International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 40 No. 2 Aug. 2023, pp. 382-396

http://www.ijias.issr-journals.org/

Evaluation of the technical and economic performances of shea mills and crushers in Benin

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ABSTRACT: Shea is a plant found in the central and northern regions of Benin. In the counties of Borgou and Alibori, for example, shea kernel provides basic cooking oil for more than 80% of the population. In recent years, the production of shea butter has emerged as a credible income generating activity alternative to the reduction in cotton income for the populations of northern Benin. It has become an important source of income to the women who are involved in collection and processing activities of shea kernel. This work is gradually witnessing the modernization of the sector by introducing new technologies to reduce the drudgery of butter extraction. Thus, the grinding (crushing) and milling operations have been mechanized, which allow labor reduction and time spent in the processing; and improve the profitability. However, in Benin, the technical and economic performance of the equipment introduced has not been documented. The study evaluated the technical and economic performance of crushers and mills of shea almonds. The technical performance of the machine is evaluated based on different parameters such as: throughput; broken rate; hourly consumption and specific consumption. The economic performance of the equipment focuses on costs and benefits, on indicators such as work times, variable costs, income and fixed costs, gross and net margins. The result obtained from the evaluation indicated that the throughput; broken rate; the crushing efficiency and gross margin of crusher BECRREMA type are respectively 501 kg/h; 100%; 98.8% and 925.32 FCFA/100 kg. The throughput; milling efficiency and gross margin of mill COBEMAG type are respectively: 62.95 kg/h; 99.5% and 2,412 FCFA/100 kg. These results show that these agro food equipment's are efficient and cost-effective for the production of shea butter. Full dissemination of these improved technologies is recommended for development of shea processing sector in Benin and West Africa.

KEYWORDS: Shea, throughput, milling efficiency, gross margin, fuel consumption.

1 INTRODUCTION

Shea (*Butyrospermun Parkii*) tree is one of the natural resources which provide oil for the rural population in many Sub-Saharan African countries. Shea nuts tree is a member of the Sapotaceaes family [1] commonly found in Africa. Benin is one of the sixteen countries that produce shea kernels in Africa [2], [3]. Shea tree plays an essential role in maintaining ecological durability in Sahel and in Sub-Saharan Africa. The locust bean (*Parkia biglobosa*) and shea are the main trees that commonly occupied the parklands of Northern Benin [4], [5]. They represent a fundamental component of forest resources, both from a socioeconomic, nutritional perspectives [5], [6] as well as ecological [7] in West Africa. The shea tree is mainly important for its kernels that are processed in shea butter, a very important vegetable oil in West Africa [8]. About 95% of shea kernels merchandised, across the world market, are destined for the agro-food sector [9], [10]. In Europe, shea butter is used in the chocolate factories, in pharmacology for making cosmetics and various types of creams. Thereby in the context of employment, the shea tree provides more opportunities, particularly to the women to reduce the poverty in the rural areas [11]. Beyond that, about 4 million women are involved in the kernel harvesting activities in the West Africa region; these fruits are an important and crescent source of income for local families and communities as well [12], [13].

On economic view, recent studies indicated that 1,000 $ US invested at the beginning of the exploitation of shea, brought back 1,580 $ to household incomes [14]. The sale of processed products generates significant income to the rural families [15], [16], [17]. Despite its economic importance in Africa countries, shea kernels sector is confronted with difficulties including low efficiency of the existing kernels processing technologies [2], [18]. For this reason, shea kernels producing countries are often processing oil for less than a third of the shea kernels production potential, due to the lack of improved techniques [19]. With a transformation capability of 12,000 tons to 35,000 tons of shea nuts harvested for exportation, Benin is an ideal place for sector actors to identify new investment opportunities which bring profit and trade for local communities. Almost the whole totality of the women in the Northern Benin involved in these activities [20].

On processing view, the shea kernels are traditionally obtained by pounding kernels in a mortar or with stone. Then shea butter is extracted following the operations of grinding or crushing, roasting, and milling of kernels, churning of the obtained dough and cooking of the cream [18]. Production of shea kernels and extraction of shea butter are usually accomplished manually by women, which is laborious and takes long time. However, these different operations are day by day improved by using equipment developed by researchers and local manufacturers. Several studies have been carried out on the physical characterization of shea kernels [21], [22], [23], [24]. Olaniyan and Oje, [25] investigated the strength properties of shea-butter nuts and realized that the rupture force, deformation, and toughness decrease while firmness increases with the increase in temperature of shea nuts in both axial and lateral loading positions. Treating the shea nuts using a temperature above 90°C may cause structural defects in the nuts. Based on those results, some equipment were developed to improve the efficiency of shea nut processing including shea nut sheller [24], [26], [27]. Research institutes and companies that manufacture agricultural machinery like COBEMAG, BECRREMA, also introduced different equipment to improve the processing of shea butter. This last five years, some equipment such as the crusher, the mill and the roasters were introduced to the women processors by different NGOs, Research Institutes, and fabricators. This helps to reduce the workload to the processor and increase the productivity. However, the technical performances of those equipment are not yet documented in Benin and West Africa. The used of equipment generated some constraints regarding the planning of the maintenance and troubleshooting. The study evaluated the technical and economic performance of the shea processing equipment.

2 Material And Methods

2.1 Material

2.1.1 Plant Material

The experiments were conducted in the women's cooperative Taa Wakadi of Simpérou in Banikoara, T'Djenga of Barei (Djougou) and Mero Bissiru of N'Dali in north region of Benin. The plant material was shea almond kernel (Figure 1) obtained from the shea fruit collected by the processors under the shea tree.

