



DEVELOPMENT OF A CONCENTRIC DRUMS PEELING MACHINE FOR COCOYAM (*Xanthosoma sagittifolium*) CORMEL

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Abstract

Cocoyam is cultivated mainly for its edible cormels. In spite of its great potential as a cheap raw material, the processing operations are still largely performed manually. Some of the equipment already developed for mechanizing the postharvest operations require further modifications and performance optimization. This study therefore, aimed at developing and evaluating the performance of a cocoyam cormel peeling machine with a view to reducing the drudgery involved in manual peeling. A cocoyam cormel peeling machine was developed using locally available materials. The machine consists of the main frame, hopper and outlet gates, two abrasive concentric drums (one stationary and the other rotating) and blower. Performance of the machine in terms of capacity, peeling efficiency and peel-cormel weight proportion were evaluated for soaked and unsoaked cormels. The average machine capacities were 188.4 and 188.9 kg/h for soaked and unsoaked cormels, respectively. The peeling efficiencies ranged between 55.5 and 87.5% while the peel-cormel weight proportions ranged between 15.3 and 22.9%. The peeling efficiency was higher for soaked cormels than unsoaked ones. The developed cocoyam cormel peeling machine helped in reducing the drudgery associated with its peeling operation while soaking as a form of pretreatment was recommended before peeling the cormels for better performance.

Keywords: Cocoyam processing, edible cormel, peeling, abrasive drums, machine development

Introduction

Cocoyam (*Xanthosoma sagittifolium*) is cultivated in Nigeria and other tropical regions of the world purposely for its edible starchy corms and cormels. Among the root and tuber crops grown, it ranks as the third most important crop after yam and cassava (Onyekaka, 2014; Boakye *et al.*, 2018). Its cultivation in Nigeria is mostly found in South-Western and South Eastern parts of the country owing to suitable and adaptable ecological conditions in these areas (Balami *et al.*, 2012). However, its cultivation is essentially by small scale farmers with minimal agricultural inputs (Dimelu *et al.*, 2008). The crop contributes significant portion of carbohydrate content of the diet in many regions in developing countries (Owusu-Darko *et al.*, 2014; Boakye *et al.*, 2018). Although it is often considered less important to other tropical root crops such as yam, cassava and sweet potato, it remains a major staple crop in many parts of the tropics and sub-tropics (Onyekaka, 2014). The vast distribution of cocoyam geographically has culminated in diverse utilization of the crop. Most of the parts (corms, cormels, petioles, leaves and inflorescence) are consumable. The corms and cormels are widely used as food while the plant parts are useful for animal feed and medicine (Owusu-Darko *et al.*, 2014). The cormels are

prepared for food by boiling, baking, roasting or frying either alone or in combination with other ingredients to obtain various delicacies (Onyekaka, 2014). It is also used industrially in the production of alcohol and drugs (Okwuowulu *et al.*, 2002).

Cocoyam cormel is highly perishable and its storability is challenging due to its high moisture content in its fresh state. This adversely affects its shelf-life and culminates in serious post-harvest losses. Prompt processing of the cormels after harvesting is therefore, necessary to obtain products such as flour, chips, flakes and fufu with improved storability and shelf life (Owusu-Darko *et al.*, 2014; Oyefeso and Raji, 2021). Several unit operations are involved in the conversion of cocoyam cormel into some of its final products (Adeyanju *et al.*, 2019; Oyefeso *et al.*, 2021). These unit operations are often preceded by peeling and this makes it a significant operation in cocoyam processing. Peeling, as a preliminary operation, is the first operation performed after the cocoyam tubers have been freshly harvested and cleaned from debris. It entails the removal of outer skin (cortex or peel) of cocoyam cormel which is often done manually in Nigeria and some other developing nations (Adetan *et al.*, 2003; Balami *et al.*, 2016; Jimoh and Olukunle,

2021). However, traditional or manual peeling with knives has been found to be labor-intensive, ineffective and unsuitable for commercialization (Olukunle and Jimoh, 2012; Balami et al., 2016).

There have been several attempts by various researchers at designing peeling machines for various root and tuber crops such as cassava, garlic, ginger and taro (Adetan et al., 2003; Olukunle et al., 2006; Olukunle and Jimoh, 2012; Egbeocha et al., 2016; Yen et al., 2020; Ettannil and Viswanathan, 2014; Balami et al., 2016; Ezeanya, 2020; Jimoh and Olukunle, 2021). This study therefore, aimed at designing, fabricating and evaluating the performance of a motorized concentric drums peeling machine for cocoyam (*Xanthosoma sagittifolium*) cormel.

