.00	800.00		
NPF-110	466.67** (38.49)	101.84	4	400.00	600.00		
N70	311.11** (101.99)	176.65	3	150.00	500.00		

Survey results: 2024. In (bracket) is the standard error, ***1% probability of significance

The perceptions of rice millers on the performance of machines on the white and/or brown rice milling recovery (%) and by-product (%) of short, medium, and long paddy grain size for all machine types: Engelberg, SB series, and multilevel type milling machines were analyzed using test statistics. Rice milling recovery refers to the quantity of husked and polished brown and/or white rice obtained from paddy rice, which varies based on operator skill, machine type, variety, paddy conditions, and grain size. Processors struggle to recognize varieties, except for long, medium, and short grain sizes with brown rice stage colors. It was believed that paddy rice is composed of roughly 20% rice hull or husk, 11% bran layers, and 69% milling recovery, also referred to as the total milled rice [16].

The Engelberg types of milling machines do not have a separation mechanism for the byproducts composed of bran and husk, which account for 31% of the mass of paddy. Therefore, the rice milling recovery of the Engelberg-type machine, specifically the NX110 model, is significantly different and has an optimum milling recovery of 69% and a byproduct of 31% for the short-grain variety, as shown in Table 7 below. The results in Table 7 also showed that the outputs of Engelberg-type milling machines, which include N70, N90, NX110, NPF90, and NPF110 machine models, have significantly lower average values of White Rice Milling Recovery (%) compared to the optimum values at a 1% significance level for short grain sizes, indicating that the byproducts are significantly higher and incur higher milling loss, as shown in Table 7.

Table 7. White Rice Milling Recovery (%) and By-product (%) of short paddy grain size for Engelberg-type milling machines

Model	White Rice Milling Recovery						By-product (Husk and bran) %					
	Mean	T-value and Sign.	SD	N	Min	Max	Mean	T-value and Sign.	SD	N	Min	Max
N70	**67.63 (3.06)**	**-0.45**	**7.51**	**4**	**60.0**	**75.0**	**32.33 (3.06)**	**0.78**	**6.12**	**4**	**25.0**	**40.0**
N90	**67.98 (0.58)**	**-1.77**	**4.26**	**54**	**52.0**	**75.0**	**31.93 (0.62)**	**1.51**	**3.52**	**54**	**25.0**	**48.0**
NX110	**66.98 (0.92)**	**-3.28****	**4.60**	**25**	**55.0**	**72.0**	**32.62 (0.91)**	**2.89****	**4.53**	**25**	**28.0**	**45.0**
NPF90	**64.90 (2.34)**	**-1.76**	**7.39**	**10**	**52.0**	**73.0**	**35.10 (2.34)**	**1.76**	**7.39**	**10**	**27.0**	**48.0**
NPF110	**69.80 (0.72)**	**1.11**	**1.60**	**5**	**67.5**	**72.0**	**30.0 (0.76)**	**-1.32**	**1.70**	**5**	**28.0**	**32.5**
Overall	**67.48 (0.48)**	**-3.15****	**4.76**	**98**	**52.0**	**75.0**	**32.35 (0.49)**	**2.74****	**4.87**	**98**	**25.0**	**48.0**

Survey results: 2024. In (bracket) is the standard error, *5%, **1% probability of significance

Some studies on the paddy grain sizes of common rice varieties, *Selam, Shaga*, and *Ediget,* consider them to be medium grain sizes [17]. However, the shape and size of the grains may vary depending on agronomic management, applied inputs, and related production methods. The milling outputs of white rice milling recovery (%) and by-product (%) of medium

paddy grain size for Engelberg-type milling machines (mainly N70, N90, and NX110 models) on the medium grain sizes revealed that they were significantly lower than the optimum values at 1% significance levels for the NX110 and N90 models, respectively, as shown in Table 8. The mechanism of Engelberg-type rice milling machines is of very low capacity, as the husk and bran are not adequately separated from the polished white rice. Consequently, this rough process leads to some breakage, especially for medium and long grain sizes [18].

Table 8. White Rice Milling Recovery (%) and By-product (%) of Medium paddy grain size for Engelberg-type milling machines

Model	White Rice Milling Recovery						By-product (Husk and bran) %					
	Mean	T-value and Sgn.	SD	N	Min	Max	Mean	T-value and Sgn.	SD	N	Min	Max
N70	64.0 (3.79)	-1.32	6.56	3	57.0	70.0	36.0(3.79)	1.32	6.56	3	30.0	43.0
N90	65.92 (0.82)	-3.71**	2.99	13	59.0	70.0	33.69 (1.02)	2.65*	3.67	13	28.0	41.0
NX110	63.40 (1.44)	-3.90*	3.20	5	60.0	67.0	36.60 (1.44)	3.90*	3.56	5	33.0	40.0
NPF-90	--	--	--	--	--	--	--	--	--	--	--	--
NPF-110	--	--	--	--	--	--	--	--	--	--	--	--
Overall	65.05 (0.79)	-5.01**	3.62	21	57.0	70.0	34.71(0.88)	4.22**	4.03	21	28.0	43.0

Survey results: 2024. In (bracket) is the standard error, *5%, **1% probability of significance

The milling output comprised of White Rice Milling Recovery (%) and By-product (%) of the Long paddy grain size for Engelberg type milling machines showed that significantly lower than the optimum value recommended by the standards at 1% significance level for NX110, N90, and NPF110 machines models, but NPF-90 is significant at 5% significant level while the N70 has not shown a significant as shown in Table 9. The common varieties that are common in the study area are Fogera-1 and Nerica-4 with slender shapes [17].

Table 9. White Rice Milling Recovery (%) and By-product (%) of Long paddy grain size for Engelberg-type milling machines

Model	White Rice Milling Recovery						By-product (Husk and bran) %					
	Mean	T-value and Sgn.	SD	N	Min	Max	Mean	T-value and Sgn.	SD	N	Min	Max
N70	60.0 (2.89)	-3.12	5.0	3	55.0	65.0	40.0 (2.89)	3.12	5.0	3	35.0	45.0
N90	65.26 (0.71)	-5.23**	4.7	47	50.0	77.5	34.21 (0.61)	5.25**	4.2	47	22.5	47.0
NX110	63.58 (1.18)	-4.57**	5.80	24	50.0	73.0	36.33 (1.11)	4.79**	5.45	24	27.0	50.0
NPF-90	64.20 (1.50)	-3.19*	4.76	10	60.0	78.0	34.80 (1.69)	2.25	5.35	10	22.00	40.0
NPF-110	63.58 (1.18)	-4.57**	5.80	5	50.0	73.0	31.80(1.71)	4.79**	5.45	5	27.0	50.0
Overall	64.68(0.55)	-7.86**	5.18	89	50.0	77.5	34.91(0.51)	7.63**	4.84	89	22.0	50.0

Survey results: 2024. In (bracket) is the standard error, *5%, **1% probability of significance

The SB series machine is a compact rice mill with a 2-stage dehusking process using rubber rollers. It separates husks through aspiration and polishes bran, feeding rough rice to flexible rubber rolls, which divide husked material into brown rice, unhusked whole grains, and rice husk [14]. The survey found that 95% of rice processors believe SB series machines aren't used for whitening or polishing brown rice, suggesting the need for formal training and demonstration to enhance rice processing and value addition [11]. As shown in Table 10, the brown rice milling recovery (%) and by-product (%) of short paddy grain size for SB series milling machines do not show a significant difference with the optimum recovery composed of roughly 20% rice hull or husk and 80% brown rice milling recovery (starchy endosperm), also referred to as the total milled rice [16]. The grain sizes of short, medium, and long resulted in a decrease in the brown rice milling recovery (%) and by-product (%) regardless of grain sizes for the SB series milling machines (Table 10). Research reports revealed that the low recovery percentage of milled rice, which is reported to be 75 percent for de-husked rice (brown rice) and 65 percent for milled rice (white rice), is related to the quality and efficiency of the machinery, the inadequacy of the skill of machine operators, and deliberate action by processors in gaining price advantage and poor quality of paddy rice supplied by farmers [6].