Fig. 1. Shea kernel

2.1.2 Equipment

Crusher

The crusher and the mills were tested in the study. The different types of shea almond crushers tested were BIO-GANDO, COBEMAG and BECRREMA. The performances of crushers and mills were compared to the traditional method of shea kernel crushing with mortar (Figure 2). The crusher COBEMAG (Figures 3 & 4) has an axis which carries a tray on which three hammers turning in the same horizontal plane are mounted. The kernel is crushed by the impact between the hammers and the kernel, then between the kernel and the perforated sheet of diameter 8 mm. The Bio Gando crusher (Figure 5 & 6) has two gears: one leading, the other led. The almond is grinding through the pressure between the two gears.

Fig. 2. ***Traditional shea kernel crushing with mortar***

Fig. 3. ***Crusher COBEMAG***

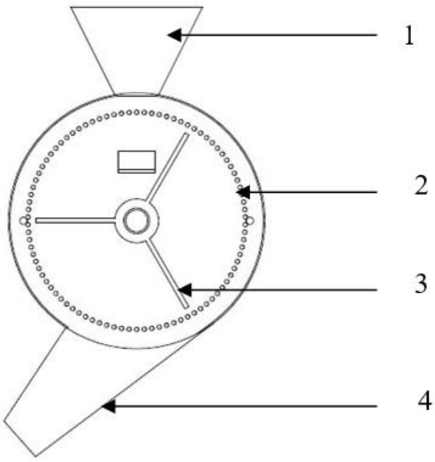

Fig. 4. ***Principe design of crusher COBEMAG***

Legend: 1-hopper; 2-sifter; 3-hammer; 4-outlet.

Fig. 5. Crusher BIO-GANDO

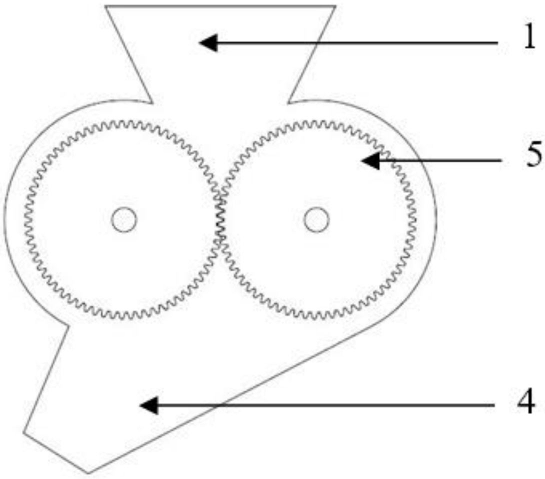

Fig. 6. Design of crusher Gando

Legend: 1-Hopper; 2- Sifter; 3- Hammer; 4-Outlet; 5- Gears.

Fig. 7. Crusher BECRREMA

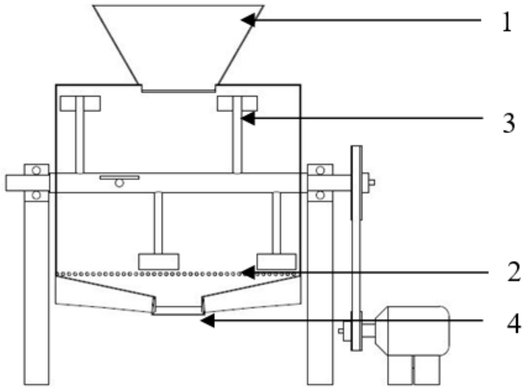

Fig. 8. Design of crusher BECRREMA

Legend: 1-Hopper; 2- Sifter; 3- Hammer; 4-Outlet.

BECRREMA has one axis on which 5 shafts turning in different horizontal plan are mounted. The kernel is crushed by the impact between the shaft and the kernel, then between the kernel and the perforated sheet of diameter 8 mm attached under the hammers (Figure 7 & 8).

SHEA MILL

Fig. 9. Shea almond mill with carborundum stone

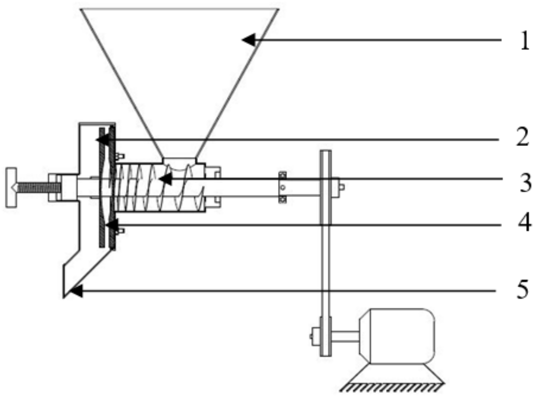

Fig. 10. Design of almond mill with carborundum stone

Legend: 1-Hopper; 2- Mobil carborundum stone; 3- Feeding screw; 4- Fixed carborundum stone; 5- Outlet.

Two mills were tested during the experimentation. The first mill is type COBEMAG with two carborundum millstones (Figure 9 & 10). One mobile and the second fixed. The roasted shea almonds are ground with the effect of the friction between the two millstones. The second tested mill was the cereal mill (Figure 11 & 12). This mill has two metal millstones: one fixed and the second mobile. The functional principle is the same with the COBEMAG mill. The fineness of the grind depends on the gap and the pressure between the millstones. The quality of the milling also depends on the quality of the roasted shea. Good roasting facilitates good grinding and fluidity of the dough.

