

Effects of Softening Time and Beater Speed on the Stripping and Cleaning Performance of an Oil Palm Fruit Processing Machine

C. S. A. Boko^{1*}, G. M. Assogba¹, G. C. Bagan¹

1- Laboratory of the School of Rural Engineering (LEGR), The National University of Agriculture (UNA), Benin
(*- Corresponding Author Email: gontrand.bagan@una.bj)
<https://doi.org/10.22067/jam.2026.100416.1518>

Abstract

The purpose of this study is to provide a practical solution to improve the performance of local strippers by enhancing their capacity and efficiency while remaining affordable for local operators. This approach addresses current limitations and meets the growing demands of the palm oil production sector. The technological gap observed in palm fruit processing is primarily due to the lack of dedicated machines for specific operations, particularly the stripping process, which still relies on manual methods. This highlights the need for machine development to improve efficiency and reduce time, space, and labour intensity. The evaluation of this machine was conducted based on three different softening times of fresh fruit bunches (24, 48, and 72 hours) and three beater (rotor) shaft speeds (144.5, 240.2, and 424.4 rpm), measured directly with a tachometer. Results showed that stripping efficiency, cleaning rate, and production capacity increased with softening time and rotor speed, achieving values ranging from 66.69% to 98.30% for stripping efficiency, 36.06% to 93.87% for cleaning efficiency, and 430.901 to 1,800.511 kg h⁻¹ for hourly capacity. Among the tested conditions, the best stripping and cleaning performance was obtained after a softening time of 72 hours at a rotor speed of 424.4 rpm.

Keywords: Cleaning efficiency, Mechanisation, Palm fruit bunches, Stripping efficiency, Thresher

Introduction

In the Republic of Benin, the agricultural sector accounts for an average of 24.05% of GDP, contributes 89.24% to export revenues (Institut National de la Statistique et de l'Analyse Économique [INSAE], 2019), and generates nearly 70% of employment (World Bank, 2019). Red palm oil, the unrefined crude oil extracted from the fruit pulp, distinguished from refined palm oil by its retained carotenoid content, is the most produced and consumed vegetable oil globally (Battaglia, 2010; Jacquemard *et al.*, 2011), with production increasing from 54 million tonnes in 2014 (Monde *et al.*, 2020) to 75.8 million tonnes in 2020 (Food and Agriculture Organization of the United Nations [FAO], n.d). It is expected to continue growing significantly, as demand is projected to reach between 120 and 156 million tonnes by 2050 (Corley, 2009). This growth is driven by ever-increasing demand, initially from the agri-food industry (Ruysschaert, 2016). Palm oil contains several fatty acids, one of the most important being palmitic acid (39.5%-47.5%), a saturated fatty acid (Lecerf,

2011). In addition to fatty acids, it is a major source of minor compounds such as carotenoids and vitamin E, especially when unrefined (Sundram, Sambanthamurthi, & Tan, 2003). Nigeria is the leading African producer with 905,000 tonnes (Food and Agriculture Organization of the United Nations [FAO] & United Nations Conference on Trade and Development [UNCTAD], 2003). Benin produced approximately 50,000 tonnes of palm oil between 2001 and 2003, with production dominated mainly by the artisanal and industrial sectors, which account for 72% and 20% of this oil, respectively (FAO & UNCTAD, 2003; Fournier, Ay, Jannot, Okounlola-Biaou, & Pédé, 2001). In an effort to improve Benin's position in global palm oil production, recent years have seen the development of village plantations and the rehabilitation of old palm groves. From 20,150 seedlings produced in 1995 and made available to planters, a record number of 477,610 seedlings was reached in 2000. In total, between 1995 and 2003, approximately 2,533,115 seedlings were planted over 22,409 hectares (Aholoukpé *et al.*, 2013). In 2006, a

clear commitment was made to revive the oil palm sector and make it a driver of economic development and growth in Benin.

The revival of the oil palm sector has highlighted, in recent years, the need to develop technologies that can meet the growing demand for small-scale processing. In response to this demand, certain equipment has been introduced through the combined efforts of the state, non-governmental organisations, and manufacturers, helping reduce the challenges associated with the labour-intensive processes of depulping, pressing, cooking, and clarification. For example, manual and motorised Dekanme presses enable efficient processing of selected Tenera and Dura fruits (Ahouansou & Monhouanou, 2001; Fassinou, 2002; Gouthon, 2000). An efficient depulper has been developed and introduced to small-scale palm fruit processing units (Ahouansou, Monhouanou, Savi, Akplogan, & Djossou, 2008; Ahouansou & Monhouanou, 2001; Agueh & Ahouansou, 2004; Adango & Ahouansou, 2004). A high-performance palm kernel oil extraction press (Okoye, Jiang, & Hui, 2008) and a technology for valorising processing by-products (Ahounou & Ahouansou, 2010) have also been developed. Although strippers are available on the market, the stripping operation (separating palm fruits from bunches) remains limited by the lack of equipment truly adapted to specific needs. Currently, stripping is done manually, resulting in a significant labour demand. This study aims to determine the performance parameters of a palm fruit stripper for effective use.

Specifically, the study will:

- Evaluate the stripper's performance based on softening time.
- Assess the stripper's performance by

studying the impact of different beater (rotor) shaft speeds on the technical performance of the palm fruit stripper.

Materials and Methods

Operating Principle

After completing the maintenance of the machine, the engine is started (Figure 1). Once running, it drives the beater, the main working component of the machine, through a motion transmission system consisting of pulleys and belts. The rotation of the beater shaft drives all the other rotating shafts via the pulley-and-belt system, mainly the paddle shaft and the shaker shaft. The hopper is fed by the operator, who pours the palm fruit bunch sections into the stripping chamber through the feeding table, between the two components (the beater and the concave). Under the rotational action of the beater against the concave, the bunches release the palm fruits and the empty bunch stalks through the concave. Only the beater shaft speed is adjusted according to the conditions and characteristics of the stripping process. After passing through the beater, the palm fruits fall onto the sieve. The fruits, empty bunches, and stalks move across the sieve, which is shaken by a connecting-rod mechanism. Through this motion, the clean palm fruits are collected through the chute, while the bunch residues and stalks are expelled.

The machine is powered by a YANMAR diesel engine rated at 4.4-4.9 kW (6.6 hp) at 2600 rpm. The beater (rotor) shaft speed is reduced relative to the engine speed through a pulley-and-belt transmission and was set, for the purpose of this study, to three levels: 144.5, 240.2, and 424.4 rpm measured directly on the beater shaft using a digital tachometer.