Table 10. Brown Rice Milling Recovery (%) and By-product (%) of Short, Medium, and long paddy grain size, respectively, for SB series milling machines

Model	Brown Rice Recovery (%)						Percentage of Husk (%)					
	Mean	T-value and Sgn.	SD	N	Min	Max	Mean	T-value and Sgn.	SD	N	Min	Max
Short grain sizes												
SB10	81.50 (1.32)	1.13	2.65	4	79.0	85.0	18.50 (1.32)	-1.13	2.65	4	15.0	21.0
SB30	79.64(1.38)	-0.26	3.66	7	72.50	85.0	19.64 (0.85)	-0.42	2.25	7	15.0	22.5
SB50	80.19 (0.44)	0.43	1.60	13	77.50	85.0	19.85 (0.46)	-0.33	1.68	13	15.0	23.0
Overall (short)	80.25 (0.51)	0.49	2.48	24	72.50	85.0	19.56 (0.41)	-1.08	1.99	24	15.0	23.0
Medium grain sizes												
SB10	78.00(0.58)	-3.46	1.0	3	77.0	79.0	22.0 (0.58)	3.46	1.0	3	1.0	23.0
SB30	79.64(1.38)	-0.26	3.66	7	72.5	5.0	19.64 (0.85)	-0.42	2.24	7	15.0	22.5
SB50	78.00(2.00)	-1.0	2.83	3	76.0	80.0	27.0(7.0)	1.0	2.58	2	20.0	34.0
Overall (Medium)	78.75(0.50)	-2.45*	1.76	12	76.0	82.0	22.08(1.17)	1.78	4.06	12	18.0	34.0
Long grain sizes												
SB10	80.00(2.89)	0.001	5.01	3	75.0	85.0	20.0(2.88)	-0.001	5.0	3	15.0	25.0
SB30	77.43(1.04)	-2.46*	2.76	7	72.5	85.0	22.57(1.04)	2.46*	2.76	7	19.0	25.0
SB50	78.30(0.93)	-1.82	3.35	13	72.0	85.0	21.69(0.93)	1.82	3.35	13	15.0	28.0
Overall (Long)	80.26(2.48)	0.49	3.33	23	72.0	85.0	21.74(0.70)	2.50	3.33	23	15.0	28.0

Survey results: 2024). In (bracket) is the standard error, *5%, **1% probability of significance

3.6. Access to maintenance and repair of machines

The study reveals that the maintenance and repair of rice milling machines in the study area pose a significant challenge to the rice milling business, with the cost of repair and maintenance directly linked to the service years, with the mean service years exceeding 8 years, as shown in Table 11. The rice milling machines N90 (34), NX110 (16), and N70 (16) are identified as the models with the longest service years in the study area. Regarding the types of machines, the mean service years of one-stage type, two-stage type, and multipurpose are 10.04, 5.26, and 2.25 years, respectively.

This indicates that Engelberg machines are the oldest introduced models in the study area, according to numerous research reports. The quality and efficiency of machinery are linked to the unavailability of standard milling machines, reducing rice breakage and the use of old and inefficient machines [7, 15]. The survey report revealed that 77.78% of the processors used one-stage or Engelberg-type machines, which aligns with the reports that most rice processors use old, poorly maintained machines imported from China, with limited ownership of other necessary facilities for producing quality rice [7].

Table 11. Service years with models and types of milling machines in the Fogera plain

Machine types	Model	Mean	N	Std. Dev.	Minimum	Maximum	Std. Error
One-stage type	**N90**	7.91	52	6.54	1	34	1.57
	N70	11.67	3	5.86	5	16	3.38
	NX110	7.48	30	7.48	1	16	1.34
	NPF-90	6.50	3	3.80	1	13	1.97
	NPF-110	6.67	3	2.79	1	14	3.27
Overall one stage		10.04	91	8.29	1	34	3.71
Two-stage type	**SB-10D**	3.42	4	3.63	1	7	2.42
	SB-30D	5.20	5	1.30	3	6	0.58
	SB-50D	7.16	15	6.41	1	23	2.31
Overall two-stage type		5.26	24	3.78	1	23	1.77
Multipurpose		2.25	2	2.47	0.5	4	1.75
Overall service years		7.58	117	6.14	0.50	34.00	2.84

Survey data: 2024

A qualitative analysis was conducted on 129 rice milling machines to determine the maintenance frequency rates of processors using a five-point Likert scale, ranging from daily to yearly. The scale was assigned values of 1 to 5, respectively. The assessment revealed that a 5-point Likert scale from 5 - 'Yearly' to 1 - 'Daily' is used in ascending order of rank for the 'Visual check', 'Cleaning', 'Dismounting', and 'Overhaul' of their rice milling machines. It was revealed that Weekly, Weekly, Seasonally, and Seasonally were

the respective frequencies for these maintenance activities as shown in Table 12. However, research reports indicate that about 87% of rice-processing machines used are old and inefficient, leading to poor service and low-quality processed grain. Additionally, the inadequacy of machine operators' skills, often owners themselves, and the lack of formal training also contribute to poor-quality processing and machine maintenance [6, 15].

Table 12. A 5-point Likert scale from 5 - 'Yearly' to 1 - 'Daily' on the maintenance of machines

	Visual check	Cleaning	Dismounting	Overhaul
Score	2.15	2.53	3.50	3.74
Decision	Weekly	Weekly	Seasonally	Seasonally
%	26.40%	25.74%	23.76%	24.09%
N	80	78	72	73
Mean	2.15	2.43	3.50	3.37
Sd	1.424	1.284	1.035	1.600

Survey data: 2024

The assessment revealed that all the power sources for milling machines are electricity from the public supply, and the company staff (mechanics/other staff) regularly check the working conditions of the machines. The frequency of the processors, company staff, or mechanics checking the machine is every day, weekly, and monthly, with 37.0%, 38.3%, and 11.1%, respectively. The remaining individuals check their machines more than once a month (7.4%), when they fail and make unusual sounds (2.5%), and when they depend on the manual (1.2%), respectively. The sample rice processors indicated that the highest average number of breakdown incidents occurred in 2023, with the N70 model experiencing approximately 11 breakdowns, while the N90 and NX110 models each recorded about 7 breakdowns. The relatively new models in the Engelberg types of milling machines are the NPF-90 and NPF-110 models, with the least number of breakdowns, only four and two times respectively. The SB series models of the rice milling machines incurred a maximum average number of breakages than the other types of milling machines, while the SB-50D, SB-30, and SB-10 models were broken approximately 14, 9, and 4 times, respectively, as shown in Table 13.

Table 13. The number of breakdown incidents and models of milling machines in 2023

Model of a machine	Mean	N	Std.	Maximum	Minimum
N90	6.92	53	5.47	30	1
N70	10.34	4	5.13	15	5
NX110	6.84	31	7.16	24	0
NPF-90	4.00	9	2.78	10	1
NPF-110	1.50	4	1.00	3	1
Overall Engelberg type	5.92	101	2.42	30.00	0.00
SB-50D	13.24	15	17.14	60	1
SB-30D	8.83	6	9.26	25	2
SB-10D	3.67	4	3.21	7	1
Overall SB series type	8.58	25	6.98	60.00	1.00
Multilevel type	2.00	2	2.83	4	0
All machine types	6.37	128	4.88	60.00	0.00

Survey data: 2024

Besides, the rate of staff checking the milling machine for maintenance and the availability of spare parts for the milling machine in nearby locations are the two basic variables and questions raised for the sample rice processors in the study area. These were analyzed using a 5-point Likert scale, with 5 representing 'don't know', 4 representing 'once in more than one month', 3 representing 'monthly', 2 representing 'weekly', and 1 representing 'every day' for the level of frequency of staff to check the milling machine for maintenance. Similarly, for the availability of spare parts, the scale ranged from 5 ('don't know') to 1 ('always') in the rice mill business. As shown in Table 14, the average rate of staff to check the milling machine for maintenance was 'weekly' for 38.69% of respondents. On the other hand, the availability of spare parts for the milling machine in nearby locations was scored as 'sometimes' by 42.97% of the respondents (Table 14).