Fig. 11. Metallic stone mill

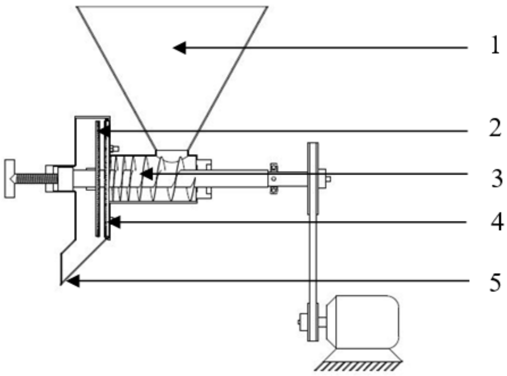

Fig. 12. Design of metallic stone mill

Legend: 1- Hopper; 2- Mobil metallic stone; 3- Feeding screw; 4- Fixed metallic stone; 5- Outlet.

2.2 Methods

2.2.1 Technology Processing Of Shea Almond

The flow diagram of production of shea butter used in the study is illustrated in Figure 13.

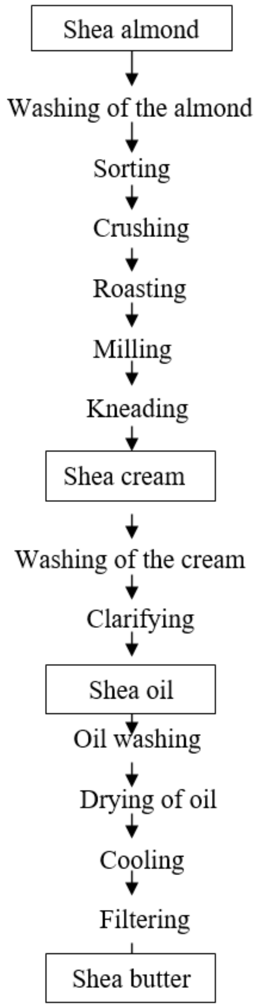

Fig. 13. Flow diagram of production of shea butter

2.2.2 CRUSHER TESTING

The three crushers (COBEMAG, BIO-GANDO and BECRREMA) were tested in comparison with the traditional pounding method by mortar. For each method, six repetitions were performed. One hundred kilograms of shea kernels was used per repetition. The collected data were weight of the sample (kg); running time (min), mass of the uncrushed kernel (kg) and the volume of consumed kernel (l). The performance of each crusher was evaluated through the following parameters: Throughput (kg/h); Rate of the broken (%); Hourly consumption (l/h) and Specific consumption (l/T). The Throughput (kg/h) was calculated with the formula expressed in Eq. 1:

$$C_H = {}^{M}\!/_{t}\,(kg/h) \tag{1}$$

where:

M: weight of the sample shea almond (kg);

T: working time (h);

The Rate of broken is calculated by the formula expressed in Eq. 2:

$$T_b = {}^{M_b}\!/_{M}\,(kg/h) \tag{2}$$

where:

$M_{b:}$ weight of broken almond;

Hourly consumption C_h is calculated by the formula expressed in Eq. 3

$$C_h = {}^{V_c}\!/_{t}\ (l/h) \tag{3}$$

where:

Vc: volume of fuel consumes during the crushing of the almond sample;

$$C_s = {}^{V_c}\!/_{M}\ (l/kg) \tag{4}$$

Three treatments were carried out for the test of shea crusher

- Treatment T_0: Mortar
- Treatment T_1: Crusher COBEMAG
- Traitement T_2: Crusher BECRREMA
- Traitement T_3: Crusher BIO-GANDO

2.2.3 MILL TESTING

The efficiency and reliability of the mills were evaluated using the following data: Throughput (kg/h); Hourly consumption (l/h); Specific consumption (l/T), Extraction rate (%); Extraction yield (%). Throughput (kg/h) *((*hourly capacity), Hourly consumption and Specific consumption are determined by the same formula expressed in Eq. 1-5 above for the crusher performance.

The extraction rate T_E is calculated by the expression:

$$T_E = {}^{M_H}\!/_{M}\ (\%) \tag{5}$$

$M_{H:}$ weight of shea butter,

The extraction rate (T_E) is expressed by the ratio between the quantity of butter obtained after extraction and the quantity of raw material (shea kernel). It varies with the technique used and the quality of the raw material used.

Three treatments have been carried out for the production of butter::

- Treatment T_1: Mill COBEMAG with Iron stone
- Traitement T_2: Mill COBEMAG with carborundum stone
- Traitement T_3: Corn millin machine with metallic stone
- Traitement 4: Manual milling roc

T_4 treatment is the traditional method. Twelve observations were performed with three repetitions per treatment.

2.2.4 ENGINE PERFORMANCE ANALYSIS

The performance of the engine used on the crusher and shea mill was evaluated. The parameter used to appreciate the performance of diesel engine are: maintenance cost (FCFA), working duration /day, number of breakdown and duration of immobilization for breakdown.

2.2.5 ECONOMIC ANALYSIS

The analysis of the economic performance of the equipment focuses on costs and benefits indicators such as work times, gross and net margins. Thus, the variable costs, income and fixed costs associated with each technology are estimated. The costs and benefits analysis method developed by UNIDO is used [18], [28], [29]. The data collected are processed using Excel 2016 software.

Variable costs

Variable costs are the labor cost, fuel, and workshop renting, repair, and maintenance costs.

Repair and maintenance costs

Repair and maintenance costs of the equipment are included in the variable costs. Indeed, at the current level of tests, the annual percentages have only been represented by these costs in the bills of equipment. Maintenance and repair costs then represent 8% of the annual cost of the equipment. Thus, based on the technical capacity of the mill and crusher, estimations were made on the repair and maintenance costs per 100 kg of processed shea almonds.

Service cost

The service cost payed by the processor for the milling or crushing of shea almond in the village of Barei, Ori and Babazahouré (north of Benin) was 1,000 CFFA for milling of 25 kg of shea and 300 FCFA[1] for crushing of 25 kg of shea kernel.

Fixed costs

Fixed costs are the costs of the machinery and other materials and these are reduced to annual costs by straight-line depreciation.