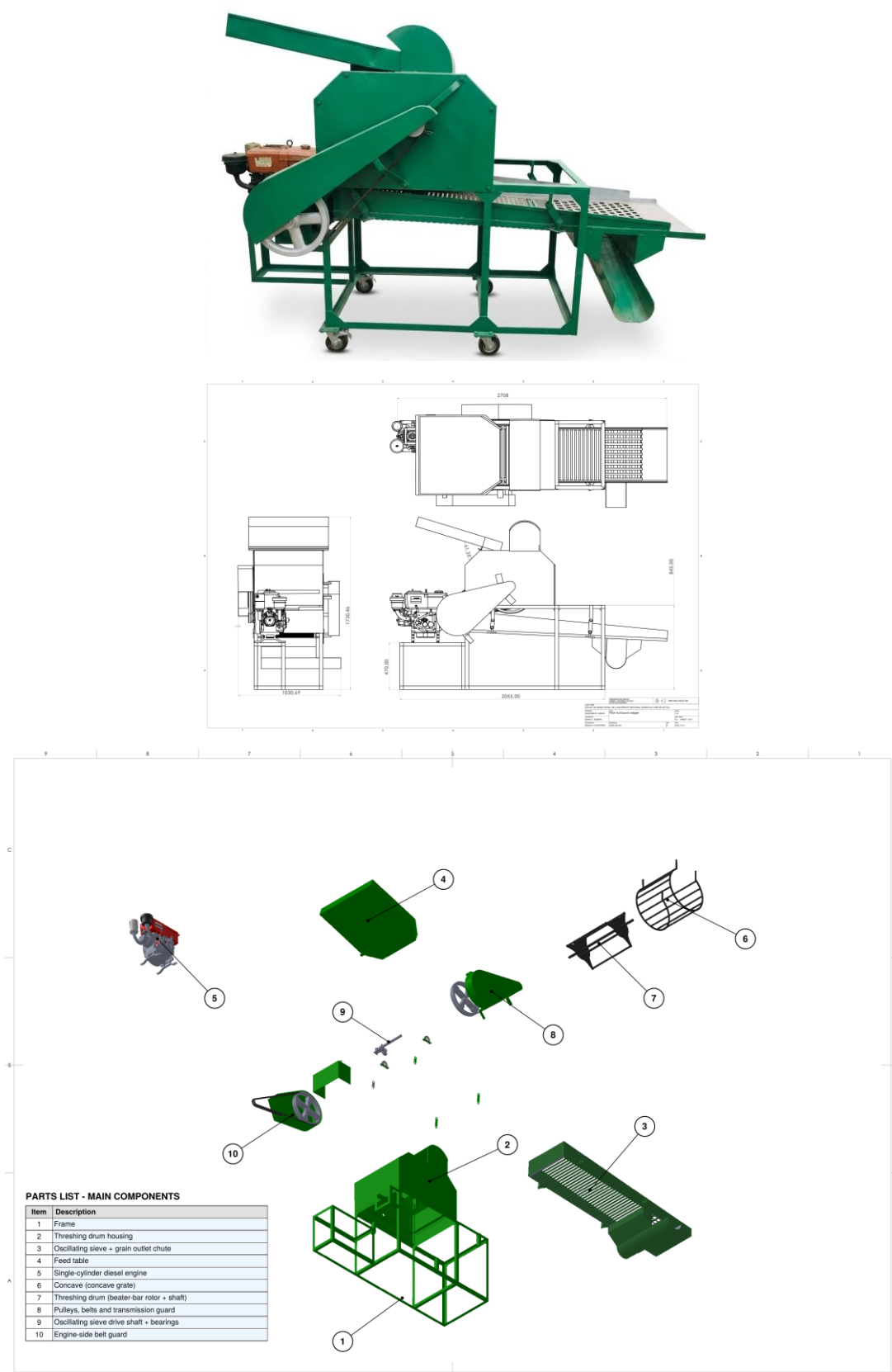


Fig. 1. Illustrations of the palm fruit thresher

Plant Material

The Tenera variety was used in this study. The Tenera type, a hybrid of the Dura and Pisifera types, is characterised by thin-shelled fruits with thick pulp and a small kernel. It provides the highest oil yield, with approximately 90% of palm oil extracted from the pulp and 10% of palm kernel oil extracted from the kernel. The selected plantations are exclusively cultivated with this hybrid (Rafflegau, 2008).

Technical Performance

To evaluate the machine's performance, an experiment was designed in which the machine was tested using oil palm fruit bunches subjected to three softening (conditioning) times—24 h, 48 h, and 72 h—following the approach of Aremu and Alade (2017). These durations denote the time the bunches were held under the softening treatment described below, rather than an independently measured physiological maturity index. Before each trial, the bunches were manually cut into sections, separating the fruit-bearing spikelets from the heaviest part of the central stalk. After transporting the oil palm fruit bunches to the experimental site, 10 kg samples of these cut sections were collected, sprayed with 0.5 litres of water each, covered, and held for the assigned softening time under ambient conditions before testing, and then tested at three beater (rotor) shaft speeds of 144.5, 240.2, and 424.4 rpm, measured directly on the shaft with a digital tachometer. Each treatment combination (softening time x rotor speed) was tested using three 10 kg samples. The weight of the samples was measured using a CAMRY needle scale (50 kg, ± 0.1 kg), and the time required (in seconds) to strip and clean each sample was recorded using a stopwatch; hourly capacity was then extrapolated from the processing time of each batch. After each operation, the stripped palm fruits, unprocessed fruit sections, and cleaned and uncleaned fruits from the machine's output were carefully sorted and weighed.

Stripping Efficiency

The stripping efficiency (%) is estimated using the equation below (Aremu & Alade, 2017).

$$E_s = \frac{W_{sf}}{W_{cf}} \times 100 \quad (1)$$

where, E_s : Stripping efficiency (%); W_{sf} : Weight of the stripped fruits (kg); and W_{cf} : Weight of the palm fruits contained in the chopped, fruit-bearing bunch sections introduced into the machine (kg).

Bunches were cut into sections and separated from the heaviest part of the central stalk before each test; W_{cf} therefore refers to the weight of these prepared fruit-bearing sections, not the weight of an intact, undivided bunch, including the stalk.

Hourly Capacity

The hourly capacity (expressed in kg of threshed palm fruits per hour) is determined using the following equation.

$$C_h = \frac{Q_{db}}{t} \quad (2)$$

where, C_h : Hourly capacity (kg h^{-1}); Q_{db} : Total mass of stripped output (whole palm fruits separated from the bunch sections, before screening) recovered from a given batch (kg); and t : Time taken to process that batch (h).

For each treatment, C_h was extrapolated from the mass and processing time of the corresponding 10 kg batch to an hourly-equivalent rate; it does not include time spent loading or unloading the machine, and should therefore be interpreted as an indicator of the machine's processing rate under continuous feeding rather than an achieved field capacity, including handling time.

Cleaning Efficiency

The cleaning efficiency is expressed using the following equation (Aremu & Alade, 2017):

$$E_a = \frac{W_d}{W_{db}} \times 100 \quad (3)$$

where, E_a : Cleaning efficiency (%); W_{db} : Weight of the unsorted de-bunched material output, which is the mixture of fruits and residues before screening (kg); and W_d : Weight of clean fruits recovered after screening (kg).

Threshing Stripping Losses

The loss rate is expressed using the following equation (Yé, Son, & Valea, 2017):

$$T_p = \frac{W_{pf}}{W_{pf} + W_{sf}} \times 100 \quad (4)$$

where, T_p : Stripping loss rate (%); W_{pf} : Total weight of the unstripped palm fruits (kg); and W_{sf} : Total weight of the stripped palm fruits (kg).

