Research Article / Review Article FUPRE JOURNAL 6(4): 65-70 (2022)

FUPRE Journal
of
Scientific and Industrial Research

ISSN: 2579-1184(Print) ISSN: 2578-1129 (Online)

https://fupre.edu.ng/journal

Mechanization and Evaluation of Knife-Edged Palm Leaflets Peeling Process of Broom Production

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ARTICLE INFO

Received: 20/08/2022
Accepted: 16/09/2022

Keywords

Broom bristle, knife edge, mechanization, palm leaflet, peeling.

ABSTRACT

Mechanization of knife-edged peeling process of broom bristles production from coconut and oil palm leaflets and its integration to a tethering system were accomplished in this study. This upshots a prototype of integrated peeling-tethering machine comprising two pairs of roller-feeders, a stripper and tethering module as basic components. The machine processes both fresh and dry palm leaflets effectively with drudgery, risk and materials 'wastes reduction potential surpassing those of the mechanized abrasive aided peeling based broom processing systems. It operates with an average efficiency and benefit-cost ratio of 96% and 2.45 respectively. The throughput of this machine exhibits inverse proportional profile with the length of leaflets processed. Thus, the innovation is technically and economically viable for advancement of palm broom processing.

1. INTRODUCTION

Palm broom is the most common and prominent floor cleaning/sweeping tool in Nigeria due to abundance of coconut and oil palm fronds in southern part of this country (Nwankwojike, 2014; Agbaji, 2018). The broom bristles made from these palm leaflets are moisture-resistant and absorb dirt, dust and wears effectively (Klassen, 2005; Nwankwojike *et al*, 2014). The bristle which constitutes the petiole of the palm leaflets is traditional produced by hand stripping (peeling) of the leaflets' blades from their petioles (stalks) with knife (John, 2008). Thus, Nwankwojike (2014) indicated rising scarcity and cost of this broom because of high risk associated with its inefficient native making process. The quest for mechanization of this peeling process prompted the development of a palm frond peeling machine by Nwankwojike *et al*, (2014) which was upgraded to an integrated peeling and tying machine by Onwuka *et al* (2019). The machines produce the broom bristles from dry oil palm leaflets. It removes the leaflets blades with rubbing friction of its abrasive coated rolling system. Nwankwojike (2014) revealed 6.96% as the optimal percentage moisture content of the oil palm leaflets required for its effective peeling operation of these innovations while Onwuka *et al* (2021) showed 94% and 6311 bristles/hr as their optimal efficiency and throughput. Although, Onwuka *et al* (2021) further showed that the abrasion based oil palm leaflets peeling system for broom production is economically viable, it cannot process fresh leaves.

In addition, Logeswaran et al, (2017) developed a midrib separation machine where the input of the machine is the coconut leaves. When the leaves are inserted into the opening, it is directed towards the spiked rollers. The machine consists of a pair of spiked rollers placed in a vertical manner and are kept rotating on opposite direction in such a way that the input leaves are taken in and the function of the spiked roller is to

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remove the leaf part from the midrib so that the midribs are taken away at the end. The removed leaves from the midrib are taken away as a waste. It consists of the three batch of rollers where one batch roller is off spiked type and the other two batches are off non-spiked type roller. This machine also didn't consider palm frond leaves and the operational module only peels partially dry coconut leaves. Therefore, pre-drying treatment of the leaflets is required for effective operation of these systems unlike the native knife edge aided process which peels both fresh and dry leaflets. Hence, this work which aimed to mechanized the knife-edged palm leaflets peeling and integrating it to an improved tethering system in line with Akor (1977) which directed for improved mechanization of palm products processing operations their corresponding native process observations to foster mass production of broom from the coconut and oil palm fronds.