Table 14. The rate of staff to check the milling machine for maintenance, and the availability of spare parts for the milling machine in nearby locations

	The rate of staff to check the milling machine for maintenance	The availability of spare parts for the milling machine in nearby locations
Score	2.11	2.99
Decision	Weekly	Sometimes
%	38.69	42.97%
N	53	55
Mean	2.17	2.51
Sd	0.93	0.79

Survey data: 2024

Milling machine components consist primarily of an electric motor and the milling machine itself. Assessment reports indicate that milling machine parts experience breakdowns far more frequently than the electric motor (97.5%). In 2023, common replacement parts for Engelberg milling machines included suction fan/blower components (impeller, washers, bearing, fan belt), milling chamber components (milling sieve screen, straight ribs/rod, connecting parts/belts, bearing, husker drum sieve/screen, drum sieve, milling shaft, milling roller, screwed iron roller), and related accessories (inner frame, bolts, and nuts), as detailed in Table 15. Bearings are another frequently failing component, particularly in two-stage or SB Series machines (Table 15). A critical challenge is the unavailability of genuine spare parts for these high-failure components in Wereta and Bahir Dar. Machine dealers often import low-quality spare parts, leading to frequent breakdowns, especially during peak milling season. Respondents reported importing machines and parts from China and attributed the problem to spare part suppliers. Consequently, millers sometimes opt to use spare parts from older machines, perceiving them as higher quality than the new replacements.

Table 15. The most frequently breaking machine parts in 2023

Machine types	Model of a milling machine	N	Percentage of response	Parts with the most frequent breakage in 2023
One-stage type	**N90**	56	39.72	Milling and blower fan chamber components (drums, rollers, screw rollers, bearings, and blower fan)
	N70	4	2.84	Milling chamber components (drum, sieve, screen bearings)
	NX110	34	24.11	Milling and blower fan chamber components (drums, rollers, screw rollers, bearings, and blower fan)
	NPF-110	4	2.84	Bearings
	NPF-90	12	8.51	Polisher drums, bearings
Two stage type	**SB-10D**	4	2.84	Bearings and husker drum
	SB-30D	7	4.96	Bearings and husker drum
	SB-50D	18	12.77	Bearings and husker drum
	Multilevel	2	1.42	Husker drums and bearings

Survey data: 2024

Some machine parts are also worn-out parts and need replacement based on a specific time recommended by the manufacturer, or depending on the load of the milling operation, as well as the service life of the parts. The survey revealed that 40% of the rice millers believed that the polisher drum, polisher sieve screen, and belt are the most worn-out parts for N90 models of milling machines within 2023, while the other 24.29% think that the polisher drum, bolts, hinges, fittings, and shafts for NX110, as shown in Table 16. On the other hand, Husker and polisher drums and bearings are worn-out parts for the two-stage type or SB Series machines, as shown in Table 16. Generally, the rice millers revealed that the husker drum and polisher drum parts are the most worn-out parts for the Engelberg and SB Series machine types, respectively.

Table 16. The most worn-out parts and models of milling machines in 2023

Machine types	Model	N	Response (%)	Parts with most worn out in 2023
One-stage type	N90	56	40.00	Polisher drum, Screen, and belt
	N70	4	2.86	Polisher drum, bolts, and sieve
	NX110	34	24.29	Polisher drum, bolts, sieve, and shafts
	NPF-110	4	2.86	Polisher drum
	NPF-90	11	7.86	Polisher drum and shafts
Two-stage type	SB-10D	4	2.86	Husker and Polisher Drums
	SB-30D	7	5.00	Husker Drums and Bearing
	SB-50D	18	12.86	Husker Drums and Bearing
	Multilevel	2	1.43	Bearing

Survey data: 2024

In rice milling, machine maintenance and repair are primarily handled by in-house staff (65.0%), as indicated by a survey of 109 rice mills (Fig. 7). Local mechanics from machine dealers (8.55%) and individual mechanics/electricians (5.47%) are also utilized. Critically, none of these maintenance personnel receive specialized training; their expertise is based solely on experience.

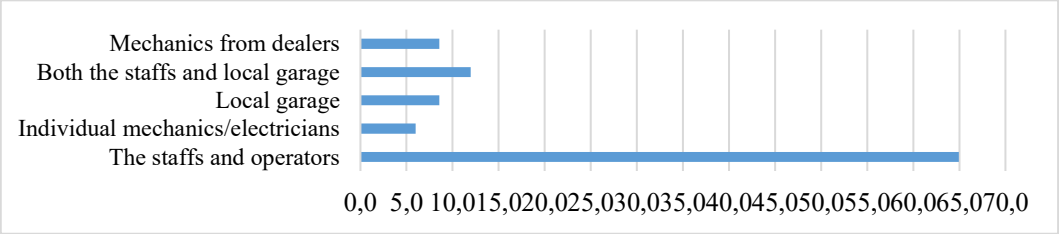

Fig. 7. Repairs of the Milling Machine in percent (%)

Although genuine spare parts for rice milling machines are more expensive, only 68.66% of users can easily find them (survey of 109 machines). Figure 8 shows the percentage of users who have difficulty finding specific spare parts. These parts are crucial for the mill's operation, and their scarcity can lead to extended downtime and reduced milling efficiency.

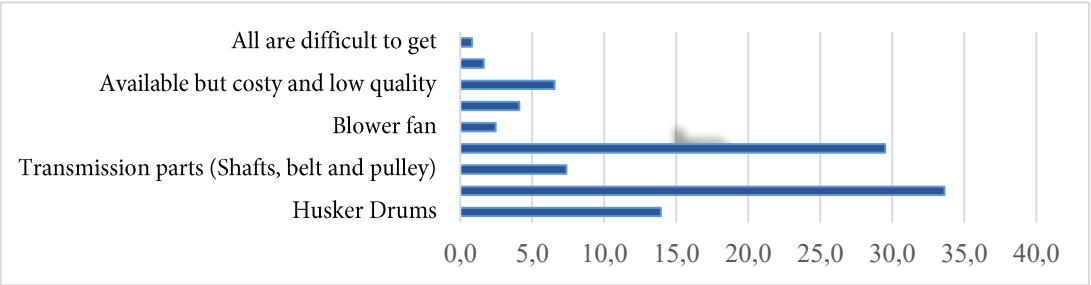

Fig. 8. Difficult spare parts to get for the rice machine in percent (%)

Millers often opt for cheaper alternatives from local auto shops (50.6%) and online retailers (25.9%), struggling to differentiate genuine parts and prioritizing price. This drives dealers to import both machines and non-genuine spares. Consequently, limited local availability of key parts, especially for Engelberg machines (drums at 33.1% and bearings at 29.51%), causes shutdowns. Husker drum scarcity also affects 13.93% of 122 SB series and multilevel machines surveyed. Fogera Plain millers struggle with inaccessible blower fans and milling chamber components, forcing them to rely on distant suppliers in Bahir Dar and Addis Ababa for potentially substandard or used parts. The survey highlights the urgent need for readily available, genuine spare parts to maintain smooth operations and minimize disruptions in rice milling. An assessment of 129 processing machines indicated that spare parts are most readily available in the districts, zones, and regions of Bahir Dar (37.98%) and Addis Ababa (10.85%), with other sources in zones (18.6%) and regions (31.01%). Specifically, Wereta,

Hamusit, and Yifag towns in the Fogera plain are the closest sources. While spare parts are also found in towns within the South Gondar zone and Bahir Dar, some are difficult to obtain, leading millers to contact dealers in Addis Ababa and manufacturers abroad. A five-point Likert scale assessment of spare part availability (1 = always, 5 = don't know) showed that parts are sometimes available (42.97%), often available (25.58%), and always available (21.71%), as shown in Figure 9.

