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Technical and Economic Performance of Semi-Mechanized Shea Butter Processing Systems in Northern Benin

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Abstract

This study compared the technical and economic performance of four shea butter processing systems used in Northern Benin. Primary data were collected from 140 women processors across three major shea parklands. Technical performance was assessed using the annual quantity of shea kernels processed, while economic performance was evaluated using gross revenue, net income, benefit-cost ratio, return on total cost, and labor productivity. Differences among systems were examined using analysis of variance. The Grinder–Mill–Churner–Roaster system recorded the highest processing capacity (2,312.26 kg/year), net income (241,644 FCFA/year), benefit-cost ratio (1.54), return on total cost (54.44%), and labor productivity (1,875.67 FCFA/person-day). The traditional system recorded the lowest performance. The findings indicate that progressive integration of semi-mechanized equipment can improve processing capacity, profitability, and the economic valuation of women's labor. Policy support should therefore combine access to appropriate equipment and finance with training, maintenance services, and organizational support.

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Keywords

Shea butter; semi-mechanization; economic performance; technical performance; value chain; Benin.

Introduction

In Benin, the shea value chain is an important source of income and employment for rural households, particularly in the departments of Borgou, Alibori, Atacora, and Donga. The processing of shea kernels into butter, which is mainly carried out by women, contributes to income diversification and local economic development (Ferris *et al.,* 2001; Lovett, 2004). Despite this socioeconomic importance, traditional processing methods remain highly labor-, water-, and fuelwood-intensive, with variable yields and sometimes heterogeneous butter quality. These constraints limit the productivity and competitiveness of processing units, particularly in response to increasingly demanding markets (Elias and Carney, 2007; Pouliot, 2012). To address these constraints, several technological innovations have gradually been introduced into shea-producing areas. In Benin, the Agricultural and Food Technologies Program (PTAA) and the Beninese Agricultural Equipment Cooperative (COBEMAG) have contributed to the dissemination of equipment such as grinders, mills, churners, and roasters. Mechanizing selected processing operations can reduce drudgery, processing time, and transformation costs while increasing production capacity (Masters *et al.,* 2004; Moore, 2008). However, technology adoption remains heterogeneous, as processors combine equipment according to their financial resources, work organization, and access to support services.

Previous studies on shea have mainly focused on technology adoption, processing constraints, income, and women's economic empowerment (Elias and Carney, 2007; Pouliot, 2012). Although this literature highlights the positive effects of mechanization on productivity and working conditions, relatively few studies have simultaneously compared the technical performance and economic profitability of different technological configurations under actual production conditions. This gap is particularly relevant in Northern Benin, where the diversity of technological configurations may generate substantial differences in productivity, costs, and profitability.

This study therefore compares four shea butter processing systems in the main production areas of Northern Benin. It jointly examines technical performance, particularly processing capacity and labor productivity, and economic performance through costs, revenues, and profitability indicators. The objective is to identify the technological configuration that offers the best trade-off between technical efficiency and economic profitability, thereby informing investment decisions and modernization strategies for women-led processing units and contributing to the competitiveness of the shea value chain in Benin.

Theoretical and Conceptual Framework

Neoclassical production theory considers the producer as a rational agent who seeks to optimize decisions under constraints related to resources, technology, and prices. In shea butter processing, this rationality is reflected in the choice of a combination of production factors—labor, capital, raw materials, energy, and equipment—that allows a given level of output to be obtained at minimum cost or maximizes the margin generated by the activity (Guerrien, 1993). The choice of a semi-mechanized system therefore represents a trade-off between the investment required for equipment and the expected gains in labor productivity, reduced processing time, increased processing volumes, and improved profitability.

However, processors' decisions are not determined solely by economic variables. They also depend on access to finance, equipment, raw materials, technical information, markets, and support services, as well as on the social and institutional constraints shaping their activities. Because processing units are embedded in a wider economic and social environment, technological choices may differ according to available resources and local conditions (CIRAD-GRET, 2002). In this study, economic analysis is therefore used to examine the performance implications of the technological combinations mobilized for shea butter processing in Northern Benin.