2. MATERIALS AND METHODS

2. 1 Description/Design Analysis of Knife-Edged Palm Leaflets Peeling-Tethering Machine

This integrated knife-edged peeling and tethering machine (Figures 1) consists of two pairs of roller-feeders, stripper, bristles' stockpile and tethering module as shown in figure 2. The inlet feeder is made up of two meshing rubber surfaced and metal surfaced rollers which receives the palm leaflets from the operator and passes/guide them to the stripping unit. The stripper consists of a knife edged cutting vanes which peels off the leaf blade from its stalks by sharing action (Figure 3) and deflector which positions the leaflet for effective peeling of the blades on both sides of the leaflets. The deflector, made of 1mm mild steel plate is positioned at angle of 225° to enable the ejection of each peeled stalk (bristle) to its stockpile which feeds them to tethering unit at a rated batch/bundle of twenty-eight (28) bristles via intermediate feeder comprising two meshing rubber surfaced roller. The tethering module is an electromechanical system of a screw driver sleeve and stationary core which ties the bristle's bundle with rubber band placed at the core periphery as the sleeve reciprocates about the core. The sleeve's overrun and returning motion during the tying and broom discharging operations were regulated with intermediate feeding of the bristles from the stockpile using limit switches.

switches.

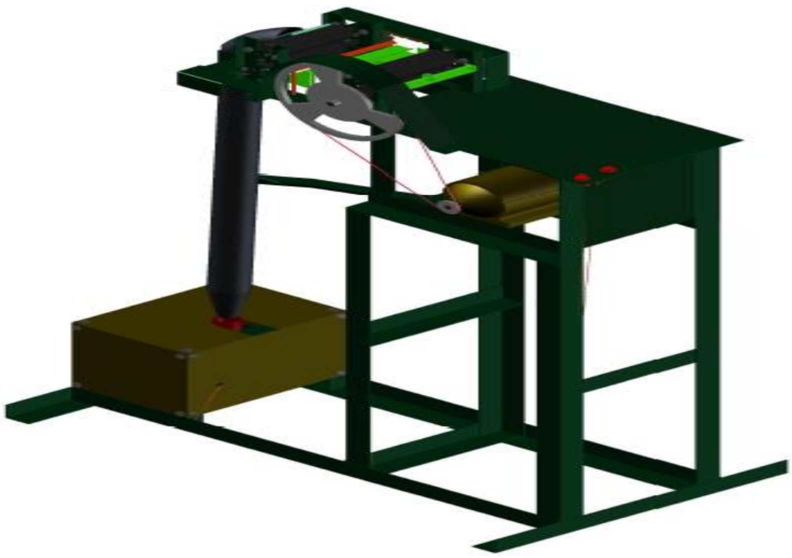

Figure 1: knife edged peeling-tethering machine for palm broom production

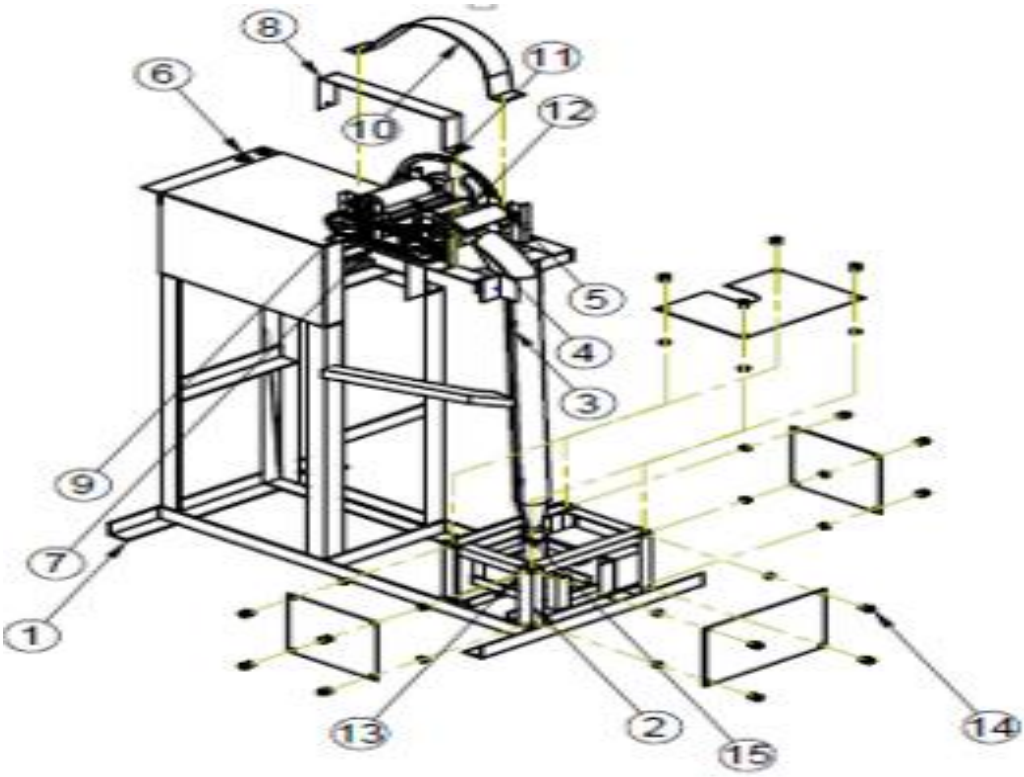