Fuel Consumption

Fuel consumption was measured in litres. The procedure involved filling the fuel tank at the start of each stripping operation lasting one hour. At the end of the operation, the amount of fuel needed to refill the tank was measured, giving the fuel consumption over the one-hour stripping process ($L h^{-1}$). Specific fuel consumption ($L tonnes^{-1}$ of threshed material) was subsequently calculated by dividing the hourly fuel consumption ($L h^{-1}$) by the corresponding hourly capacity ($kg h^{-1}$, Equation 2), in order to compare the fuel efficiency of the three rotor speeds on a per-unit-of-output basis

rather than on a per-hour basis alone.

Results and Analysis

Data and Processing

Excel was used to build the databases, while R software version 4.2.2 was used for the statistical analysis of the data collected for the various parameters. A 5% significance level was set to assess statistical significance. Before conducting the analysis, the normality of the data for each parameter was tested using the Shapiro-Wilk test. Where the data followed a normal distribution, a two-way or one-way ANOVA (as relevant) followed by Tukey's post hoc test was used to compare means across categories. Where the data did not conform to a normal distribution, the Kruskal-Wallis test was applied. Table 1 summarises the descriptive statistics; the three rotor speeds are V1 (144.5 rpm), V2 (240.2 rpm), and V3 (424.4 rpm).

Table 1- Descriptive statistics (mean $\pm$ SD, $n = 3$) by treatment combination

Softening time (h)	Rotor speed	Stripping efficiency (%)	Loss rate (%)	Cleaning efficiency (%)	Stripping time (s)
24	V1	66.70 $\pm$ 1.49	42.57 $\pm$ 1.54	36.06 $\pm$ 3.01	44.00 $\pm$ 0.17
24	V2	70.52 $\pm$ 1.39	38.95 $\pm$ 1.58	38.38 $\pm$ 3.54	35.33 $\pm$ 0.32
24	V3	76.21 $\pm$ 5.10	33.80 $\pm$ 4.40	39.15 $\pm$ 4.19	25.51 $\pm$ 2.25
48	V1	82.03 $\pm$ 0.82	18.17 $\pm$ 1.00	57.27 $\pm$ 0.52	25.06 $\pm$ 0.49
48	V2	88.82 $\pm$ 1.14	14.08 $\pm$ 1.15	60.20 $\pm$ 1.48	22.00 $\pm$ 0.09
48	V3	91.76 $\pm$ 3.42	11.88 $\pm$ 1.07	66.39 $\pm$ 2.64	15.62 $\pm$ 0.28
72	V1	97.25 $\pm$ 0.04	2.24 $\pm$ 0.03	80.24 $\pm$ 5.36	25.09 $\pm$ 0.44
72	V2	97.27 $\pm$ 0.04	2.96 $\pm$ 1.28	87.86 $\pm$ 1.52	22.48 $\pm$ 0.13
72	V3	98.30 $\pm$ 0.69	1.50 $\pm$ 0.67	93.88 $\pm$ 1.72	15.33 $\pm$ 0.21

Assessment of Hourly Capacity in Relation to Rotor Speed and Softening Time

Figure 2 shows the hourly capacities ($kg h^{-1}$) at the three beater (rotor) speeds of V1 (144.5

rpm), V2 (240.2 rpm), and V3 (424.4 rpm), across the softening periods of 24, 48, and 72 hours.

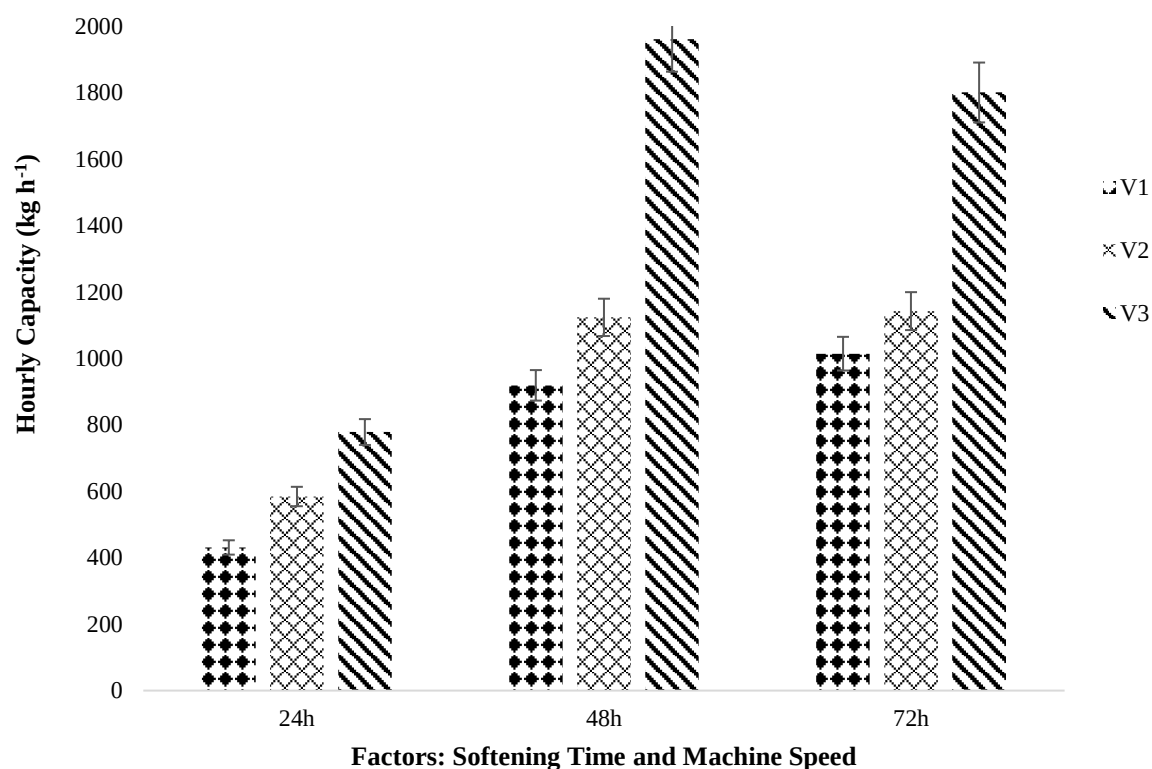


Fig. 2. Hourly capacities as a function of softening time and rotor speed

A steady increase in performance is observed as the softening time extends. The V3 speed (424.4 rpm) stands out with the highest capacity and the most significant improvements, rising from 778.282 kg h⁻¹ to 1,800.511 kg h⁻¹ after 72 hours of softening. The V2 speed (240.2 rpm), with capacities ranging from 584.235 kg h⁻¹ to 1,142.303 kg h⁻¹, closely follows V3 and outperforms V1 (144.5 rpm), which shows the lowest performance, with capacities ranging from 430.901 kg h⁻¹ to 1,014.217 kg h⁻¹, although it also shows considerable improvement. Among the tested conditions, the V3 speed produced the highest hourly capacity over an extended softening period, while V2 performed as an intermediate alternative, and V1 remained the

lowest of the three. As noted, these hourly-equivalent values were extrapolated from the processing time of 10 kg batches under continuous feeding; sustained field capacity, which also depends on loading, unloading, and operator handling time, was not measured and may be lower than the values reported here.