Margins

The gross margin is the difference between total revenue and total variable costs. The net margin is calculated by deducting the fixed costs from the gross margin. Total revenue is the operation income of the operator in the village for milling or crushing shea almond in each of the three villages of Barei, Bori and Babazahouré (1,000 FCFA for milling of 25 kg of shea and 300 FCFA for crushing).

For the calculation of technical capacity, it is assumed that the shea mill and crusher operate for six (06) days per week and 40 weeks in the year. This is equivalent to two hundred and sixteen (240) days per year, at the rate of 3.5 hours of work per day for the mill and 2.5 hours per day for the crusher. The remaining time of the day is spent on maintenance. Therefore, the capacity of the equipment is determined using the Eq. 6.

$$K = C_h \times N \times m \times n \text{ (kg/an)} \quad (6)$$

where:

C_h: Hourly capacity of the machine (kg/h)
N: Number of working days per week
m: number of working weeks in the year
n: number of working hours per day.

2.2.6 Statistical Analysis

The data collected were processed using the Excel software (2016) for descriptive statistics (mean and SD). SPSS 20 was used to perform means comparison of two groups (Student's t-test or Mann and Whitney U test) and more than two groups (one-way ANOVA or ANOVA of Kruskal-Wallis). A significant difference was accepted when p <.05

[1] $1 US = 628.90 F CFA in 2022 or 1 Eur = 655.957 F CFA

3 Result

3.1 Technical Performance Of The Crusher

3.1.1 Capacity And Efficiency

Table 1. Technical performance of shea kernel crusher

Equipment	Hourly Capacity (kg/hr)	Crushing rate (%)	Crushing efficiency (%)	Shea water content (%)
Bio Gando + IMEX	177.22 ±5.45$_a$	94.21 ±2.35a	98.15± 0.25$_a$	0,75± 0.03$_a$
Cobemag + R175A	259.93 ±34.26$_b$	100$_b$	98.81±0.18$_a$	0,85 ±0.02$_a$
Cobemag + IMEX	368.32±44.36$_c$	100$_b$	98.72±0.22$_a$	0,79± 0.22$_a$
BECRREMA +IMEX	501.32±67.45$_d$	100$_b$	98.85±0.34$_a$	0,70±0.08$_a$
Moter	7.21±0.89$_e$	100$_b$	98.91±0.44$_a$	0.78± 0.19$_a$

Note: Values with different letters in the same column are significantly different at α threshold of 5%.

The results in Table 1 shows that the crusher type BECRREMA has the best technical performance when it is connected to the IMEX engine. It was followed by the COBEMAG crusher with an hourly capacity of 368 kg/h, with low consumption (0.75 l/hr) and a crushing rate of 100%. The use of the 8 hp IMEX engine seems to have a positive effect on the performance of the shea almond crusher.

Fuel consumption

The Figure 14 presents the performance of the engine connected with the different types of shea almond crusher. The crusher BECRREMA+Imex present the lower specific consumption (1.25 l/T) when Bio Gando + Engine Imex have the lower hourly consumption (0.79 l/hr).

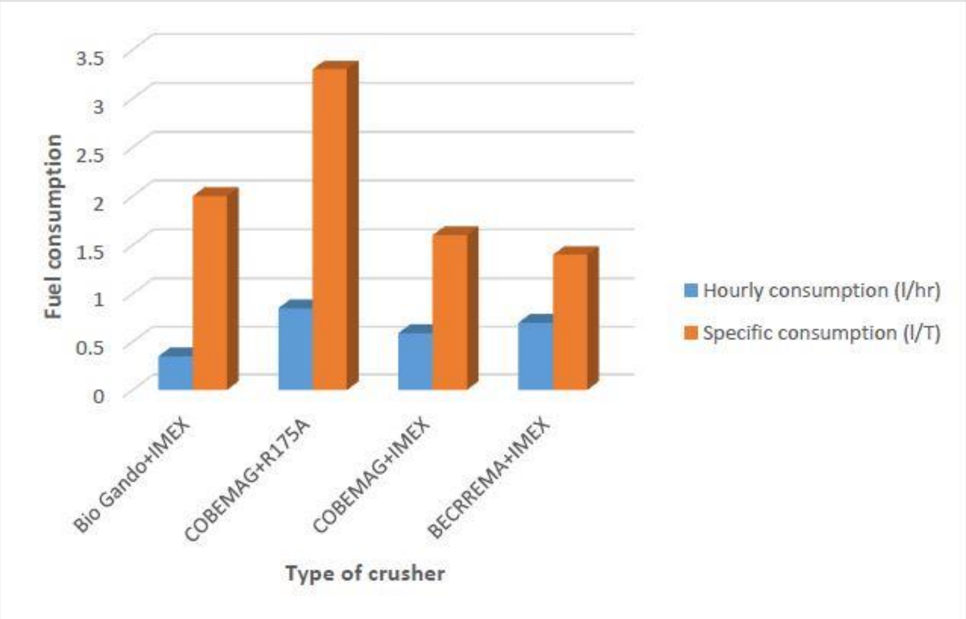

Fig. 14. Fuel consumption of crusher

3.2 Technical Performance Of Shea Almond Mills

3.2.1 Capacity And Efficiency

Table 2 show the technical performance of the shea almond mill. COMEMAG mill and Traditional corn mill with iron milling stone presents the higher throughput (66.96 kg/hr). But all the equipment showed approximately the same extraction yield and the same milling efficiency (99.8).