The performance of a processing system can be assessed through its ability to convert mobilized resources into processed products efficiently. Technical efficiency refers to the ability of a unit to obtain the maximum output from a given set of inputs or to produce a given quantity with the minimum amount of resources (Farrell, 1957; Amara and Romain, 2002). In shea processing, it can be assessed through the quantities of butter obtained, the quantities of kernels processed, labor time, and other inputs used.

Economic profitability refers to the capacity of a processing system to generate a satisfactory financial result relative to the costs incurred. It depends on production levels, butter selling prices, raw material costs, labor, energy, equipment maintenance, and depreciation. Thus, a technological configuration may be technically efficient without being the most profitable if its additional operating costs exceed the productivity gains generated. Comparative analysis of semi-mechanized systems is therefore useful for identifying configurations that provide the best balance between technical efficiency, cost control, and economic profitability.

Accordingly, the performance of semi-mechanized shea butter processing systems is considered the outcome of the interaction between technological choices, the use of production factors, and the economic conditions under which processing units operate. In this study, labor productivity and economic and financial profitability indicators are used to assess economic performance, while the quantity of shea kernels processed is used as the principal indicator of technical performance.

Materials and Methods

Study area

The detailed survey was conducted in the shea parklands of Northern Benin, specifically the Parakou, Bembéréké, and Kandi parklands. Shea butter production and, particularly, the mechanization of processing operations are more developed in these parklands than in the Savè and Bohicon parklands, partly because of the presence of support structures such as COBEMAG and PTAA

(Sokpon and Yabi, 2006). The source study also reports better butter quality in these parklands.

The Parakou shea parkland extends between 9°N and 10°N and covers the area from Tchaourou to N'Dali and from Parakou to Djougou. The climate is Sudanian, with average annual rainfall ranging from 1,000 to 1,200 mm. The Bembéréké parkland lies between approximately 9°N and 10°N and extends from Bembéréké to Gogounou, with average annual rainfall of about 1,100 mm. The Kandi parkland is located north of 11°N and extends from Kandi to Malanville and from Kandi to Banikoara, with average annual rainfall of about 800 mm.

The study area is characterized by an extensive shea–néré parkland (Vitellaria paradoxa–Parkia biglobosa) strongly integrated into traditional farming systems (Sokpon and Yabi, 2006). Other woody species are also retained and used for fruits, leaves, timber, rituals, or other products. Shea and néré are therefore important natural resources from both socioeconomic and ecological perspectives (Agbahungba, 1989). Agriculture is the main economic activity in the study environment; the source study reports that it involves more than 96% of rural households in Alibori-Borgou. Livestock production is the second major activity. Trade, inland fishing, and agricultural processing, which is predominantly undertaken by women, are also important activities.

Sampling procedure

The target population consisted of women involved in artisanal or semi-mechanized processing of shea kernels. A multistage sampling approach was used. First, three shea parklands (Parakou, Bembéréké, and Kandi) were purposively selected because of their importance in national shea production and the presence of semi-mechanized equipment. Second, seven municipalities—Parakou, N'Dali, Bembéréké, Sinendé, Nikki, Pèrèrè, and Banikoara—were selected. Finally, 12 villages with active processor groups were identified. Respondents were randomly selected from membership lists of these groups. A total of 140 women processors were interviewed.

Data collection

Data were collected between October and December 2023 using a structured questionnaire administered through individual interviews. Before the main survey, an exploratory survey conducted in April 2023 was used to test and improve the questionnaire. Quantitative data were complemented by semi-structured interviews, focus group discussions, and direct observations at processing sites. This methodological triangulation was used to strengthen the reliability of the information collected.

The main variables collected are summarized in Table 2.

Data analysis

Data were analyzed using IBM SPSS Statistics version 21. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were first calculated to characterize the processors and processing systems. Economic performance was then assessed using indicators commonly applied in production economics, drawing on Yabi *et al.,* (2008, 2010). The indicators are summarized in Table 3.

A one-way analysis of variance (ANOVA) was subsequently used to compare the technical and economic performance of the four processing systems. Before ANOVA, residual normality and homogeneity of variances were assessed using the Shapiro–Wilk and Levene tests, respectively. When ANOVA indicated significant differences, Tukey's HSD post hoc test was used to identify statistically different groups. The significance level was set at 5% ($p < 0.05$).