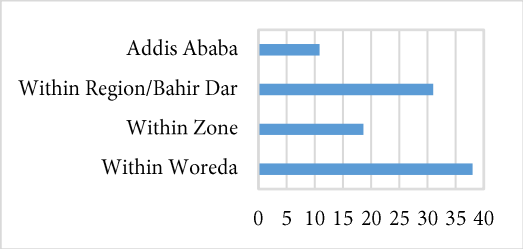

Fig. 9. The nearest location finds the spare parts in percent (%) for the milling machine.

Genuine spare parts are essential for maintaining imported rice milling machines. However, rice millers in Ethiopia, including those in the Fogera plain, struggle to acquire them. When spare parts are unavailable locally, millers resort to various solutions. A survey of 129 machines (Figure 10) revealed that 32.56% of processors modify existing parts, while 27.91% search other shops, and 26.36% place orders at the initial shop.

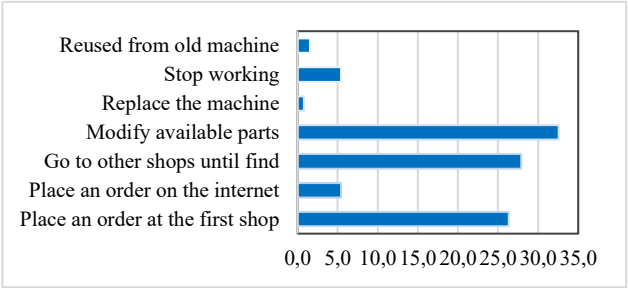

Fig. 10. Decision of millers when they cannot find the spare parts in the nearest location (%)

Rice processors' perceptions of machinery maintenance were assessed using a 5-point Likert scale (1 = easy, 5 = difficult). Key factors influencing processing quality were machine durability, spare part availability and price, and operator skills. Results (Table 17) showed processors rated machine durability and operator skills as neutral, spare part availability as slightly difficult, and spare part price as difficult. The absence of formal operator training, often for owners themselves, contributes to poor processing quality, aligning with Assaye and Alemu [7]. This skill deficit results in inefficiencies and safety hazards, highlighting the importance of enhanced training and certification programs.

Table 17. A 5-point Likert scale from 5 – 'Easy' to 1 - 'Difficult' is used to assess the difficulty of maintaining the milling machinery.

	Durability of the machine	Availability of spare parts	Price of spare parts	Technical skills of operators
Score	3.38	4.00	4.22	2.69
Decision	Neutral	A little difficult	Difficult	Neutral
%	25.25%	24.92%	26.25%	23.59%
N	76	75	79	71
Mean	3.38	3.95	4.22	2.62
Sd	1.233	1.346	0.887	1.308

Survey data: 2024

3.7. Analysis of cost and labour use in rice processing

3.7.1. Analysis of rice processing costs

Rice milling offers big employment opportunities. Commercial millers in the study area purchase and process paddy, whereas custom millers provide hulling and polishing services for a fee [19]. Survey results indicate that 30.86% of individuals engage solely in commercial milling, 4.94% in custom milling, and 61.73% in both. The study examined rice milling costs, including fixed and variable expenses like power, labour, workspace, machinery, operating costs, and taxes. Average monthly power consumption and annual tax payments were 10,518.50 ETB and 37,666.67 ETB, respectively (Table 18). The survey revealed that multilevel machine owners experienced operational challenges due to high electricity consumption and limited space, aligning with findings by [7].

Table 18. Rice milling experience, monthly power use, and annual tax payment of rice millers

	Mean	N	Std. Error of Mean	Std. Deviation	Minimum	Maximum
Experience in Rice milling in years	8.63	81	1.77	5.30	1	26
Monthly power consumption in ETB	10518.50	42	1441.66	8649.97	3000.00	50000.00
Annual tax in ETB	37666.67	32	14678.03	25423.09	10000.00	60000.00

Survey data: 2024

In 2023, the assessment of rice millers showed that the maximum mean annual costs for repair, maintenance, and spare parts were 27,900.44 ETB for one-stage (Engelberg type) machines, 43,997.22 ETB for two-stage (SB series) machines, and 50,000.00 ETB for multistage machines (Table 19). Older models (N90 and N70) of the one-stage type incurred costs of 33,150.30 and 27,500.00 ETB per year, respectively, while two-stage models (SB-30D and SB-50D) cost 55,500.00 and 44,575.00 ETB, respectively (Table 19). Newer two-stage and multistage machines had higher repair and maintenance costs (Table 19). Maintenance and repair are typically performed by dealers in Bahir Dar and Addis Ababa due to a lack of specialized local manpower. This aligns with reports of inadequate skills among machine operators due to a lack of formal training, which can lead to poor-quality grain processing [7].

Table 19. The total cost of the repair, maintenance, and spare parts of the milling machine for 2023

Machine types	Model	Mean	N	Std. Dev	Minimum	Maximum
One-stage type	**N90**	33,150.30	50.00	34,342.69	2,000.00	150,000.00
	N70	27,500.00	4.00	5,000.00	20,000.00	30,000.00
	NX110	31,247.73	31.00	24,784.28	5,000.00	100,000.00
	NPF-110	21,666.67	3.00	20,207.26	0.00	40,000.00
	NPF-90	25,937.50	9.00	13,611.31	10,000.00	50,000.00
Overall one stage		27,900.44	97.00	11,108.74	0.00	150,000.00
Two-stage type	**SB-10D**	31,916.67	4.00	15,069.28	20,000.00	50,000.00
	SB-30D	55,500.00	6.00	62,892.77	3,000.00	150,000.00
	SB-50D	44,575.00	14.00	32,134.83	700.00	100,000.00
Overall two-stage type		43,997.22	24.00	24,236.23	700.00	150,000.00
Multilevel		50,000.00	2.00	3,535.53	45,000.00	50,000.00
Overall repair cost		35,762.87	123.00	16,757.09	0.00	150,000.00

Survey data: 2024

Pre-milling costs—including drying, weighing, packaging, transportation, and loading/unloading of paddy—averaged 31.85 ETB per quintal**,** while post-milling rice loading and unloading labor costs were 17.50 ETB per quintal**.** Processors incurred monthly labor costs for paddy dehulling (3,545.07 ETB per quintal) and polishing (32.40 ETB per quintal) (Table 20). Transportation from sellers to buyers was not borne by processors. Custom millers in the study area provide rice and flour milling services, offering free dehusking with paddy purchases while charging for flouring at rates of 3.7% and 22.2%**,** respectively. Service fees for paddy dehulling, polishing, and combined dehulling and polishing were 1.48, 1.27, and 1.55 ETB per kilogram**,** respectively (Table 20). These negotiated pricing arrangements enable processors to maximize profits from milling by-products, which are processed into rice flour and sold [7].