Figure 2: Exploded view of the knife edge peeling-tethering machine for palm broom production with 1-15 as its frame, tethering motor, stockpile, stripping blade, roller, regulator, chain, chain guard, sprocket, belt guard, pulley, deflector, stationary core, bolt and sleeve respectively.

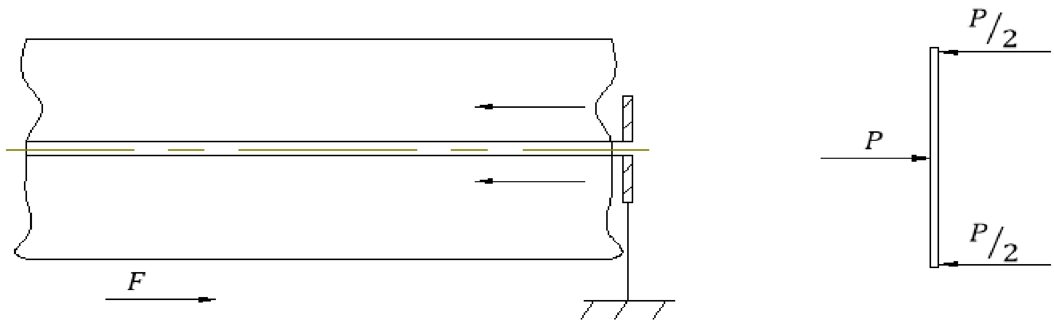

Figure 3: Shear Stress analysis of the knife edged stripper

An electric motor rated 2Hp with speed of 1400rpm drives the rollers of the inlet and intermediate feeders via belt and chain respectively with a driven speed of 247rpm each. The machine's power requirement and the driven speed were determined from the following relations

Power of the required prime mover (motor), $P_{RM} = T_m \cdot \omega$ (1)
The required motor torque, $T_m = K_S T_T$ (2)
Where ω is the angular velocity of the motor in rad/s while the safety factor, K_S = 2.0
The total torque due to drives' inertia and frictional forces, $T_T = T_a + P$ (3)

The acceleration torque, $T_a = \frac{J\Delta\omega}{h}$ (4)

$$J = \frac{1}{4} m {D_L}^2 G^2 \quad (5)$$

Where m and D_L are the mass and diameter of each roller while G is the speed ratio of the belt drive determined from the following Equation (6) derived from Khurmi and Gupta (2006)

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} = \frac{T_2}{T_1} \quad (6)$$

Where N_1 and N_2 are respective speeds of driving and driven pulley or sprocket, D_1 and D_2 constitutes driving and driven pulleys' diameters while T_1 and T_2 are number of teeth on the small and large sprockets respectively.

The load torque, $P = 0.5\tau hw$ (7)

Where w and h are the palm leaflets width and thickness respectively while measured shear stress (τ) resulting from traction on the leaflet during the peeling process.