Results and Discussion

Classification of processing systems

Not all technologies were available in every surveyed village, and even where technologies were available, they were not necessarily used by all processors. Processors therefore combined the equipment available to them in different configurations. Based on these technological choices, the respondents were classified into four processing systems.

This classification constitutes the main explanatory variable used in the comparative analysis.

Adoption of processing systems

The distribution shown in Figure 1 indicates that the four systems were represented in the sample. The traditional system accounted for 28.57% of processors, followed by SM1 (32.86%), SM2 (17.14%), and SM3 (21.43%). Among processors using semi-mechanized systems, SM1 was the most common configuration, accounting for approximately 46% of semi-mechanized users, followed by SM3 (30%) and SM2 (24%).

Technical and economic performance

Technical performance

Technical performance was assessed using the annual quantity of shea kernels processed under each system. Figure 2 shows a clear increase in processing capacity with the progressive integration of semi-mechanized equipment. The SM3 configuration processed an average of 2,312.26 kg of kernels per year, compared with 1,664.21 kg for SM2 and 1,332.00 kg for SM1, whereas the traditional system processed 599.78 kg. ANOVA confirmed statistically significant differences among the four systems ($F = 39.73$; $df1 = 3$; $df2 = 136$; $p < 0.001$).

The superior performance of SM3 may be related to the greater organization and structural capacity of processor groups in villages where SM2 and SM3 were available. These groups had also attracted support from non-governmental organizations and other institutions that provided equipment such as churners and roasters.

Economic performance

Gross revenue and net income

Mean net income was 241,644.41 FCFA/year for users of SM3, 148,199.71 FCFA/year for SM2, 127,327.90 FCFA/year for SM1, and 41,343.90 FCFA/year for traditional processors. Mean gross revenue was 254,348.52 FCFA/year for SM3, 159,777.04 FCFA/year for SM2, 135,333.98 FCFA/year for SM1, and 47,983.78 FCFA/year for traditional processors. ANOVA indicated significant differences among systems for both net income ($F = 37.39$; $df = 136$; $p < 0.001$) and gross revenue ($F = 38.25$; $df = 136$; $p < 0.001$).

The differences in revenue were closely associated with the quantities of kernels processed. Semi-mechanized systems process larger quantities but incur higher variable costs per kilogram because of machine-related operating costs.

In contrast, traditional processing has lower operating costs because it does not involve machinery. Since yields were assumed to be similar across systems in the source analysis, gross and net revenues increased with the quantity of kernels processed.

Benefit-cost ratio and return on total cost

The benefit-cost ratios were greater than 1 for all four systems, indicating positive returns relative to total costs under the costing assumptions used in the study. The highest BCR was observed for SM3 (1.54), followed by SM1 (1.38), SM2 (1.36), and the traditional system (1.24). The differences were statistically significant ($p < 0.001$).

The original manuscript referred to RN/TC as an "internal rate of return." Because RN/TC is a return-on-cost ratio rather than a conventional investment IRR calculated from a time series of cash flows, the indicator is reported here as **return on total cost (RTC)**. The RTC was 54.44% for SM3, 37.86% for SM1, 35.63% for SM2, and 24.00% for the traditional system. These differences were statistically significant ($p < 0.001$).