Table 20. Cost for different rice milling operations

Costs of operation	Mean	N	Std. Error of Mean	Std. Deviation	Minimum	Maximum
Paddy dehulling and polishing per month	3545.07	71	93.44	787.36	1500.0	5500.0
Paddy dehulling and polishing per quintal	32.40	68	2.26	17.91	5.0	100.0
Pre-milling ETB per quintal	31.85	68	1.69	13.97	10.0	80.0

Costs of operation	Mean	N	Std. Error of Mean	Std. Deviation	Minimum	Maximum
Rice load/unload ETB per quintal	17.50	6	1.12	2.74	15.0	20.0

Survey data: 2024

3.7.2. Labour use in rice processing

Table 21 indicates the average daily working hours for paddy collection (8.49), drying (9.1), dehulling/polishing (10), and loading/unloading (2.50), excluding weekends, religious holidays, and the quantity of paddy processed. Dehulling and polishing require the most labour. Paddy collection and drying are the second and third most labour-intensive, respectively. Unlike other farm operations, rice milling lacks consistent labour trends. Operators rely on experience rather than specialized training, corroborating research [15] that 52% of processors cite a lack of skilled labour as a key challenge to business sustainability and expansion.

Table 21. Typical working hours per day for different rice milling operations

Rice milling operation	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
Paddy collection	8.49	53	0.37	2.70	3	20
Paddy drying	9.1	49	0.40	2.81	1	20
Paddy dehulling and polishing	10	5	0.63	1.41	8	12
Paddy loading/unloading	2.50	2	1.50	2.12	1.0	4.0

Survey data: 2024

Table 22 presents the daily labour needs for paddy milling, based on operator wage agreements. Labour requirements correlate with the number of milling machines, averaging two per processor in the survey. Family members comprised a substantial portion (61.5%) of the operators.

Table 22. Number of labourers per day for different rice milling operations

Rice milling operation	Mean	N	Std. Error.	Std. Dev.	Minimum	Maximum
Paddy collection	1.61	33	0.15	0.83	1	5
Paddy drying	1.71	34	0.17	0.97	1	5
Paddy dehulling and polishing	2.27	75	0.13	1.10	1	7
Packaging	1.5	2	0.5	0.71	1	2

Survey data: 2024

Table 23 presents a breakdown of each activity involved in the rice processing operation, which requires a total of 55.68 labor days. This task typically employs two operators who use an average of two machines, as discussed in section 3.4 and illustrated in Figure 3.

Table 23. Total labour-days used by the rice processing operation (labour-days)

Rice milling operation	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
Paddy collection	13.7	33	0.06	2.24	3.00	100.0
Paddy drying	15.6	34	0.07	2.73	1.00	100.0
Paddy dehulling and polishing	22.7	75	0.08	1.55	8.00	84.0
Paddy loading, unloading, and packaging	3.8	2	0.75	1.51	1.00	8.0

Survey data: 2024

3.8. Marketing and Modality of the Rice Processing

Rice millers mainly obtain paddy from the Fogera plain's rice-producing districts (Fogera, Libokemkem, and Dera). According to Table 24, 88.01% of paddy is sourced locally, 2.67% from outside the districts, and the rest from both local and external sources. Millers also acquire paddy from new rice-growing areas near the Fogera plain, indicating the growth of rice farming.

Table 24. Paddy sourcing for the rice processor in 2023

Paddy Sourcing in 2023 per quintal	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
Within district	2905.62	74	600.73	5167.69	100.00	35000.00
Outside districts	88.11	53	49.36	359.36	0.00	1850.00
Total Paddy collected	3301.92	--	5970.72	827.99	100.00	35000.00

Survey data: 2024

Milling companies primarily obtain paddy from farmers, with middlemen and millers negotiating collection prices. Although rice processors often offer a flat price regardless of quality, increased mobile phone access has improved farmers' negotiation leverage [6]. Individual farmers (17.74%) and middlemen (6.45%) are direct sources for rice millers, but most paddy comes from a combination of both (74.19%). Some millers also supply paddy to others, likely due to capacity constraints or overstock. Overall, farmers supply 55.62% of paddy to millers, while middlemen supply 42.38% (Table 25). Middlemen collect paddy from farmers and local markets before supplying it to millers. Poor rural road infrastructure, market isolation, and limited vehicle access increase transport costs, hindering farmers' commercialization [20]. While traditional transport methods persist, Bajaj vehicles are increasingly used in inaccessible areas [21].

Improved roads would improve access to urban markets and prices, stimulating new businesses [6]. Sellers handle most of the transportation (91.04%), with rice mills (1.49%) and buyers (7.46%) handling little. Animal carts (62%), trailers/Bajaj (18%), and donkey carts (10%) are the main transport methods from sellers to mills or middlemen. In the Fogera Plain, farmers typically sell to local processors [6] who assess paddy quality based on indigenous knowledge, considering variety, moisture, foreign matter, market price, smell, and rice crop index. Low prices often result from undesirable varieties, high moisture, immature paddy, and contamination. Processors attribute poor rice quality to farmers' drying practices for teff and wheat. Overall, Ethiopian rice quality suffers from broken grains and ineffective cleaning due to inadequate agricultural practices, poor-quality seeds, and supply chain weaknesses [22]. Late harvesting and prolonged field storage can raise moisture content above the optimal 15% [6], and foreign matter further degrades the product. Processors, therefore, meticulously evaluate paddy quality before purchase, using the criteria in Table 25.

Table 25. Factors for business deals of rice millers during paddy marketing

Factors for business deals of millers	Frequency (n = 81)	Percentage (%)
Variety, moisture, foreign matter, and market price	5	6.17
Variety, moisture, and market price	6	7.41
Moisture, foreign, and smell	1	1.23
Variety, moisture, foreign matter, market price, and paddy price	5	6.17
Variety, foreign matter, smell, market price, Rice crop index, and paddy price purchased	8	9.88
All the above deals	48	59.26

Survey data (2024)

In Ethiopia, milled rice sales are heavily influenced by producers' dependence on processors, who act as both millers and traders. A lack of price differentiation for high-quality rice, due to similar pricing for broken rice, further shapes the market [6]. Processors often sell rice directly or via brokers to wholesalers and retailers in major markets such as Addis Ababa and Mekele. Prices are mainly determined through spot negotiations (91.4%), with processor judgment and market forces having less influence. Rice processing is essential for providing quality domestic rice and increasing its value. The growth of rice processing in Fogera Plain towns like Wereta has strengthened rural-urban links and driven agrarian change, fostering production, market development, employment, and investment [7]. Ethiopian rice processors are central to the sector, acting as service providers, buyers, and sellers. A 2013 study reported average processor revenues of 12,873,358.9 ETB, with milled rice at 57.7 ETB /kg and byproducts at 3.05 ETB /kg (Table 26). While the byproduct cost aligns with previous research [7], the milled rice cost seems high. Most processors operate on a small scale due to limitations in machinery and capital, emphasizing the need for efficient small to medium-scale milling systems and quality improvements to maintain competitiveness.

Table 26. Annual income and gross sales of rice processors in the rice milling system in 2023

Variables	Mean	N	Std. Error	Std. Dev.	Minimum	Maximum
Total sale (ETB /year)	12,873,358.9	70	3,130,259.1	26,189,626.5	35,000.0	180,460,000.0
Milled rice (ETB /year)	11,519,527.8	72	2,811,168.7	23,853,557.1	30,000.0	178,500,000.0
Byproduct (ETB /year)	221,321.7	70	53,893.2	450,903.2	-	3,000,000.0
Cost of milled rice (kg/ ETB)	57.7	72	0.8	6.8	40.0	75.0
Cost of byproduct (kg/ ETB)	3.05	66	0.17	1.39	2.00	10.00
Milled rice (Qui/year)	2,301.9	67	484.7	3,967.0	60.0	23,800.0
Byproduct (Qui/year)	885.6	65	198.6	1601.1	30.0	9800.0

Survey data (2024)

Abebe [23] identified three categories of Ethiopian rice consumers: those preferring high-quality (e.g., packed, long-grain, aromatic) rice; those preferring both imported and local rice; and those favouring local rice, especially for Injera flour. The latter group, including rural communities, constitutes the largest segment of the local rice market. Hence, all wholesalers, retailers, middlemen, and consumers are buyers of milled rice. The survey revealed the percentage of customers or buyers of milled rice as follows: millers sell to wholesalers (59.65%), retailers (23.59%), middlemen (12.67%), and consumers (4.09%). Notably, there were no recorded exports of domestic milled rice. However, the quality of domestic milled rice is very low, as the quality of processed rice does not provide price incentives. This is because broken rice is also priced more or less equally to the higher quality, de-husked rice [6, 7, 15].