Table 2. Technical performance of shea almond mills

Equipment	Hourly Capacity (kg/hr)	Milling efficiency (%)	Extraction yield (%)	Water content of shea butter (%)
COBEMAG+iron stone	62.96_b	99.5_a	$36{,}95_a$	$2{,}8_a$
COBEMAG + carborundum stone	53.96_a	99.7_a	$36{,}51_a$	$2{,}36_a$
Corn milling machine	61.2_b	99.5_a	$36{,}99_a$	$2{,}57_a$
Manual milling roc	2.4_c	99.8_a	$36{,}55_a$	$2{,}18_a$

NB: Note: Values with different letters in the same column are significantly different at α threshold of 5%.

3.2.2 Fuel Consumption

The Figure 15 presents the performance of engine connected with the different type of shea mills. The engine of corn milling machine presents the lower specific consumption when COBEMAG + rock stone has the lower hourly consumption.

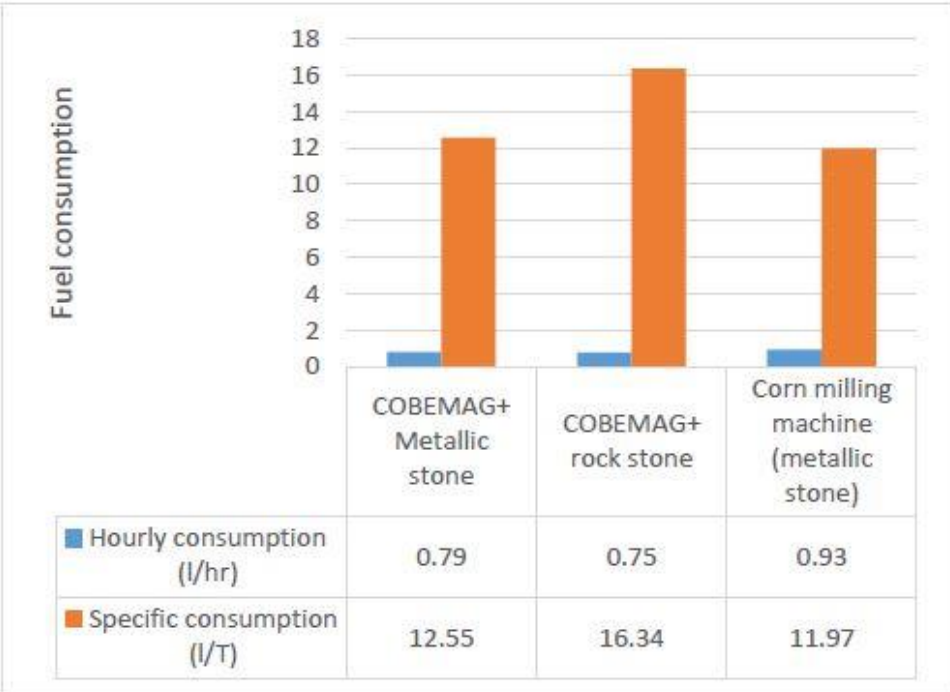

Fig. 15. Fuel consumption of milling machine

3.2.3 Technical Performance Of The Engines On Shea Milling Machine

The results from Table 3 indicate that engine R175A have the highest maintenance cost for the crushing and the milling compared with the engine 9,255 CFA and 4,060 CFA respectively. Engine IMEX shows the highest working duration per day and the smaller number of breakdown per month. The duration of immobilization for breakdown is 6 times higher for engine R175 compared with IMEX with the crusher. With the mill, it is 2.85 time higher.

Table 3. Technical performance of the engine on shea crushing and milling machine

Parameters	Crusher		Mill (milling stone)	
	Engine R175A	Engine IMEX	Engine R175A	Engine IMEX
Maintenance cost (FCFA/month)	9,255	1,996	18,156	4,060
Working duration per day (h/day)	3	8	2	6
Number of breakdown per month	1	0.25	2	0.5
Duration of immobilization for breakdown (number days/month	3	0.5	10	3.5

3.3 Economic Performance Of The Equipment

3.3.1 Fixed Cost

Table 4 presents the fixed cost of crusher and shea mill. Crusher BECRREMA shows the lowest depreciation cost (73.34 FCA/100 kg) compared with Crusher COBEMAG. The metallic stone mill presents the lowest depreciation cost 408.74 FCFA

Table 4. Fixed costs for different technologies

Parameter	Crusher COBEMAG	Crusher BECRREMA	Mill COBEMAG	Metallic stone mill
Machine cost (FCFA) (M)	1,350,000	1,100,000	1,435,000	1,030,000
Hourly capacity (Kg/h) (A)	368	500	58	60
Number for working hours per day (B)	2.5	2.5	3.5	3.5
Number of working days per week (C)	6	6	6	6
Number of working weeks in the year (D)	40	40	40	40
Technical capacity (K=A*B*C*D) (kg/year)	220,800	300,000	48,720	50,400
Depreciation (M/5) (FCFA)	270,000	220,000	287,000	206,000
Depreciation per 100 kg (FCFA/100kg)	122.29	73.34	589.09	408.74

3.3.2 Variable Cost

Table 5. Variable costs for different technologies

Parameter	Crusher		Mill	
	Crusher COBEMAG	Crusher BECRREMA	Mill COBEMAG	Metallic stone mill
Repair and maintenance cost (FCFA)	108,000	88,000	114,800	82,400
Repair and maintenance cost for 100 kg (FCFA)	48.92	29.34	235.64	163.5
Specific consumption (l/t)	1.6	1.4	16.34	11.97
Cost fuel for 1 ton (FCFA)	880	770	8987	6583.5
Cost fuel for 100 kg (FCFA/100kg)	88	77	898.7	658.35
Daily workmanship (FCFA)	2000	2000	2000	2000
Workmanship for 100 kg	90.58	66.67	574.72	555.56
Workshop renting /Month (FCFA)	5000	5000	5000	5000
Renting cost for 100 kg (FCFA/100kg)	2.27	1,67	10.27	9.93
Total variable cost for 100 kg (FCFA/100 kg)	229.77	174.68	1,719.33	1,387.34

Table 5 shows that Crusher BECRREMA has the lower variable cost (174.68 FCA/100 kg) compared with Crusher COBEMAG. The metallic stone mill has the lower variable cost 1,378.34 FCFA, while the mill COBEMAG with rock stone estimates variable cost at 1,719.33 FCFA.