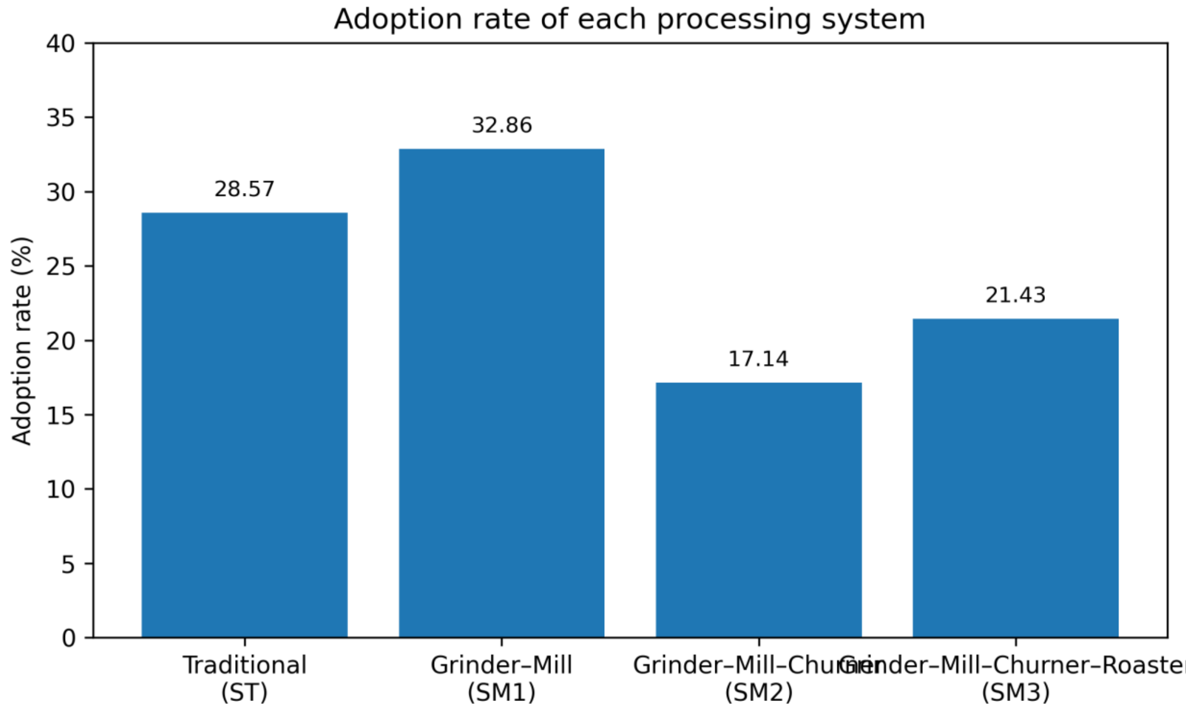
Under the costing assumptions, the returns for the semi-mechanized systems exceeded the 24% lending rate reported for the nearest microfinance institution (CLCAM). However, this comparison should be interpreted cautiously because processors often obtain water, fuelwood, and sometimes kernels at little or no cash cost. In the present analysis, these resources were nevertheless assigned monetary costs. The profitability indicators should therefore be interpreted primarily as comparative estimates rather than absolute measures of realized cash profitability.

Labor use and labor productivity

SM3 used the largest amount of labor, averaging 128.15 person-days/year, followed by SM2 with 104.46 person-days/year, SM1 with 91.12 person-days/year, and the traditional system with 56.80 person-days/year. However, the higher labor use in the more mechanized systems was accompanied by substantially higher labor productivity. Labor productivity averaged 1,875.67 FCFA/person-day in SM3, 1,349.21 FCFA/person-day in SM2, and 1,190.51 FCFA/person-day in SM1, compared with only 722.53 FCFA/person-day under traditional processing.