Performance Evaluation of the Thresher Based on Softening Time

Combined Effect of Rotor Speed and Softening Time on Stripping Efficiency

Figure 3 shows the effect of the three rotor speeds, V1 (144.5 rpm), V2 (240.2 rpm), and V3 (424.4 rpm), and the softening periods of 24, 48, and 7 hours, on the stripping rate of palm fruits.

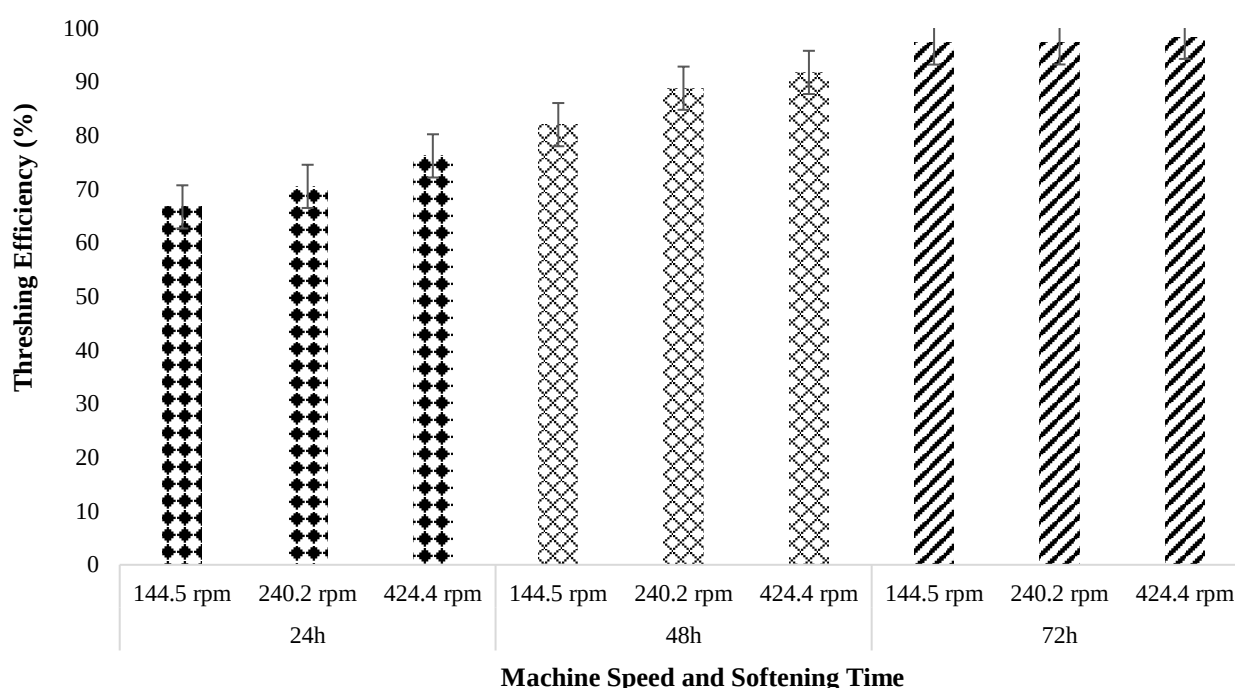


Fig. 3. Stripping efficiency as a function of softening time and rotor speed

The stripping rate increases with the softening time of the oil palm fruits. For each rotor speed, the best stripping rates were achieved after 72 hours of softening, with a gradual improvement as softening time increases. The two-way ANOVA confirms a significant main effect of softening time ($p < 0.05$) and a significant, though comparatively smaller, main effect of rotor speed ($p < 0.05$);

the softening time $\times$ rotor speed interaction is also significant ($p = 0.014$, Table 2), indicating that the magnitude of the speed effect is not strictly constant across softening times. In other words, the longer the palm bunch sections remain in contact with water, the more easily the fruits detach, resulting in a higher stripping rate, and this effect is the dominant driver of performance relative to rotor speed.

Table 2- Two-factor ANOVA Threshing efficiency (Es) as a function of softening time (TR) and rotor speed (VB)

Source of variation	df	Sum of squares	Mean square	F	p-value
Softening time (TR)	2	3,212	1,605.8	326.284	0.000
Rotor speed (VB)	2	206	103.1	20.943	0.000
TR $\times$ VB	4	83	20.7	4.211	0.014
Error	18	89	4.9	-	-

Combined Effect of Rotor Speed and Softening Time on Stripping Loss Rate

Figure 4 shows the combined effect of each rotor speed, V1 (144.5 rpm), V2 (240.2 rpm),

and V3 (424.4 rpm), at softening times of 24, 48, and 72 hours, on the stripping loss rate of palm fruits.

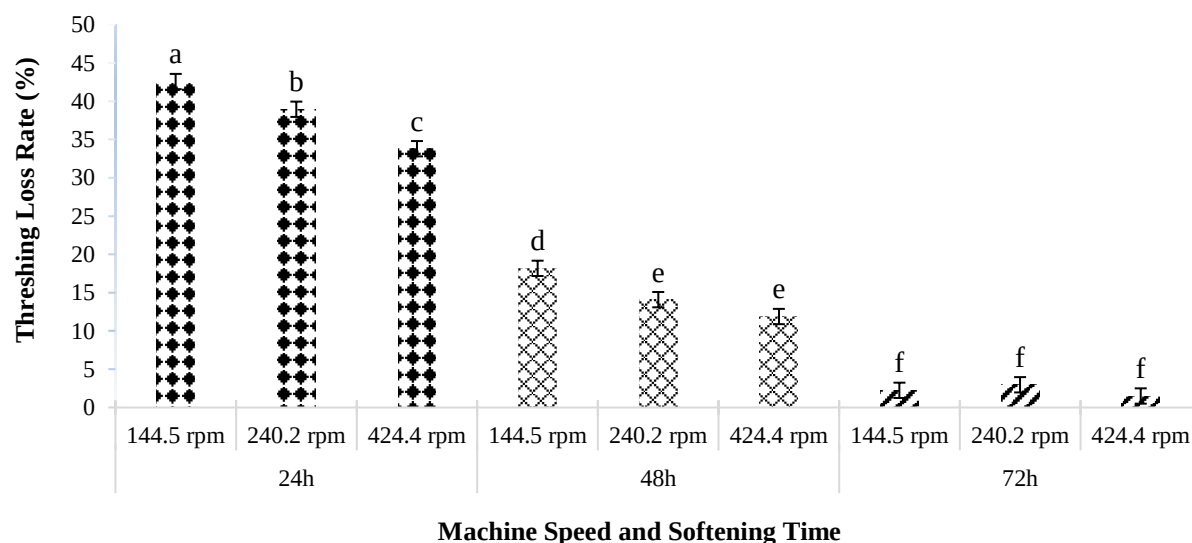


Fig. 4. Stripping loss rate as a function of softening time

The stripping loss rate decreases as the softening time increases, reaching its minimum after 72 hours, regardless of rotor speed. The two-way ANOVA confirms the significant main effects of both softening time and rotor speed ($p < 0.05$), together with a significant

softening time x rotor speed interaction ($p = 0.0141$, Table 3), meaning that the reduction in losses with softening time is not perfectly uniform across the three speeds. Prolonged softening of the fruits nonetheless remains the dominant factor reducing losses.