Millers consider milling and paddy trading as their most profitable businesses (42.2% and 55.6%, respectively), aligning with rice processors primarily offering de-husking and bran cleaning, with some rice-grain-milling services. Processors also act as buyers and traders, with fees often based on farmer-processor relationships [6]. Milling and paddy supply are also considered the riskiest businesses, yet processors aim to expand them without altering other business plans. Workload assessments over the past five years (2019-2023) reveal monthly variations in milling service demand (Figure 11, Table 27), measured by ratings from "no paddy to mill" to "peak." Figure 11, indicates the following rating ranges: "no paddy to mill" (1.81-2.6), "not so busy" (2.61-3.4), "busy" (3.41-4.2), and "peak" (4.21-5.0). Paddy supply is available year-round, but workload fluctuates monthly from "not so busy" (1.8-2.6) to "peak" (4.2-5.0) (Figure 11, Table 27), mirroring cropping patterns. Grass peas are harvested around late January, and farmers with irrigation access plant vegetables like onions and tomatoes in February.

Table 27. A 5-point Likert scale from 5 – 'don't know' to 1 - 'Peak' for the level of the workload of millers' milling services in a month, based on the last five years (2019-2023)

	January	February	March	April	May	June	July	August	September	October	November	December
Decision	Peak	Peak	Busy	Busy	Not so busy	Not so busy	Not so busy	Not so busy	Not so busy	Not so busy	Peak	Peak
Score	4.96	4.49	3.88	3.49	3.17	2.96	2.79	2.64	2.72	3.21	4.27	4.83
%	96.3	53.09	67.9	50.6	60.1	61.7	59.3	60.05	64.2	50.06	43.20	87.7
N	78	43	55	41	49	50	48	49	52	41	35	71
Mean	1.04	1.49	2.12	2.48	2.80	3.01	3.21	3.36	3.26	2.78	1.78	1.17
SD	0.190	.551	0.56	0.55	0.66	0.73	0.67	0.56	0.54	0.75	0.84	0.52

Survey data (2024)

Peak workload for rice processes occurs from November to February, encompassing 75% of the total. March and April also experience significant activity, while other months are less busy (Figure 11). Milling service customers are primarily individual farmers (55.6%), wholesalers (37.0%), and local traders (33.3%). Customers support the value chain, allowing farmers to invest in off-season crops by selling paddy during peak months. Wholesalers and traders then store and distribute this paddy, maximizing profits in later months.

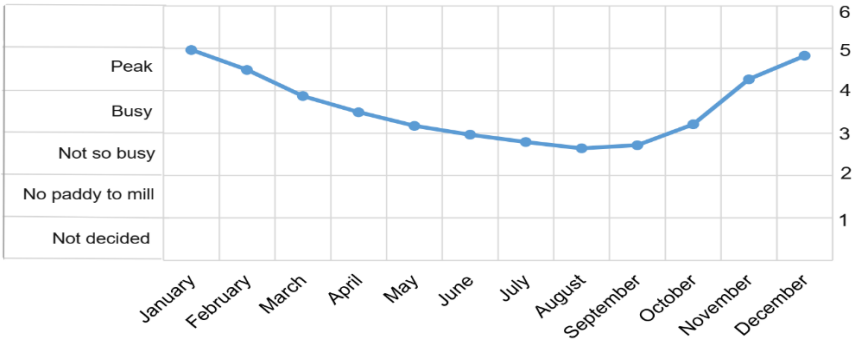

Fig. 11. Level of workload of milling services (%) in percent per month based on the miller's own experience in the last five years (2019-2023)

3.9. Challenges in the rice processing business

Rice millers face challenges like unorganized competition, market volatility, unfair trade practices, capital scarcity, and development taxes, all impacting milling quality. A 5-point Likert scale (1 = Easy to 5 = Difficult) assessed these challenges. Individual perceptions rated competition as neutral, while market fluctuations, unfair trade, capital, and taxes were perceived as slightly difficult (Table 28).

Table 28. A 5-point Likert scale from 5 – 'Difficult' to 1 - 'Easy' for the level of difficulties in the milling business

	Many Compotators	Fluctuation of the market	Lack of fair trade	lack of capital	Tax
Score	3.40	3.89	3.45	4.14	3.43
Decision	Neutral	A little Difficult	A little Difficult	A little Difficult	A little Difficult
N	77	71	71	74	56
%	26.28%	24.23%	24.23%	25.26%	19.11%
Mean	3.40	3.89	3.72	4.14	3.47
SD	1.259	0.785	0.934	1.025	1.142

Survey data (2024)

A marketing strategy is a fundamental component of the rice processing business. Assessments revealed that 80.2% of businesses have a marketing strategy, while the remainder rely on other millers' initiatives. A 5-point Likert scale (1 = "No attention" to 5 = "very much attention") was used to analyze the attention given to key marketing strategies: quality, price, advertisement, market survey, stock, satisfaction, and client expansion (Table 29). Increased processors in the Fogera Plain signal rising competition and potentially lower processing fees. Rice processors should invest in larger, more efficient machines to meet demand and capitalize on economies of scale [6, 7, 15].

Table 29. A 5-point Likert scale from 5 – 'very much attention' to 1 - 'No attention' for marketing strategy in the rice milling business

Challenge	Better quality	Competitive price	Advertisement	Market survey	Sufficient stock	Client satisfaction	Expand the number of clients
Score	3.93	3.40	2.73	3.27	3.16	3.29	3.04
Decision	Much Attention	So so Attention	So so Attention	So so Attention	So so Attention	So so Attention	So so Attention
%	16.98	19.25	13.72	14.65	11.70	13.02	11.63
N	73	72	59	63	57	56	50

Challenge	Better quality	Competitive price	Advertisement	Market survey	Sufficient stock	Client satisfaction	Expand the number of clients
SD	1.05	1.134	1.157	1.125	1.29	3.23	3.06
Mean	3.93	3.40	2.73	3.27	3.12	1.25	1.14

Survey data (2024)

A recent assessment revealed that 11.11% of respondents were dissatisfied with the milling facility's performance, citing outdated equipment, inconsistent rice quality, and inadequate operator training as key issues. While satisfaction with milling recovery rate and capacity was slightly positive, and whiteness grading was neutral, opinions on head rice recovery and power source were neutral and slightly negative, respectively (Table 30).

Table 30. A 5-point Likert scale from 5 – 'positive' to 1 - 'Negative' based on the performance level of satisfaction with the performance of present ability of the milling business

	Milling recovery rate	Head rice recovery	Whiteness of milled rice	Grading equipment	Power source	Capacity of milling
N	9	8	7	6	7	7
%	19.35%	19.10%	16.33%	12.81%	15.83%	16.58%
Score	3.74	3.18	3.15	2.35	2.92	3.48
Decision	A little Positive	Neutral	Neutral	A little negative	Neutral	A little Positive
Mean	3.74	3.18	3.15	2.35	2.92	3.48
SD	1.17	1.24	1.14	1.21	1.29	1.27

Survey data (2024)

The assessment report categorized the milling business's performance as slightly positive, slightly negative, or neutral, reflecting some level of dissatisfaction (Table 31). A 5-point Likert scale (5 = "very much intention" to 1 = "no intention") revealed rice millers' intentions to improve rice quality. They indicated "very much intention" for obtaining high-quality paddy and replacing milling machines, and "so-so intention" for replacing grading equipment, improving operator skills, and improving storage facilities. The prevalence of outdated and inefficient rice-processing machines (87%) contributes to poor service and low-quality rice. Additionally, grading processed rice is uncommon [6].