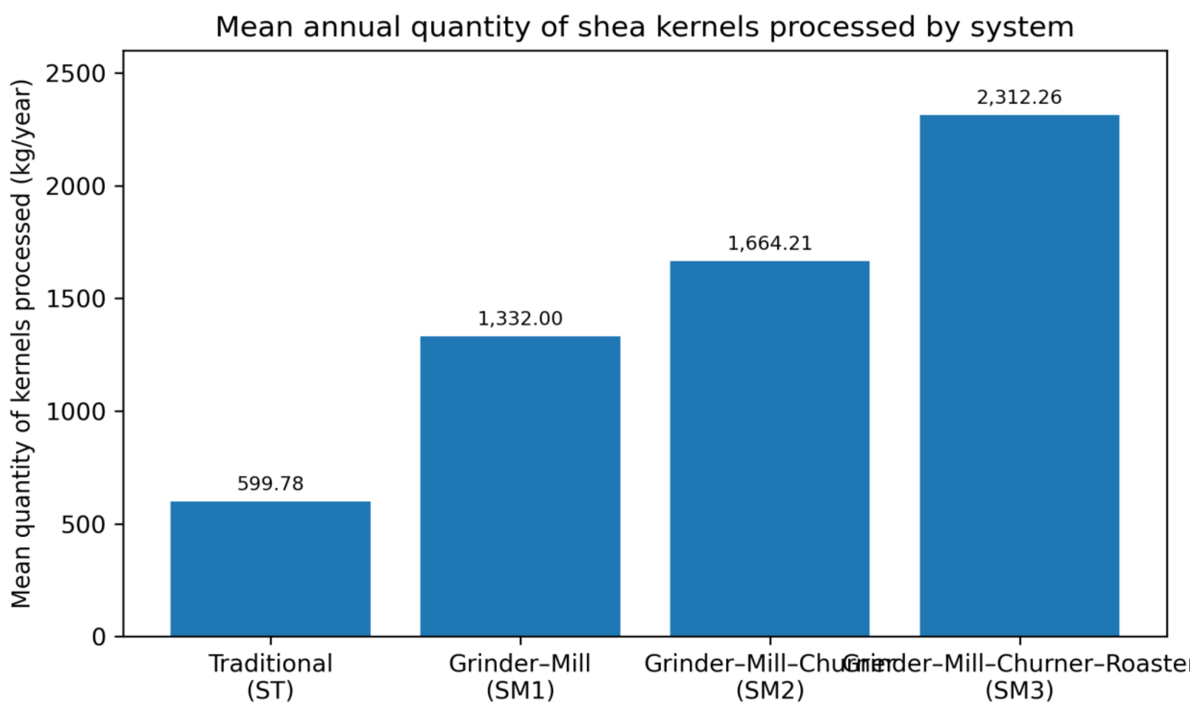
These productivity levels were above the average labor price reported in the surveyed villages, which was 1,100 FCFA/person-day in Nikki, Parakou, N'Dali, Sinendé, and Pèrèrè and 1,000 FCFA/person-day in Banikoara and Bembéréké. Thus, the semi-mechanized systems provided greater economic valuation of labor, which was predominantly family labor.

Figure.1 Adoption rate of each processing system.



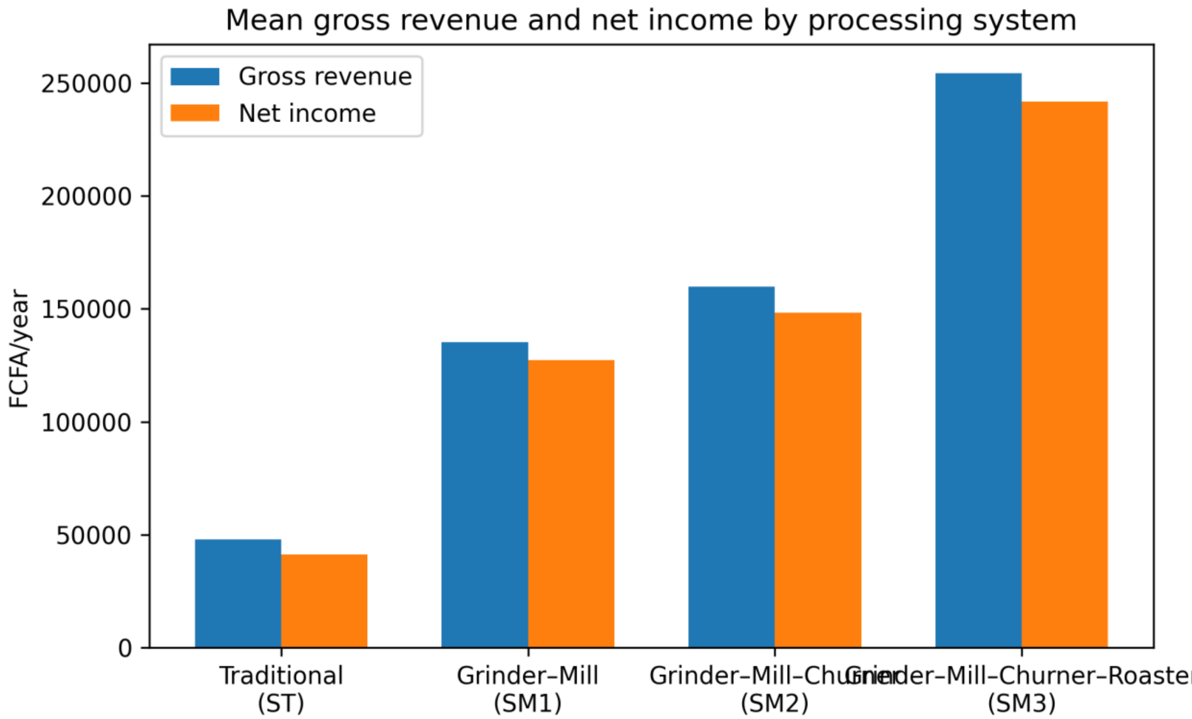
Source: Survey data, October 2023.