2.2 Evaluation Methodology

The integrated knife edged peeling and tethering machine developed for processing palm leaflets to broom was evaluated using fresh and dry coconut and oil palm leaflets of different lengths to determine its peeling efficiency (η) throughput (*TP*) and benefit-cost ratio (*BCR*). The efficiency and throughput were assessed through experiment measurement of the time this machine used for processing ten batches of leaflets with different lengths as well the number of well peeled bristles, m_g and scraps, m_s (which consists of those that were not peeled well and broken ones) as per each test. The benefit-cost ratio of this innovation was evaluated with its five years useful life/business plan using the experimental results and prevailing economic indicators/market prices in Nigeria from 2018 to 2022. The performance and economic viability indicators assessed were determine from these records using the following relations given by Nwankwojike *et al*, (2014) and Gerald and Marta (2015).

$$TP = \frac{M_T}{t} \quad (8)$$

$$\eta = \frac{M_g}{M_T} \quad (9)$$

$$BCR = \frac{PVB}{PVC} \quad (10)$$

$$M_T = M_g + M_s \quad (11)$$

$$PVC = \sum_{t=1}^{T} \frac{C_t}{(1+r_i)^t} \quad (12)$$

$$PVB = \sum_{t=1}^{T} \frac{B_t}{(1+r_i)^t} \quad (13)$$

Where t, r_i, C_t and B_t constitute the processing time, prevailing interest rate of 14%, total cost and revenue (benefits) while PVC and PVB are present values of the cost and benefit respectively.

3. RESULTS AND DISCUSSİION

The performance analysis of the integrated knife-edged peeling and tethering machine developed for palm broom production shown in tables 1 indicates that peels both fresh and dry palm leaflets effectively with an average efficiency of 96%. This surpasses 94% peeling efficiency of the latest abrasive-roller aided peeling based broom processing machine of Onwuka *et al* (2021). This table also revealed that this novel knife- edged based broom processing machine exhibits inverse proportional processing capacity (throughput) profile with the length of leaflets processed. The decreasing trend of its throughput with the lengths of leaflets processed is practically and theoretically proven because the stripping blade of this machine moves from the leaflets' bottom to tip during the peeling operation. Thus, long peeling period translates to less number of bristles processed and vice versa. The cost benefit analysis (Table 2) of this innovation revealed its positive investment prospect with benefit-cost ratio of 2.45 which implies a revenue of ₦2.45 per ₦1 expended and this is better than 1.76 record of Onwuka *et al* (2021). The higher sustainability and viability indices of this knife- edged peeling over abrasive-peeling based broom processing machines is expected because it was developed in adherence to native process.

Table 1: Performance Analysis of the Knife-Edged Palm Leaflets Peeling-Tethering Machine

Length of Leaflets (m)	Number of Broom Bristles Peeled				Broom Bundle Processing Time (s)	Throughput (Kg/h)
	Total	Non-Defectives	Defectives	Efficiency (%)		
0.50	10.00	0.00	10.00	100.00	49.84	72.00
0.55	9.00	1.00	10.00	90.00	56.84	65.00
0.60	10.00	0.00	10.00	100.00	57.12	63.00
0.65	10.00	0.00	10.00	100.00	60.20	60.00
0.70	9.00	1.00	10.00	90.00	70.84	51.00
Average Peeling Efficiency				**96.00**		

Table 2: Cost-Benefit Analysis of the Knife-Edged Palm Leaflets Peeling-Tethering Machine

Description	Costs (₦)	Benefit (₦)
Fabrication and installation cost of the machine	178,300.00	
Salvage value @ 5yrs Business Plan		80,000.00
Wages	60,000.00	
Palm frond Purchase	951,200.00	
Maintenance/Utilities	19,480.00	
Sales		2,600,000.00
Total	***1,208,980.00***	***2,600,000.00***
Present Value @ 5yrs Business Plan	4,834,119.92	11,744,801.28
Benefit Cost Ratio	**2.45**	

4. CONCLUSION

The knife-edged peeling process of broom bristles production from coconut and oil palm leaflets was mechanized and integrated to a tethering system in this study in accord with observations of native process. The upshot integrated peeling-tethering machine comprising two pairs of rollers, a stripping blade, deflector and tying module as basic components processes both fresh and dry palm leaflets effectively. Its 96% efficiency, benefit-cost ratio of 2.45 and drudgery, risk and materials ‘wastes reduction potential surpassed those of the mechanized abrasive aided peeling based broom processing systems. Thus, the innovation is recommended for advancement of palm broom processing.

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