3.3.3 Gross Margin And Net Margin For Different Technologies

Table 6 illustrates the gross and net margin for the utilization of shea equipment to provide service to the processor. Crusher BECRREMA combine with the engine IMEX provide the higher margin. Shea mill with the metallic stone provide the higher gross margin and net margin; 2,412.66 FCFA and 2003.92 FCFA respectively.

Table 6. Gross margin and net margin for different technologies

Parameter	Crusher COBEMAG	Crusher BECRREMA	Mill COBEMAG	Metallic stone mill
Quantity of shea almond (kg)	100	100	100	100
Depreciation per 100 kg (FCFA)	122.29	73.34	589.09	408.74
Variable cost for 100 kg	229.77	174.68	1719.33	1387.34
Income (FCFA/100 kg)	1,100	1,100	3,800	3,800
Gross margin (FCFA/100 kg)	870.23	925.32	2,080.67	2,412.66
Unitary gross margin (FCFA/ kg	8.70	9.25	20.81	24.13
Net margin (FCFA/100 kg)	747.94	851,98	1,491.58	2,003.92
Unitary net margin (FCFA/kg)	7.48	8.52	14.92	20.04

4 DISCUSSION

The results indicated in Table 1 illustrate the performance of different shea kernel crushers introduced to the processor in a modern shea kernel processing technology. Crusher BIO-GANDO showed the less crushing rate (95%) while the crusher BECRREMA showed the higher hourly capacity with the engine IMEX (501.32 kg/hr). The number of the hammer and the larger area of contact of the sifter should explain this performance. The design of the crusher allows the quick evacuation of crushed almond. The performance of the crusher depends on the physical and mechanical characteristics of the shea almond [23], [24]. The rupture force point of the almond has a key influence on the performance of the crusher [24], [30]. Ojolo and Eweina [30] evaluated the cracking force of the shea nutshell. The force required for the design of the suitable cashew nutshell cracking machine should be considered in the range of 400–500 N. The performance of the shea crusher depends on the cracking energy [31] and the temperature of treatment [26]. The majority of the crusher present a 100% of broken rate (crushing efficiency) but Bio Gando has the least value (94%). The utilization of gear to crush the shea kernel was not appropriate. The performance of crusher BECRREMA and COBEMAG was obtained with the shaft speed of 550 rpm. The crusher developed by Shehu *et al.,* [32] presents the highest values of crushing efficiency (crushing rate) of 98.23% from a combination of speed and crushing time of 1200 rpm and 360 seconds respectively, while the least value of crushing efficiency of 56.24% was obtained from combination of speed and crushing time of 959 rpm and 330 seconds respectively [32].

The analysis as indicated in Table 2 shows that out of the stone wheel, there was no significant difference at the 5% level between the hourly capacities of the different mills tested. Nevertheless, it is noted that the use of the metal grinding wheel resulting a higher capacity of 11% than the stone grinding wheel. Moreover, the different equipment tested produced almost the same quantities of butter from the same quantity of almonds that are harvested in the same region. Indeed, the extraction rate varies between 36.51% and 36.95%. From the analysis, it can be deducted that the fabricator of COBEMAG can without risk of reduction of performance, deliver to the shea processor the version of the mill with metal grindstones. In addition, the use of the IMEX corn mill for grinding shea may be recommended to processors. Yield of shea extraction varies between 36 to 40%. Abdul-Mumeen *et al.,* [33] have reported that the yield (efficiency) of the mechanical method extraction is 30-45% and the traditional method 25-40%. In Nigeria, yield of shea oil ranges between 27.41% and 45.23% [32]. Gana observed milling efficiency decreases from 79% to 68.5% with an increase in moisture content from 11% to 13% [32], [34].

From the analysed results indicated in Table 3, it appears that the engine R175A type was not suitable for driving shea mills. The engine has the highest repair cost with frequent breakdown. Beyond that, the motor heats up excessively. The downtime for high breakdown was due to the high cost and the difficulty of finding spare parts, the technical skills to repair this engine are not always available. On the other hand, the IMEX type engine shows its endurance with ability to work continuously for more than six hours. Local skills are available for engine maintenance and repair. In addition, spare parts for IMEX engine are available and at a reduced cost compared with the R175A engine. The IMEX motor can be adapted to drive the mill and the grinder, which is not the case for R175A.

Economic analysis of equipment used to provide service shows that the gross margin of the BECRREMA crusher was 6% higher than the COBEMAG crusher. The income of the operator was 55 FCFA/100 kg higher than the COBEMAG crusher. It is recommended to COBEMAG fabricator to improve the performance of this equipment. A better quality of the engine should be adapted, and the dimension of the screen should be increased. Utilization of the two types of the mill to provide service to the processors is profitable to the operator. The income provided by the metallic stone mill is 15% higher than COBEMAG mill with the roc stone. This study revealed that the use of a good shea processing equipment to provide service gives profit to the operator. This confirms the analysis of Tiamiyu *et al.* [11] who reported that, the business of shea production, processing and marketing is profitable in Nigeria. The cost and return in the processing of 1 ton in Nigeria was 2,000 Naira (7,500 FCFA) [11]. and in Uganda, it is reported that shea is a highly valued commodity [35].