Table 32 shows millers' intention to obtain various types of information from the millers' association using a 5-point Likert scale. Governmental regulation had the highest mean (3.41, "much intention"), while international trade was lowest (2.34, "seldom intention"). Other categories—credit (3.24), other rice millers (3.03), market trend (2.81), and technical information (2.61)—were rated as "intention." Overall, millers prioritize regulatory and financial information over technical or trade-related details, which can guide the focus of millers' associations.

Table 31. A 5-point Likert scale from 5 – 'very much intention' to 1 - 'No intention' about why rice millers are not satisfied with the quality of milled rice and intend to improve it

	Obtain high-quality paddy	Replace the milling machine	Replace grading equipment	Improve the operator's skill	Improve storage facility
Score	4.00	3.62	2.73	3.21	3.08
Decision	Much intention	Much intention	So so intention	So so intention	So so intention
%	24.11%	21.34%	16.21%	18.58%	20.16%
N	61	53	41	47	51
Mean	4	3.65	2.73	3.21	3.08
Sd	1.17	1.11	1.25	0.98	1.31

Survey data (2024)

Table 32. A 5-point Likert scale from 5 – 'very much intention' to 1 - 'No intention' based on the kind of information the millers expect from the millers' association

	Other rice millers	Governmental regulation	Market trend	International trade	Credit	Technical information
Score	3.03	3.41	2.81	2.34	3.24	2.61

	Other rice millers	Governmental regulation	Market trend	International trade	Credit	Technical information
Decision	Intention	Much intention	Intention	Seldom intention	Intention	Intention
%	17.78%	17.78%	20.00%	17.78%	13.89%	12.78%
N	32	32	36	32	25	23
Mean	3.03	3.41	2.81	2.34	3.24	2.61
Sd	1.15	1.103	1.305	1.066	1.165	1.406

Survey data (2024)

The competitiveness of locally milled rice is hampered by its poor quality. A survey indicates widespread disregard for government rice quality standards (76.5% of millers) and unfamiliarity with international standards (85.2%). Processors attribute this quality gap to outdated equipment, inadequate inputs, and insufficient training. The majority (90.1%) do not monitor international rice prices. Low milling recovery rates (75% for de-husked, 65% for white rice) are linked to insufficient operator training, while poor-quality paddy and milling practices result in high breakage. Some processors utilize substandard rice for flour production. Inadequate rice-drying methods, stemming from practices used for other grains, contribute to suboptimal moisture content. Empowering farmers and processors with resources and market information is essential for improving rice production [6].

3.10. Storage trends and rice processing

Rice processors reported a 3.50% storage space availability, with 95.2% possessing both storage and drying facilities, while 1.2% lacked either. Storage presents a challenge for approximately 90.1% of rice millers, though the same percentage reported having storage structures. Primary storage materials include sacks (75.3%) and metal silos (14.8%). Warehouses are used to store 87.7% of paddy and white rice, employing methods like sheet covers (15.71%), aeration (48.57%), redrying (22.86%), and 12.86% use other methods. Rice loss severity was rated as not severe (39.5%), moderately severe (49.4%), and severe (3.7%) (Figure 12).

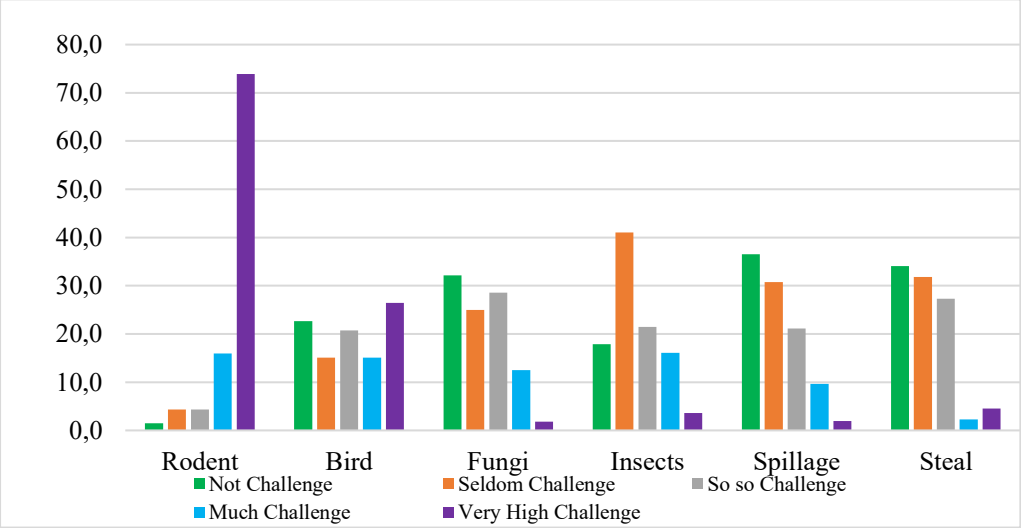

Fig. 12. Storage challenges of rice processors (%)

As shown in Figure 12, about 58.0% of processors believe storage leads to quality losses, mainly color changes. Major storage challenges include rodents, birds, fungi, insects, spillage, and theft. Rodents pose a very high challenge for 73.91% of processors, while 26.42% reported birds as a lesser challenge. Insects, theft, spillage, and fungi were reported as challenges by 41.07%, 27.27%, 21.15%, and 25.0% of processors, respectively.

These findings align with previous studies showing that inadequate storage conditions, pest infestations, and improper handling are key factors contributing to post-harvest losses and quality deterioration in rice [18, 24]. Proper storage infrastructure, combined with improved post-harvest handling and pest management, is critical to reducing losses and maintaining rice quality

4. Conclusion and recommendation

Ethiopia's rice-processing sector, particularly in the Fogera Plain, plays a critical role in ensuring rice supply, generating employment, and supporting local livelihoods. Despite rapid growth, small-scale millers face persistent challenges, including outdated and poorly maintained milling equipment, limited technical knowledge, unreliable electricity, inconsistent paddy quality, and inadequate price incentives. From 1998 to 2023, an average of 6.15 new machines were purchased annually, with N90 and NX110 models dominating the sector (61.35% and 36.5%, respectively). Reliance on untrained mechanics, budget constraints, and expensive spare parts further limit operational efficiency. Seasonal concentration of milling activity, transport bottlenecks, and suboptimal post-harvest management exacerbate inefficiencies, while the production of high-quality rice remains contingent on access to quality paddy, skilled labour, and efficient machinery.

To enhance sector performance, competitiveness, and sustainability, the study recommends:

- **Modernization of Milling Technologies:** Adoption of higher-efficiency machines with condition-based maintenance to increase productivity, reduce grain breakage, and improve milling quality.
- **Capacity Building and Technical Training:** Targeted programs for millers and value chain actors on machine operation, maintenance, and post-harvest management to strengthen technical skills and operational efficiency.
- **Policy and Regulatory Support:** Implementation of tax incentives, standardized licensing, improved access to financing, and integration of rice marketing into the Ethiopian Commodity Exchange (ECX) to strengthen market linkages and stabilize pricing.
- **Supply Chain and Post-Harvest Management:** Development of effective storage solutions (bag, bulk, or hermetic), establishment of quality standards, and improvement of logistics to minimize post-harvest losses and ensure consistent rice quality.
- **Future Research Directions:** Pilot interventions testing modern milling technologies and maintenance practices, economic analyses (cost-benefit and break-even studies) to guide investments, expansion to other rice-producing regions to validate findings, and structured stakeholder engagement through workshops and knowledge-sharing to translate research into practice.