Table 3- Two-factor ANOVA of threshing loss rate as a function of softening time (TR) and rotor speed (VB)

Source of variation	df	Sum of squares	Mean square	F	p-value
Softening time (TR)	2	6,090	3,044.8	921.185	0.000
Rotor speed (VB)	2	126	62.8	18.989	0.000
TR × VB	4	56	13.9	4.205	0.0141
Error	18	59	3.3	-	-

Combined Effect of Rotor Speed and Softening Time on Cleaning Rate

Figure 5 shows the combined effect of each rotor speed, V1 (144.5 rpm), V2 (240.2 rpm),

and V3 (424.4 rpm), at softening times of 24, 48, and 72 hours, on the cleaning rate after de-bunching of the palm fruits.

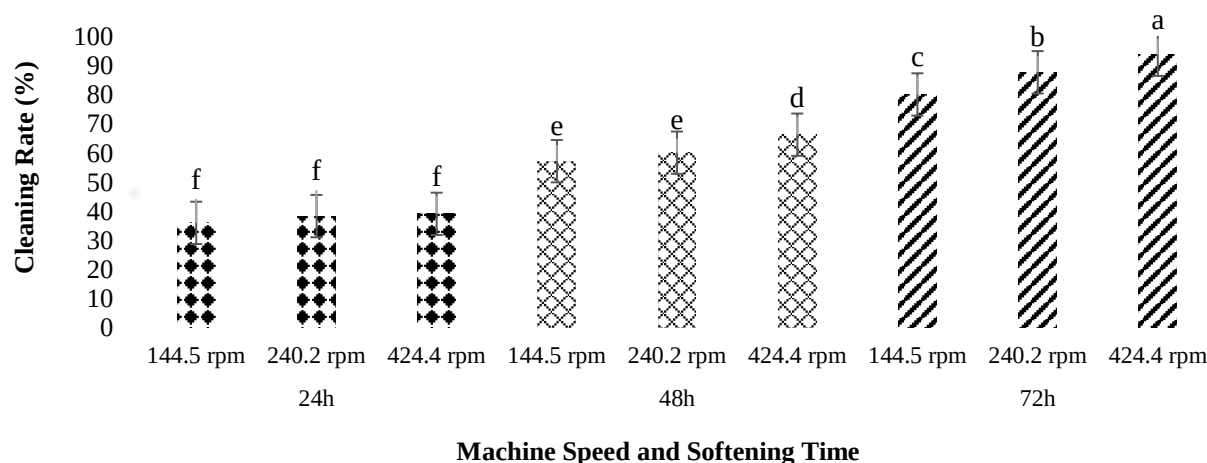


Fig. 5. Cleaning rate as a function of softening time

The cleaning rate increases as the softening time extends, reaching its highest observed value after 72 hours, regardless of rotor speed. Prolonged softening aids the separation and screening process, reducing residue and improving quality. The two-way ANOVA confirms the significant main effects of both softening time and rotor speed ($p < 0.05$); unlike stripping efficiency and loss rate, the

softening time x rotor speed interaction is not significant at the 5% level ($p = 0.078$, Table 4), indicating that the effect of softening time on the cleaning rate is comparatively more consistent across the three rotor speeds. Among the tested conditions, a softening time of 72 hours gave the best combination of yield and quality.

Table 4- Two-factor ANOVA of cleaning efficiency (Ea) as a function of softening time (TR) and rotor speed (VB)

Source of variation	df	Sum of squares	Mean square	F	p-value
Softening time (TR)	2	11,018	5,509	600.346	0.000
Rotor speed (VB)	2	334	167	18.187	0.000
TR × VB	4	92	23	2.505	0.078
Error	18	165	9	-	-

Performance Evaluation of the Thresher Based on Rotor Speed After Optimal Softening Time

Impact of Rotor Speed on Stripping Efficiency

Figure 6 shows the variation in threshing rate

as a function of rotor speed V1 (144.5 rpm), V2 (240.2 rpm), and V3 (424.4 rpm) after the optimal softening time of 72 hours.

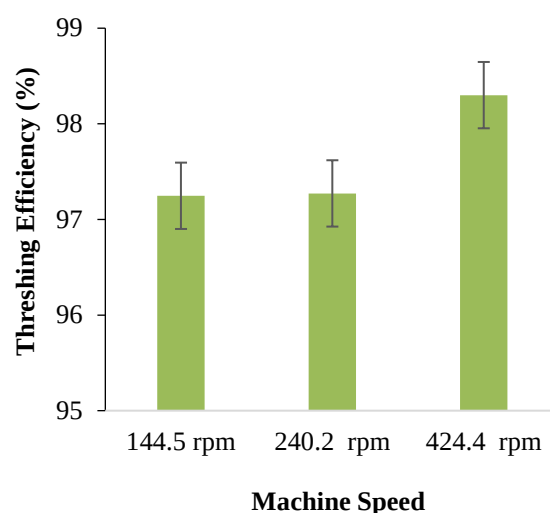


Fig. 6. Impact of rotor speed on the stripping efficiency

Threshing stripping rates for V1 (144.5 rpm) and V2 (240.2 rpm) are similar, while V3 (424.4 rpm) achieves a slightly higher rate of 98.30%. ANOVA reveals significant differences between the groups ($p < 0.05$, Table 5). Tukey's post hoc test confirms no

significant difference between V1 and V2 ($p = 0.9$), but a significant difference between V3 and the other two speeds ($p = 0.001$). These findings demonstrate that the V3 rotor speed significantly enhances the stripping rate.

Table 5- One-factor ANOVA of threshing efficiency as a function of rotor speed, at the optimal softening time (72 h)

Source of variation	df	Sum of squares	Mean square	F	p-value
Rotor speed (VB)	2	4.123	2.061	30.45	0.0001
Error	6	0.407	0.068	-	-

Impact of Rotor Speed on Stripping Loss Rate

Figure 7 shows the variation in stripping loss rate as a function of rotor speed V1 (144.5 rpm),

V2 (240.2 rpm), and V3 (424.4 rpm) after the best-performing softening time of 72 hours.