5 CONCLUSION

Introduction of new equipement for crushing and milling shea almond in Benin contributes to reduce the workload to the processor and increase the productivity. The crusher type BECRREMA showed the best technical performance with 501.32 kg/hr and broken rate of 100% when it is connected with the IMEX engine. It was followed by the COBEMAG crusher with a capacity of 368 kg/hr, with low consumption and a grinding rate of 100%. COMEMAG mill and Traditional corn mill showed the higher throughput. This equipment showed approximately the same extraction yield and the same milling efficiency. The use of a good shea processing equipment to provide service gives a profit to the operator. Economic analysis of equipment used to provide service shows that the gross margin of the BECRREMA crusher was 55 FCFA/100kg higher than the COBEMAG crusher. It is recommended to the COBEMAG fabricator to improve the performance of this equipment. A better quality of engine should be adapted, and the dimension of the screen should be increased. Utilization of the two types of the mill to provide service to the processors is profitable to the operator. Shea mill with the metallic stone provide the higher gross margin and net margin; 2,412.66 FCFA and 2003.92 FCFA respectively. Full dissemination of those improved technologies is recommended for the development of shea processing sector in Benin and West Africa. This will contribute to reduce the poverty and increase the livelihood of the community.

ACKNOWLEDGMENT

Our thanks go to the shea processors of the Taa Waadi Ekeba groups of Simpérou (Banikoara), T'Djenga of Barei (Djougou), Mero Bissiru of N'Dali, Bori of N'Dali, Wanru Suru of Ina, Tibobeni of Perma, Abagaye of Babazahunré for participating in the collection of technical and economic data.

REFERENCES

[1] F.A Oluwolé, N.A. Aviara and M.A. Haque, «Effet of moisture content and impact energy on crackability of sheanut», *Agric. Eng. Int.: The CIGR Ejournal*. Manuscript FP 007 002, IX, 2007.

[2] D.N. Bup, A.M. Mohagir, C. Kapseu and Z. Mouloungui, « Production zones and systems, markets benefits and constraints of shea (*Vitellaria paradoxa Gaertn*) butter processing», *OCL,* 21 (2) D206, 2014.

[3] A. A. Wara, «Cosmetic potentials of African shea nut (Vitellaria paradoxa) butter. Current Research in Chemistry», 3 (2): 80-86, 2011.

[4] P. B Agbobatinkpo, S. D. Dabadé, F. Laleyè, N.Akissoe, P Azokpota. and J.D. Hounhouigan, « Softening effect of Ikpiru and Yanyanku, two traditional additives used for the fermentation of African Locust Bean (*Parkia biglobosa*) seeds in Benin». *Int. J. Biol. Chem. Sci.* 6 (3): 1281 1292, ISSN 1991-8631. DOI: http://dx.doi.org/10.4314/ijbcs.v6i3.31., 2012.

[5] F.G.Honfo, A.R, Linnemann, N.Akissoe, M.M. Soumanou, & M. A. J. S van Boekel.,. «Characteristics of traditionally processed shea kernels and butter, » *International Journal of Food Science & Technology*; 48 (8); 1714–1721, 2013.

[6] C. Fatoumata, S. Soronikpoho, T. Souleymane, B. Kouakou. and D.K. Marcellin. «Caractérisation biochimiques et microbiologiques de moutardes africaines produites à base de graines fermentées de *Parkia biglobosa* et de *Glycine max,* vendues en Côte d'Ivoire». *Int. J. Biol.Chem*. *Sci.,* 10 (2): 506-518. DOI: http://dx.doi.org/10.4314/ijbcs.v10i2.5., 2016.

[7] R. G. Adeola, «Farmers' perception of African locust bean tree (*parkia bigloblosa)* as an economic tree in Oyo state», *American International Journal of Research in Humanities, Arts and Social Sciences,* 10 (2), 127- 130, 2015.

[8] A.M. Kouyate, U Dembele,. and A.M. Lykke,. «Les espèces ligneuses locales à huile: une ressource utile pour les communautés locales au Sud du Mali», *Int. J. Biol. Chem. Sci.* 9 (6): 2754-2763, ISSN 1997-342X (Online), ISSN 1991-8631 (Print), 2015.

[9] Rantrua, S. Un marché, une concentration d'acteurs. In *Marchés Tropicaux.* Avril (ed): 792 – 794, 2004.

[10] F.G. Honfo, N. Akissoe, A.R Linnemann., M. Soumanou and. M. A. J. S. van Boekel,: «Nutritional composition of shea products and chemical properties of shea butter», *Food Science and Nutrition,* 54: 5, 673-686, DOI: 10.1080/10408398.2011. 604142., 2014.

[11] S.A.Tiamiyu, M.A. Adagba, and A., Shaah, « Profitability analysis of shea nuts supply chain in selected states in Nigeria», *Journal of Agricultural and Crop Research* Vol. 2 (12), pp. 222-227, ISSN: 2384-731X, 2014.

[12] R.A.B. Kpadonou, P.Y. Adégbola and S.D. Tovignan, «Local knowledge and adaptation to climate change in Oueme Valley Benin» *African Crop Science Journal,* Vol. 20, Issue Supplement s2, pp. 181 – 192, ISSN 1021-9730/2012, 2012.

[13] P.C. Gnangle, J. Egah, M.N., Baco, C.D.S.J. Gbemavo, R.G. Kakaï and N. Sokpon «Perceptions locales du changement climatique et mesures d'adaptation dans la gestion des parcs à karité au Nord-Bénin», *Int. J. Biol. Chem. Sci*. 6 (1): 136-149, ISSN 1991-8631, 2012.

[14] J. O. Oluwasusi and S.A. Tijani, «Farmers adaptation strategies to the effect of climate variation on yam production: a case study in Ekiti State, Nigeria», *Agrosearch* Volume 13 (2): 20-31, 2013.