Figure.2 Mean annual quantity of shea kernels processed by system.



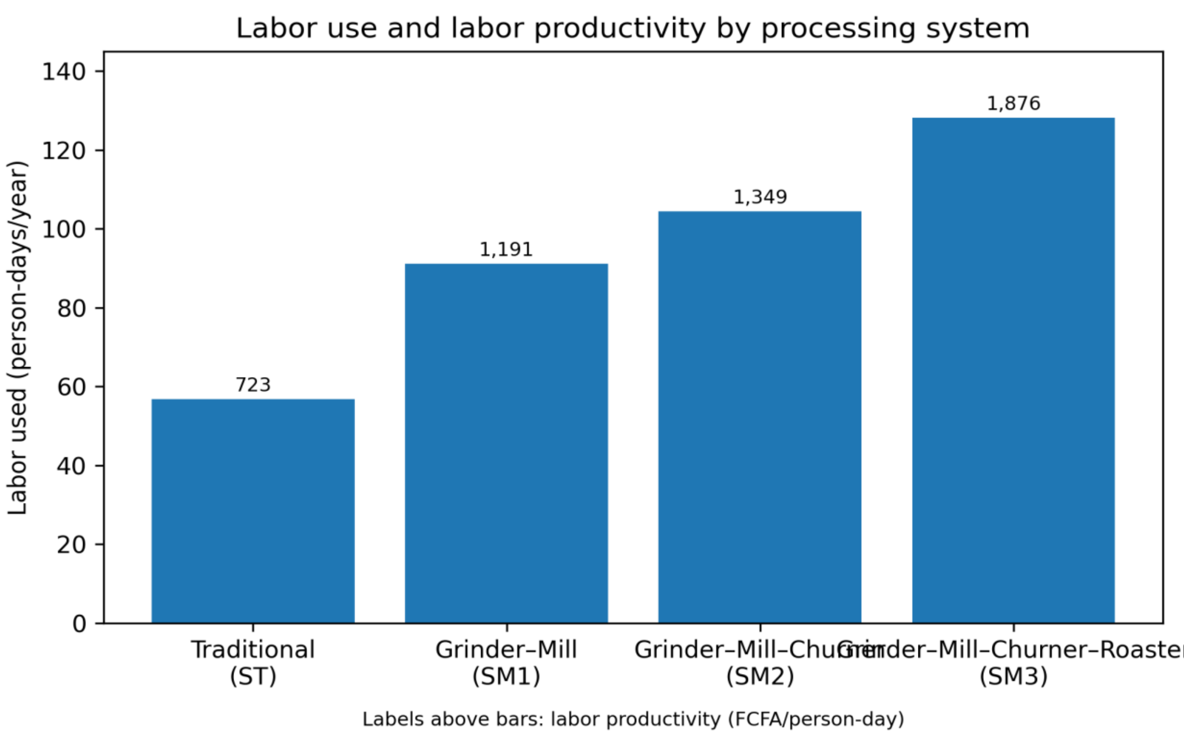
Source: Survey data, October 2023.

Figure.3 Mean gross revenue and net income by processing system.



Source: Survey data, October 2023.

Figure.4 Labor use and labor productivity by processing system.



Source: Survey data, October 2023. Labels above bars indicate labor productivity in FCFA/person-day.