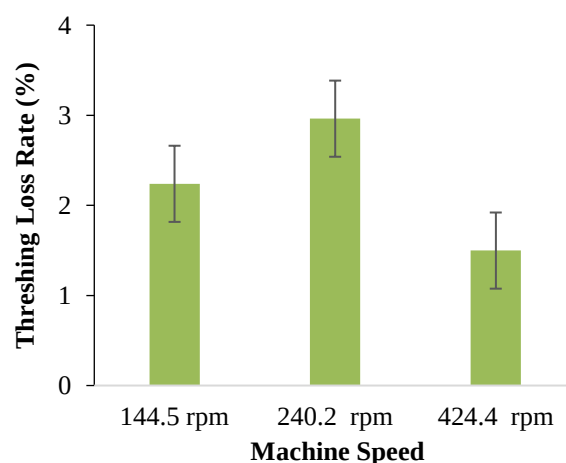


Fig. 7. Impact of rotor speed on the stripping loss rate

Threshing stripping loss rates show only slight variation across rotor speeds. V1 and V2

perform similarly, with a small improvement in V2, and V3 appears to further reduce losses.

However, statistical analysis shows no significant difference between the three speeds ($p > 0.05$, Table 6), as confirmed by ANOVA

and Tukey's post hoc test. These findings suggest that rotor speed does not have a significant impact on the stripping loss rate.

Table 6- One-factor ANOVA of threshing loss rate as a function of rotor speed, at the optimal softening time (72 h)

Source of variation	df	Sum of squares	Mean square	F	p-value
Rotor speed (VB)	2	1.1887	0.5944	3.8175	0.085
Error	6	0.9342	0.1557	-	-

Impact of Rotor Speed on Cleaning Rate

Figure 8 shows the variation in the cleaning rate of stripped fruits as a function of rotor

speed V1 (144.5 rpm), V2 (240.2 rpm), and V3 (424.4 rpm) after the best-performing softening time of 72 hours.

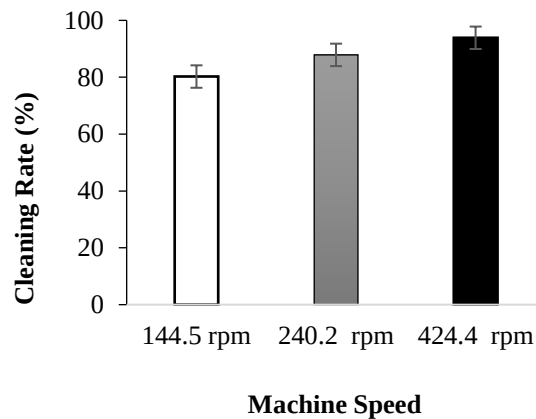


Fig. 8. Impact of rotor speed on the cleaning rate

The cleaning rate improves with rotor speed, increasing from 80.23% at V1 to 87.85% at V2, and reaching 93.878% at V3. Statistical analysis confirms a significant difference between the groups ($p < 0.05$, Table 7). Post hoc tests indicate that V3 achieves a significantly

higher cleaning rate than V1 ($p = 0.0016$) and V2 ($p = 0.0294$), while no significant difference is observed between V1 and V2 ($p = 0.0564$). These findings suggest that increasing rotor speed leads to a significant improvement in the cleaning rate.

Table 7- One-factor ANOVA of cleaning efficiency as a function of rotor speed, at the optimal softening time (72 h)

Source of variation	df	Sum of squares	Mean square	F	p-value
Rotor speed (VB)	2	280.3670	140.1835	12.3644	0.0074
Error	6	68.0262	11.3377	-	-

Impact of Rotor Speed on Fuel Consumption

Figure 9 shows the variation in fuel consumption as a function of rotor speed V1

(144.5 rpm), V2 (240.2 rpm), and V3 (424.4 rpm).

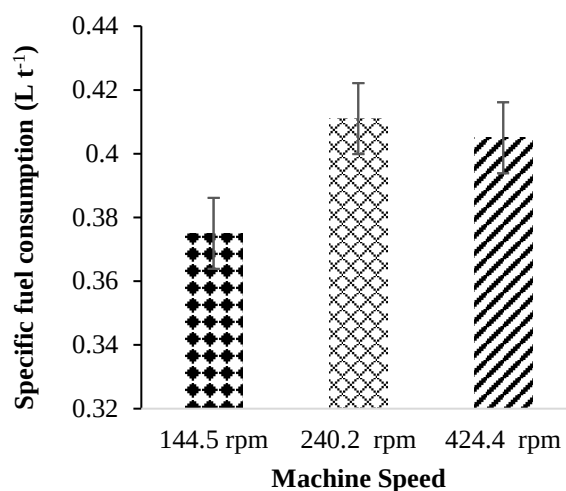


Fig. 9. Impact of Rotor Speed on Fuel Consumption ($L h^{-1}$ and $L tonne^{-1}$)

Fuel consumption was measured at three rotor speeds following the best-performing softening time of 72 hours; it was not separately measured across all nine-softening time x rotor speed combinations, and any dependence of fuel consumption on softening time is therefore not addressed by the present data. Hourly fuel consumption ($L h^{-1}$) increases with rotor speed, from $0.38 L h^{-1}$ at V1 to $0.47 L h^{-1}$ at V2, and $0.73 L h^{-1}$ at V3. Statistical analysis reveals significant differences between the speeds ($p < 0.05$, Table 8). However, hourly consumption alone is not an appropriate measure of fuel efficiency, since the three speeds process very different quantities of fruit per hour. Expressed as specific fuel consumption (L per tonne of stripped material), obtained by dividing hourly

consumption by the corresponding hourly capacity at 72 hours of softening, the ranking narrows considerably: $0.375 L tonne^{-1}$ at V1, $0.411 L tonne^{-1}$ at V2, and $0.405 L tonne^{-1}$ at V3. On this basis, V1 remains the most fuel-efficient speed, but the gap between V1 and V3 falls from close to a factor of two in $L h^{-1}$ to about 8% in $L tonne^{-1}$, and V3 is, in fact, slightly more efficient than V2. This indicates that the higher hourly consumption at V3 is largely offset by its substantially higher throughput, and that the choice of rotor speed should be guided primarily by the intended balance between processing capacity and quality rather than by hourly fuel consumption alone.

Table 8- One-factor ANOVA of hourly fuel consumption as a function of rotor speed

Source of variation	df	Sum of squares	Mean square	F	p-value
Rotor speed (VB)	2	0.106	0.053	28.35	0.0001
Error	6	0.011	0.002	-	-

Discussion

The results clearly show that the softening time of the palm bunch sections has a significant effect on the stripping rate. The longer the softening time, the more easily the fruits detach from the bunch, which improves stripping efficiency. This observation is consistent with the findings of (Aremu & Alade

2017), who also noted that extending the softening time of palm bunches enhances the stripping rate. Research by Ruswanto, Gunawan, Hermantoro, Putra, and Wirutomo (2024) similarly highlights that the maturity level of the bunches and the waiting time before stripping are key factors influencing process efficiency. Fresh palm fruit bunches with a 24-hour softening time (1 day) did not yield good

results in terms of fruit separation, whereas bunches softened for 48 to 72 hours (2-3 days) showed better results, particularly in terms of the quantity of threshed fruits. These findings confirm the positive impact of prolonged softening time on the stripping rate. At the rotor speed of 424.4 rpm, after 72 hours of softening, the hourly capacity increased from 778.282 kg h⁻¹ to 1800.511 kg h⁻¹, with a stripping rate of 98.3%, demonstrating superior efficiency in the palm fruit stripping process. These conclusions align with previous research emphasising the importance of optimising rotor speed and pre-treating the fruit to improve stripping efficiency (Aremu & Alade, 2017).