[15] F.G. Honfo, K. Hell, N. Akissoé, A. Linnemann and O. Coulibaly, «Microbiological and physicochemical characterization of shea butter sold on Benin markets». *Journal of Stored Products and Postharvest Research* Vol. 3 (3), pp. 24 - 29, DOI: 10.5897/JSPPR11.045, 2012.

[16] W. O Abdul, I. T., Omoniyi, E. O., Adekoya, O. S Daniel and O. S. Olowe, Some stock parameters of elops lacerta during estuarine phase of life history. Ife Journal of Science vol. 17, (2) 323-324, 2015.

[17] C.A.T. Ouattara, M.K. Somda, R.Moyen and A.S. Traore, «Comparative physico-chemical and proximate analysis of oils of Shea nut, Sesamum indicum, Cucurbita pepo, Cucumis melo seeds commonly cultivated»,. *West Africa, African Journal of Biotechnology* Vol. 14 (31), pp. 2449-2454, 5 DOI: 10.5897/AJB2015.14642, 2015.

[18] A. Singbo, and R.Ahouansou, «Etude de faisabilité de l'implantation d'un atelier mécanisé de production de beurre de karité au Bénin (Afrique de l'Ouest) ». *Bull. Rech. Agr. Bénin (BRAB).* 50: 38- 46, 2005.

[19] V.T., I Tame, and I., Hassan and D.T. Gungula «Influence of Heating Time of Shea Nuts (*Vitellaria paradoxa*) on Some Chemical Properties of Shea Butter». *World Journal of Engineering and Technology,* 3, 13-18, 2015.

[20] G.S. Akouehou, A. Houndonougbo, and B. Tente, «La dynamique des systèmes de production dans les terroirs agricoles riverains de la forêt intercommunale de Fita-Agbado dans les communes de Dassa-Zoumé et de Savalou, Département des Collines au Centre du Bénin», *Int. J. Biol. Chem. Sci*. 7 (5): 1877-1891, 2013.

[21] Yê, G.S. & Destain, M. F. Etude d'une presse à huile: Caractérisation technique des presses manuelles à karité existant au Burkina Faso et détermination de l'effort de concassage de l'amande de karité. Mémoire DEA. Sciences Agronomiques et Ingénierie biologique. Faculté Universitaire des Sciences Agronomiques de Gembloux, 75p, 2004.

[22] N.A. Aviara, F.A. Oluwole and M.A. Haque, « Effect of moisture content on some physical properties of sheanuts (*Butyrospernum paradoxum*)», *Int. Agrophysics,* 19: 193–198, 2005.

[23] R.H, Ahouansou, E.A. Sanya, G. Bagan and E.A. Foudjet, «Etude de quelques caractéristiques physiques des noix et amandes de karité produites au Benin». *Sciences et techniques,* Sci. Appl. Technol., 1, 2: 29-38, 2008.

[24] R.H. Ahouansou, G.C Bagan, E.A Sanya, A. Vianou, and D.J. Hounhouigan, « Réalisation d'une décortiqueuse à graines de néré «*Parkia Biglobosa*»: optimisation et validation des performances techniques centrées sur les utilisateurs». *Journal of Applied Biosciences* 111: 10841-10853; ISSN 1997-5902, 2017.

[25] A.M. Olaniyan and K. Oje, «Strength properties of shea-butter nuts under compressive loading »N*igerian Journal of Technology,* Vol. 21, No. 1, 2002.

[26] F. A. Oluwole, M. Ben Oumarou and G. M. Ngala, «Dynamics of Centrifugal Impact Nut Cracker», *International Journal of Research Studies in Science, Engineering and Technology* Volume 3, Issue 1, 15-21 ISSN 2349-4751 (Print) & ISSN 2349-476X (Online), 2016.

[27] F.A. Oluwolé, N.A Aviara,. and M.A. Haque, «Development and performance test of sheanut craker». *Jour. Food Eng,* 65: 117 – 123, 2004.

[28] R. Ahouansou, P. Houssou and A. Singbo, «Mise au point et évaluation technique de concasseur de noix palmistes.»*Bulletin de la Recherche Agronomique du Bénin*. N° 51. 20-27. http://www.slire.net, ISSN 1025-2355, 2006.

[29] P. Y., Adégbola, A. G., Singbo, R. Ahouansou and M-C. Savi, « Analyse socio-économique de la presse manuelle à huile de palme « Dékanmé »» *Bulletin de la recherche Agronomique du Bénin,* INRAB N°40, 1-9, 2003.

[30] J. S. Ojolo and B. A. Eweina,.«Predicting cashew nut cracking using hertz theory of contact stress», *Journal of the Saudi Society of Agricultural Sciences* 18, 157–167, 2019.

[31] K. Oje, Y.J. Adigun, and A. Alonge,. «Craking energy for shea nut in centrifugal cracker». *Nigerian Journal of Pure and Applied Science,* 12; 550 -555,1997.

[32] A.A. Shehu, I.M. Gana and A.A., Balami, Development and Testing of Indigenous Shea Butter Processing Plant in Nigeria. *J Food Chem Nanotechnol* 4 (2): 38-50. 2018.

[33] I. Abdul-Mumeen, B. Didia & A. Abdulai, «Shea butter extraction technologies: Current status and future perspective». *African Journal of Biochemistry Research,* Vol. 13 (2), pp. 9-22, DOI: 10.5897/AJBR2018.1007, 2019.

[34] Gana, I.M. Development and optimization of functional parameters of an automated grain drinks processing machine PhD. Engineering Thesis, Minna: Federal University of Technology, Nigeria, 2016.

[35] Ferris, RSB., Collinson, C., Wanda, K., Jagwe, J. and Wright, P. Evaluating the marketing opportunities for shea nut and shea nut processed products in Uganda. Technical Report. Natural Resources Institute, Chatham, UK. 76p, 2001.