Table.1 Distribution of the sample

Shea parkland	Municipality	Village	Sample size
Kandi	Banikoara	Sompérékou	10
Bembéréké	Bembéréké	Saoré	10
Bembéréké	Bembéréké	Bouanri	10
Bembéréké	Bembéréké	Wanrarou	10
Bembéréké	Sinendé	Fo-Bouré	15
Bembéréké	Sinendé	Guessou-Bani	10
Bembéréké	Nikki	Ouénou	15
Parakou	Pèrèrè	Soubado	10
Parakou	Pèrèrè	Pèrèrè Gourou	15
Parakou	Parakou	Tourou	15
Parakou	Parakou	Koroborou	10
Parakou	N'Dali	Komiguéa	10
		Total	140

Source: Survey data, October–December 2023.

Table.2 Variables used in the analysis

Variable	Unit	Type	Analytical use
Age	Years	Quantitative	Socioeconomic characteristics
Education level	Years/level	Qualitative	Human capital
Experience	Years	Quantitative	Processing experience
Quantity of kernels processed	kg/year	Quantitative	Technical performance
Labor used	Person-days	Quantitative	Labor productivity
Variable costs	FCFA	Quantitative	Economic analysis
Fixed costs	FCFA	Quantitative	Economic analysis
Gross output value	FCFA	Quantitative	Economic performance
Net income	FCFA	Quantitative	Profitability
Benefit-cost ratio	Dimensionless	Quantitative	Financial profitability
Return on total cost	%	Quantitative	Financial profitability

Source: Survey data, October 2023.

Table.3 Economic performance indicators

Indicator	Formula	Interpretation
Gross output value (GOV)	Quantity × Price	Total value of production
Gross income (GI)	GOV − VC	Gross margin
Net income (NI)	GOV − TC	Economic profitability
Benefit-cost ratio (BCR)	GOV / TC	Financial efficiency
Labor productivity	NI / Labor	Economic valuation of labor
Return on total cost (RTC)	NI / TC	Return relative to total cost

Source: Adapted from Yabi et al., (2008, 2010).

Table.4 Classification of shea butter processing systems

System	Technological configuration
ST	Traditional processing (mortar and mill)
SM1	Grinder + Mill
SM2	Grinder + Mill + Churner
SM3	Grinder + Mill + Churner + Roaster

Source: Survey data, OJctober 2023.

Table.5 Mean quantity of shea kernels processed by system

System	Mean quantity (kg/year)	Standard deviation
Traditional (ST)	599.78 a	109.285
Grinder–Mill (SM1)	1,332.00 b	931.419
Grinder–Mill–Churner (SM2)	1,664.21 c	598.614
Grinder–Mill–Churner–Roaster (SM3)	2,312.26 d	538.731

ANOVA: $F = 39.73$; $df1 = 3$; $df2 = 136$; $p < 0.001$. Means followed by different letters differ significantly. Source: Survey data, October 2023.

Table.6 Benefit-cost ratio and return on total cost by processing system

Indicator	Processing system	Mean	Standard deviation
Benefit-cost ratio	Traditional (ST)	1.2400 a	0.04420
	Grinder–Mill (SM1)	1.3786 b	0.15916
	Grinder–Mill–Churner (SM2)	1.3563 b	0.15053
	Grinder–Mill–Churner–Roaster (SM3)	1.5444 c	0.06869
	Total	1.3671	0.15733
Return on total cost	Traditional (ST)	24.00% a	4.42%
	Grinder–Mill (SM1)	37.86% b	15.92%
	Grinder–Mill–Churner (SM2)	35.63% b	15.05%
	Grinder–Mill–Churner–Roaster (SM3)	54.44% c	6.87%
	Total	36.71%	15.73%

BCR test: $F = 35.23$, $df = 136$, $p < 0.001$. RTC test: $F = 39.63$, $df = 136$, $p < 0.001$. Means followed by different letters differ significantly. Source: Survey data, October 2023.

The results reveal a clear advantage of semi-mechanized systems over traditional processing in both technical and economic performance. SM3 recorded the highest technical performance, with an average processing capacity of 2,312.26 kg of kernels per year, compared with 1,664.21 kg for SM2 and 1,332.00 kg for SM1. The difference among systems was statistically significant ($p < 0.001$). This superiority may result from the complementarity of equipment and the reduction of technical constraints at several stages of processing. It is consistent with Masters *et al.,* (2004) and Moore (2008), who emphasized the role of appropriate equipment in increasing productive capacity and reducing labor drudgery. It is also consistent with Farrell's (1957) concept of technical efficiency, which emphasizes obtaining the maximum output from a given set of inputs.