Collectively, these measures are expected to improve rice quality, enhance profitability, strengthen sector sustainability, and support broader agricultural and economic development objectives in Ethiopia. This integrated approach ensures that the research not only advances scientific understanding but also provides actionable solutions for policymakers, processors, and other stakeholders in the rice value chain.

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References

[1] Yemane A.: Determinants of adoption of upland rice varieties in Fogera district, South Gondar, Ethiopia. Journal of Agricultural Extension and Rural Development, 2014. 8(12), 332-338. Available: https://academicjournals.org/journal/JAERD/article-full-text-pdf/E8C2D8747624

[2] Ministry of Agriculture and Rural Development (MoARD). National Rice Research and Development Strategy of Ethiopia. The Federal Democratic Republic of Ethiopia, Ministry of Agriculture and Rural Development, 2010, 48. AU Library, Available: https://library.au.int/national-rice-research-and-development-strategy-ethiopia-nrrdse-3

[3] CSS (Ethiopia Statistics Service). Report on crop and livestock product utilization (Private peasant holdings, Meher season). 2021, Volume VII. Statistical Bulletin 588. In Volume VII Report (Vol. 2, Issue January 2021). Available: https://ess.gov.et/wp-content/uploads/2013/09/2013EC.LAND-UTILIZATION-2021.pdf

[4] Tadesse T.: History, current status, and future directions of rice research in Ethiopia. Journal of Emerging Technologies and Innovative Research (JETIR), 2020, 7(2), 767–774. Available at: https://www.jetir.org/papers/JETIR2002324.pdf

[5] Assaye A., Habte E., Sakurai S.: Adoption of improved rice technologies in major rice producing areas of Ethiopia: a multivariate probit approach. Agriculture and Food Security, 2023, 12(1), 1–19. Available at: https://doi.org/10.1186/s40066-023-00412-w

[6] Alemu D., Tesfaye A., Assaye A., Addis D., Tadesse T., Thompson J.: A historical analysis of rice commercialization in Ethiopia: the case of the Fogera Plain. APRA Working Paper, 2018, 18, Future Agricultures Consortium. Available at: https://hdl.handle.net/20.500.12413/14283

[7] Assaye A., Alemu D.: Enhancing production of quality rice in Ethiopia: dis/incentives for rice processors. APRA Policy Brief, 2020, 22, Brighton: Future Agricultures Consortium. Available at: https://hdl.handle.net/20.500.12413/16700
[8] Ministry of Agriculture (MoA). National Rice Development Strategy-II, 2020–2030. Ministry of Agriculture, 2020, pp. 1–53. Available at: https://riceforafrica.net/wp-content/uploads/2021/09/ethiopia_nrds2.pdf
[9] Marouzé C., Fliedel G., Thaunay P., and Cruz J. F.: Designing a Fonio Mill. Screening an operating principle and its validation. Agricultural Mechanization in Asia, Africa, and Latin America, 2008, 39(3). Available at: https://www.shin-norin.co.jp/english/pdf/VOL_39_NO3_SUMMER_2008.pdf
[10] Worku G.: Shrinkage and carbon stock in Wetlands of Fogera Plain, North West Ethiopia. British Journal of Environmental Sciences, 2014, 2(4), 41–50. Retrieved from https://eajournals.org/wp-content/uploads/Shrinkage-And-Carbon-Stock-In-Wetlands-Of-Fogera-Plain-North-West-Ethiopia.pdf
[11] Alemu D. & Thompson J.: The emerging importance of rice as a strategic crop in Ethiopia (APRA Working Paper 44). Future Agricultures Consortium, 2020. Retrieved from: https://doi.org/10.19088/apra.2020.009
[12] Taherdoost H.: Determining sample size; how to calculate survey sample size. International Journal of Economics and Management Systems, 2017, *2*. Available at: https://ssrn.com/abstract=3224205
[13] Sarkar T., Lee H.-S., Hossen M., Rahman M., Siddiquee M., and Mamun M. Al.: Development of existing Engelberg Rice Mill for improving milling yield and quality. Eco-Friendly Agril. J., 2018, 11(01), 1–12. Available: https://www.researchgate.net/publication/322654236_Development_of_Existing_Engelberg_Rice_Mill_for_Improving_Milling_Yield_and_Quality
[14] Hegazy R.: Rice milling situation and technology to replace small-scale old husking mills in Bangladesh. 2016. Retrieved from: https://figshare.com/articles/dataset/Rice_Milling/12780116/3?file=24176786 or https://doi.org/10.6084/m9.figshare.12780116.v3, (Accessed on 20 December 2025)
[15] Alemu D., Isinika A., Odame H., Thompson J.: The role of small-scale processors in supporting agricultural commercialisation among smallholder rice farmers in East Africa: lessons from Ethiopia and Tanzania, APRA Working Paper, 2021, 74, Brighton: Future Agricultures Consortium. https://doi.org/10.19088/APRA.2021.040
[16] Dhankhar P.: Rice milling. IOSR Journal of Engineering, 2014, *4*(5), 34–42. Retrieved from: https://iosrjen.org/Papers/vol4_issue5%20%28part-4%29/F04543442.pdf
[17] Belay, D., Alebachew, M., Alemayehu, T., Tesfaye, R., & Ageze, M.: *Introduction of rice quality-enhancing and loss-reduction technologies in the Fogera Plain.* In G. Moges, L. Kebede, D. Alemu, F. Kelemu, & A. Fanta (Eds.), *Results of Agricultural Engineering Research 2024: Proceedings of Agricultural Engineering Completed Research Activities*, 2024. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia. Available: https://www.researchgate.net/publication/380928887_Introduction_of_Rice_Quality_Enhancing_and_Loss_Reduction_Technologies_in_the_Fogera_plain
[18] IRRI: Rice milling systems (Rice Knowledge Bank). International Rice Research Institute (IRRI), 2013. https://www.irri.org/resources/rice-knowledge-bank/postharvest/rice-milling
[19] Musdalipa and Zain M. M.: The case study examines the efficiency analysis of a mobile rice milling business in Pinrang District, specifically in Marannu Village, Mattirobulu District, Indonesia. Pakistan Journal of Life and Social Sciences, 2022, 20(2), 264–270. Available at: https://doi.org/10.57239/PJLSS-2022-20.2.009
[20] Tikuneh DB. and W/Senbet LK.: Rice mechanization in Ethiopia: trends, and prospects. INMATEH - Agricultural Engineering, 2013, 69(1), 335–348. Available at: https://doi.org/10.35633/inmateh-69-31
[21] Ekimie G.M.: "ከውሃው በላኝ ወደ ውሃ አበላኝ /Kä Wuhaw Bälañ Wädä Wuha abälañ (From Water logged Me to Water nourished Me*): A Historical analysis of rice production on enhancing livelihood in Fogera Woreda, 1970s to 2017," ERJSSH, 2022, vol. 9, 126–142. Available: https://www.ajol.info/index.php/erjssh/article/view/239306
[22] Teamir M.: Rice Processing and Consumption Experiences: Implications for Research in Ethiopia. Advances in Rice Research and Development in Ethiopia, 2019, 199. Available: https://www.researchgate.net/publication/381312675_Advances_in_Rice_Research_and_Development_in_Ethiopia
[23] Abebe M.: The contributions and challenges of rice value chain development on the livelihood of small holder rice farmers. (In the case of the Ethiopia Driving Growth Entrepreneurship and Trade (EDGET) project in Fogera and Libokmkem District). Addis Ababa University, Addis Ababa, Ethiopia, 2016. Available at: http://etd.aau.edu.et/handle/12345678/5635
[24] FAO (Food and Agriculture Organization of the United Nations). Rice post-harvest operations. FAO Agricultural Services Bulletin, 2016. Available: https://www.fao.org/3/i6030e/i6030e.pdf