The prolonged softening time that maximises mechanical performance also carries a biochemical trade-off. Keeping fresh palm fruit bunch sections under warm, moist conditions for up to 72 hours favours endogenous lipase activity, which hydrolyses triglycerides into Free Fatty Acids (FFA) and can lower the commercial grade of the extracted oil. The present study measured only the mechanical performance of the stripping and cleaning operations (stripping rate, cleaning rate, losses, and fuel consumption) and did not include oil quality analysis on the processed fruits. The 72-hour softening time is therefore presented here as the optimum for mechanical performance, and the associated oil-quality trade-off is identified as a limitation of the present work, to be addressed through FFA

measurement in future studies.

Previous technologies developed for palm fruit stripping have also shown significant progress. The mechanical stripper described by BEVULTA (2006) processes approximately 12 tonnes per 24-hour day, equivalent to about 500 kg h⁻¹, at a stripping rate of 96%. The combined palm fruit stripping-cleaning machine described by Aremu and Alade (2017) processes 500 kg h⁻¹ at a stripping rate of 95%. A separately reported motorised palm fruit thresher (Idowu, Olaniran, Adebayo, & Onifade, 2023) achieved throughput capacities of 258 to 468 kg h⁻¹ and stripping efficiencies of 87.0% to 93.0% depending on storage time, without a combined cleaning function. Under its best-performing tested configuration (72-hour softening, 424.4 rpm), the machine evaluated in the present study reaches 1,800.5 kg h⁻¹ at a stripping efficiency of 98.30%, corresponding to approximately 3.6 times the hourly capacity of both benchmark machines, combined with a higher stripping efficiency of 2.3 to 3.3 percentage points (Table 9). This comparison indicates that optimising softening time and rotor speed, together with the machine's combined stripping-and-cleaning design, can substantially outperform existing local and literature-reported strippers on both throughput and efficiency.

Table 9- Quantitative benchmarking against previous threshing technologies

Machine	Hourly capacity (kg h ⁻¹)	Threshing efficiency (%)
BEVULTA (2006) mechanical thresher	~500 (12 t (24h) ⁻¹)	96
Aremu and Alade (2017) chopper/stripper	500	95
Present machine (72 h, 424.4 rpm)	1,800.5	98.30

Overall, this study proposes a viable solution compared to local threshers, combining both threshing and cleaning while offering higher capacity and better efficiency, helping to overcome current limitations and meet the growing needs of the sector.

Conclusion

Stripping and cleaning are challenging steps after harvesting palm fruits. Mechanising these tasks using a motorised stripping machine has

become essential. However, precise control of performance parameters and proper machine maintenance are crucial for reliable operation. The aim of this study was to assess the impact of softening time and rotor (beater shaft) speed on the performance parameters of the stripping machine, including the stripping rate, cleaning rate, stripping losses, and fuel consumption. Among the three softening times and the three rotor speeds tested, the best-performing combination was 72 hours of softening at a

rotor speed of 424.4 rpm, which provided the highest stripping rate, the lowest stripping losses, the highest cleaning rate, and a specific fuel consumption comparable to, or better than, the lower rotor speeds expressed per tonne of throughput. As only three levels of each factor were tested, this combination should be read as the best-performing condition among those evaluated rather than as a proven global optimum; further trials with additional softening times and speeds, together with an explicit multicriteria optimisation accounting jointly for productivity, quality, losses, and fuel consumption, would be needed to confirm it. These results nonetheless represent a measurable improvement over the benchmarked strippers described in the

discussion section. In summary, the data collected and presented in this study indicate that, under the tested conditions, the evaluated stripping machine delivers strong technical performance.

Author Contributions

CSA. Boko: Data acquisition, Text mining, technical advice, Methodology, Supervision and Validation.

GM. Assogba: Data acquisition, Text mining, Software services, Numerical/computer simulation.

GC. Bagan: Technical advice, Visualisation, Review and editing services, Validation.

References

1. Adango, E., & Ahouansou, R. (2004). *Pré vulgarisation du dé pulpeur de fruits de palme dans le département de l'Ouémé* [Technical report]. PTAA/CRA-A/INRAB/MAEP, Benin. (11 pp.).
2. Agueh, G., & Ahouansou, R. (2004). *Pré vulgarisation du dé pulpeur de fruits de palme dans le département de l'Atlantique* [Technical report]. PTAA/CRA-A/INRAB/MAEP, Benin.
3. Ahouansou, R. H., & Monhouanou, J. (2002). *Tests en station des dé pulpeurs de fruit de palme* [Technical report]. PTAA/CRA-A/INRAB/MAEP, Benin.
4. Ahouansou, R. H., Monhouanou, J., Savi, M.-C., Akplogan, F., & Djossou, P. (2008). Evaluation of technical and economic performances of a palm fruit skinning machine in Benin. *Bulletin de la Recherche Agronomique du Bénin*, 60, 43–49.
5. Ahouansou, R., & Monhouanou, J. (2001). Tests en station de la presse Dékanmè manuelle. In *Actes de l'Atelier scientifique post-récolte 2001* (pp. 254–261). PTAA/CRA-A/INRAB/MAEP, Bénin. ISBN 99919-51-52-0.
6. Ahounou, J.-L., & Ahouansou, R. (2010). *Development of a technology for producing fire sticks from palm fruit processing by-products in Benin* [Technical report]. MAEP/INRAB/PTAA, Benin.
7. Aremu, A. K., & Alade, O. A. (2017). Development of a palm fruit bunch chopper and spikelet stripper. *International Journal of Engineering Science Invention*, 6(2), 47–53.
8. Battaglia, M. (2010). Drowned in palm oil: The explosion of world demand. *The World Magazine*, (39), 14.
9. BEVULTA. (2006). *Technical sheet for agricultural and processing equipment manufacturing* (p. 1). Benin: Author.
10. Corley, R. H. V. (2009). How much palm oil do we need? *Environmental Science & Policy*, 12(2), 134–139. <https://doi.org/10.1016/j.envsci.2008.10.011>
11. Food and Agriculture Organization of the United Nations. (n.d.). *FAO: Food and Agriculture Organization of the United Nations*. Retrieved March 3, 2024, from <https://www.fao.org/>
12. Food and Agriculture Organization of the United Nations, & United Nations Conference on Trade and Development. (2003). *Market information in the commodities sector: Information on the palm tree*.
13. Fassinou, A. (2002). *Étude comparative des presses à huile de palme OPC, Dekanme et Colin* [Mémoire du Diplôme d'Études Agricoles Tropicales]. LAMS/MESRS, Bénin.