The increase in the level of mechanization was also associated with a substantial improvement in labor productivity. Labor productivity reached 1,875.67

FCFA/person-day in SM3, compared with 1,349.21 FCFA in SM2, 1,190.51 FCFA in SM1, and 722.53 FCFA in the traditional system. This result supports the view of McConnell and Dillon (1997), as discussed by Kadekoy (2010), that factor productivity is an important criterion for assessing the performance of production units. It is also consistent with Gafsi *et al.,* (2007), who emphasized the importance of monetary income in the economic strategies of family production units. In the shea sector, the increase in labor productivity is particularly important because processing is predominantly a female income-generating activity (Ferris *et al.,* 2001; Lovett, 2004).

Economic performance followed the same ranking. Mean net income reached 241,644 FCFA/year in SM3, compared with 148,200 FCFA in SM2, 127,328 FCFA in SM1, and only 41,344 FCFA in the traditional system, with statistically significant differences ($p < 0.001$). The BCR and RTC also confirmed this pattern. SM3 recorded a BCR of 1.54 and an RTC of 54.44%, compared with 1.36 and 35.63% for SM2 and 1.38 and 37.86% for SM1. These findings are consistent with Elias and Carney (2007) and Pouliot (2012), who highlighted the potential of shea-related activities to expand women's economic opportunities. They also support the economic logic that producers seek combinations of production factors that improve economic returns under resource and technology constraints.

The superior performance of SM3 suggests that the additional costs associated with mechanization can be offset by higher processing volumes and revenues. Nevertheless, this conclusion requires qualification because some resources—particularly water, fuelwood, and sometimes kernels—may be obtained without direct cash expenditure.

These resources were assigned monetary costs in the present analysis. The profitability indicators should therefore be interpreted as comparative measures based on a standardized costing framework rather than as direct measures of cash income.

Finally, the observed differences cannot necessarily be attributed to equipment alone. SM2 and SM3 were more common in villages characterized by better-organized processor groups and by interventions from support organizations that facilitated access to equipment. This observation is consistent with CIRAD-GRET (2002), which emphasizes the influence of the economic, social, and institutional environment on technological choices. As Yabi *et al.,* (2014) also suggest, sustainable improvements in processor performance depend not only on introducing technologies but also on the conditions that enable their effective adoption and use.

Overall, the findings indicate that progressive technological integration can improve technical performance, labor productivity, and economic profitability simultaneously. SM3 offers the best observed combination of technical and economic performance. Its wider diffusion should nevertheless be accompanied by appropriate access to finance, training, equipment maintenance, and organizational support to ensure sustainable and economically viable mechanization.

In conclusion, the comparative analysis of shea butter processing systems in Northern Benin revealed substantial differences in technical performance and economic profitability.

The Grinder–Mill–Churner–Roaster configuration was the most performant system, processing the largest quantities of shea kernels and generating the highest net income, benefit-cost ratio, return on total cost, and labor productivity.

It was followed by the Grinder–Mill–Churner and Grinder–Mill configurations, while the traditional system recorded the lowest performance.

The results suggest that increasing the level of mechanization is not only a means of reducing processing constraints but also a potential lever for improving the economic performance of women-led processing units. However, the additional costs associated with acquiring and operating equipment should be assessed against the productivity and profitability gains generated. Access to credit should therefore be considered only after assessing repayment capacity and the economic viability of the investment.
Policies and development programs supporting the shea value chain should facilitate access to appropriate equipment, affordable finance, technical training, and maintenance services.

Support should prioritize technological configurations that match processors' production capacity, financial resources, and organizational conditions. Progressive and economically managed mechanization therefore appears to be a relevant pathway for strengthening the long-term competitiveness of women's shea butter processing units in Northern Benin.

Conflict of Interest

The authors declare that they have no conflict of interest related to this study.

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