14. Fournier, S., Ay, P., Jannot, C., Okounlola-Biaou, A., & Pédé, E. (2001). *La transformation artisanale de l'huile de palme au Bénin et au Nigeria: Dynamiques des systèmes artisanaux*. Montpellier, France: CIRAD.
15. Gouthon, M. (2000). *Impacts des presses Dékanmè motorisée et manuelle* [Technical report]. ATI/ONG, Bénin.
16. Idowu, D. O., Olaniran, J. A., Adebayo, J. M., & Onifade, T. B. (2023). Design and evaluation of a palm fruit thresher. *Journal of Engineering Research and Reports*, 24(1), 60-68. <https://doi.org/10.9734/jerr/2023/v24i1797>
17. Institut National de la Statistique et de l'Analyse Économique. (2019). *Annuaire statistique national 2019*. Bénin: Author.
18. Jacquemard, J.-C., Berthaud, A., Ollivier, J., Ollivier, L., Verwilghen, A., Graille, J., & de Franqueville, H. (2011). *Le palmier à huile*. Versailles, France: Éditions Quæ; CTA; Presses agronomiques de Gembloux. <https://doi.org/10.35690/978-2-7592-1679-6>
19. Lecerf, J.-M. (2011). Les huiles végétales: Particularités et utilités [Vegetable oils: Particularities and usefulness]. *Médecine des Maladies Métaboliques*, 5(3), 257–262. [https://doi.org/10.1016/S1957-2557\(11\)70237-1](https://doi.org/10.1016/S1957-2557(11)70237-1)
20. Monde, A. A., Cisse-Camara, M., Ake, A. A., Koffi, G., Gauze, G. G.-A., Djohan, F., Abodo, J. R., Coulibaly, I., Tiahou, G. G., Thomasset, B., Morena, M., & Cristol, J.-P. (2020). Biochemical properties, nutritional values, health benefits and sustainability of palm oil. *Biochimie*, 178, 81–95. <https://doi.org/10.1016/J.BIOCHI.2020.09.019>
21. Aholoukpé, H. N. S., Vissoh, P. V., Amadji, G. L., Deleporte, P., Dubos, B., Nodichao, L., Glele Kakaï, R. L., Chotte, J. L., & Blavet, D. (2013). Typologie des plantations villageoises de palmier à huile (*Elaeis guineensis* Jacq.) dans le département du Plateau au Bénin. *International Journal of Biological and Chemical Sciences*, 7(3), 978–999. <https://doi.org/10.4314/IJBCS.V7I3.8>
22. Okoye, C. N., Jiang, J., & Hui, L. Y. (2008). Design and development of secondary controlled industrial palm kernel nut vegetable oil expeller plant for energy saving and recuperation. *Journal of Food Engineering*, 87(4), 578–590. <https://doi.org/10.1016/j.jfoodeng.2007.01.030>
23. Raffleau, S. (2008). *Dynamique d'implantation et conduite technique des plantations villageoises de palmier à huile au Cameroun: facteurs limitants et raisons des pratiques* [Thèse de doctorat en agronomie]. AgroParisTech, Paris, France.
24. Ruswanto, A., Gunawan, S., Hermantoro, H., Putra, A. P., & Wirutomo, P. (2024). Effect of ripe level on palm fruit threshing efficiency. *BIO Web of Conferences*, 98, Article 06004. <https://doi.org/10.1051/bioconf/20249806004>
25. Ruysschaert, D. (2016). *Palm oil, a danger to farmers here and elsewhere*. ResearchGate. <https://doi.org/10.13140/RG.2.2.10541.90088>
26. Sundram, S., Sambanthamurthi, R., & Tan, Y.-A. (2003). Palm fruit chemistry and nutrition. *Asia Pacific Journal of Clinical Nutrition*, 12(3), 355-362.
27. World Bank. (2019). *World Development Indicators: Benin*. <https://data.worldbank.org/country/BJ>
28. Yé, S. G., Son, G., & Valea, N. (2017). Évaluation technique et économique de la vanneuse artisanale motorisée dans la chaîne de transformation du riz et du maïs. *Journal of Applied Biosciences*, 118, 11781–11793. <https://doi.org/10.4314/jab.v118i1.4>

تأثیر زمان نرم‌سازی و سرعت کوبنده بر عملکرد جداسازی و تمیزکاری دستگاه فرآوری میوه نخل روغنی

کریستل ساندرآ آینا بوکو^{۱*}، گاماس ماهوتوندجی آسوب^۱، گونتران کوملان باگان^۱

تاریخ دریافت: ۱۴۰۵/۰۵/۲۶

تاریخ پذیرش: ۱۴۰۵/۰۷/۱۲

چکیده

هدف این پژوهش، ارائه راهکاری عملی برای بهبود عملکرد دستگاه‌های بومی جداسازی میوه نخل از طریق افزایش ظرفیت و کارایی آن‌هاست، به گونه‌ای که برای بهره‌برداران محلی مقرون به صرفه باقی بمانند. این رویکرد به محدودیت‌های موجود می‌پردازد و پاسخگوی تقاضای روزافزون در بخش تولید روغن نخل است. شکاف فناورانه مشاهده شده در فرآوری میوه نخل، عمدتاً ناشی از فقدان ماشین‌آلات اختصاصی برای عملیات خاص، به ویژه فرایند جداسازی است که همچنان به روش‌های دستی متکی می‌باشد. این امر ضرورت توسعه ماشین‌آلات برای افزایش بهره‌وری و کاهش زمان، فضای مورد نیاز و شدت نیروی کار را برجسته می‌سازد. ارزیابی این دستگاه بر اساس سه زمان مختلف نرم‌سازی خوشه‌های تازه میوه (۲۴، ۴۸ و ۷۲ ساعت) و سه سرعت چرخش محور کوبنده یا روتور (۱۴۴/۵، ۲۴۰/۲ و ۴۲۴/۴ دور در دقیقه) انجام شد که مستقیماً با دورسنج (تاکومتر) اندازه‌گیری شدند. نتایج نشان داد که با افزایش زمان نرم‌سازی و سرعت روتور، کارایی جداسازی، نرخ تمیزکاری و ظرفیت تولید افزایش یافت؛ به طوری که مقادیر حاصله برای کارایی جداسازی بین ۶۶/۶۹٪ تا ۹۸/۳۰٪، برای کارایی تمیزکاری بین ۳۶/۰۶٪ تا ۹۳/۸۷٪ و برای ظرفیت ساعتی بین ۴۳۰/۹۰۱ تا ۱۸۰۰/۵۱۱ کیلوگرم در ساعت متغیر بود. در بین شرایط آزمایش شده، بهترین عملکرد جداسازی و تمیزکاری پس از ۷۲ ساعت نرم‌سازی و با سرعت روتور ۴۲۴/۴ دور در دقیقه حاصل شد.

واژه‌های کلیدی: خوشه‌های میوه نخل، کارایی تمیزکاری، کارایی جداسازی، کوبنده، مکانیزاسیون

۱- آزمایشگاه دانشکده مهندسی روستایی (LEGR)، دانشگاه ملی کشاورزی (UNA)، بنین

*-نویسنده مسئول: (Email: gontrand.bagan@una.bj)