Materials and Methods

Design Considerations

In the design of the cocoyam cormel peeling machine, the physical characteristics of the cormel such as mass, volume, linear dimensions and projected areas along the three mutually perpendicular axes as reported by

Raji and Oyefeso (2010) were taken into consideration for an appropriate and practicable design. The machine was ergonomically designed to enhance ease of operation and fabricated using locally available materials.

The peeling machine was designed to accommodate 40 cormels of average length of 110 mm and diameter of 60 mm. Each cormel weighed an average of 0.25 kg, giving a total weight of cormels that can be accommodated by the machine to be about 10 kg.

Design of Machine Components

Inlet Unit

The inlet unit for feeding in the cormels consists of a pyramid-shaped hopper with a vertical channel. The angle of inclination of the hopper walls was determined to be 45° based on the knowledge of the angle of repose of cocoyam cormels on galvanized steel as reported by Olalusi (2014). Figure 1 shows the diagram of the inlet unit. A sliding gate was incorporated to control the feeding rate of the cormels. The volumetric capacity of the hopper is 0.045 m³.

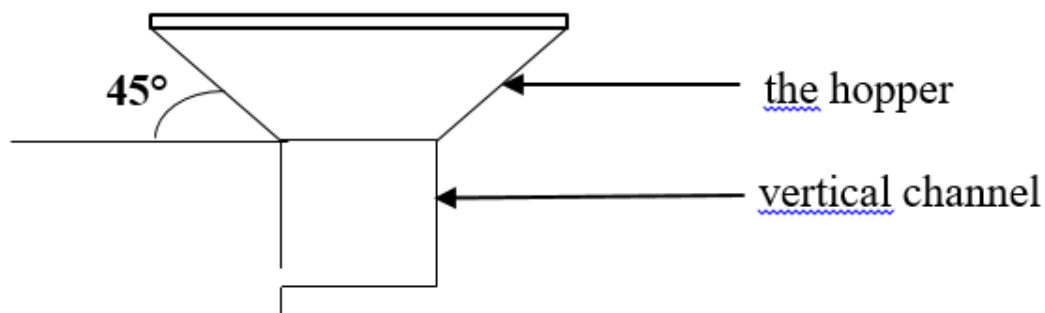


Figure 1: The inlet unit

Shaft Design

The shaft diameter required for the machine having combined bending and torsional loads was determined using Equation 1 (Adeleke, 2012).

$$d^3 = \frac{16}{\pi \times S} \sqrt{(K_t M_t)^2 + (K_b M_b)^2} \quad (1)$$

where d is shaft diameter (m), S is allowable stress (40 MNm⁻²) based on ASME code, K_t is combined shock and fatigue factor for torsion (Nm⁻²), K_b is combined shock and fatigue factor for bending (Nm⁻²), M_b is shaft bending moment (Nm) and M_t is shaft torsional moment (9.852 × 10⁻⁵ Nm) calculated from p/2πN where p is power (kW) and N is the rotational speed (rpm). Assuming that the load is gradually applied on the rotating shaft, K_t and K_b were taken to be 1.5 (Shittu and Ndirika, 2012). Therefore, the shaft diameter was calculated to be 24.1 mm although 25 mm diameter was used.

Design of Pulley

With the purpose of varying the machine speed as one of the evaluation parameters, three sets of pulleys were

designed for. The pulley diameters were obtained from the speed ratio as expressed in Equation 2 (Khurmi and Gupta, 2005; Oluwale and Adio, 2013). The pulley diameters for the machine were determined to be 215, 165 and 95 mm to obtain operational speed levels of 426, 539 and 917 rpm, respectively.

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad (2)$$

where d₁ is diameter of the driving pulley (0.065 m), d₂ is diameter of the driven pulley (m), N₁ is speed of the driving pulley (1,410 rpm) and N₂ is speed of the driven pulley (rpm).

Belt Design

V-belt (A-type) was selected in transmitting motion from the prime mover to the inner abrasive drum of the peeling machine. The angle of wrap and angle of contact of the open belt were determined using Equations 3 and 4, respectively (Khurmi and Gupta, 2005; Oluwale and Adio, 2013).

$$\theta = 2.3 \times \frac{1}{\mu} \log \left(\frac{T_1}{T_2} \right) \quad (3)$$

$$\alpha = \sin^{-1} \left[\frac{R+r}{x} \right] \quad (4)$$

Where θ is angle of wrap of an open belt (calculated as 152.82° and 161.12° on first and second pulleys respectively), μ is coefficient of friction between belt and pulley, taken as 0.30 (Khurmi and Gupta, 2012), T_1 is tension in the tight side of the belt (74.1 N), T_2 is tension in the slack side of the belt (32.2 N). α is angle of contact on both pulleys (calculated as 9.44° and 13.59°), r is radius of smaller pulley (m), R is radius of larger pulley (m) and x is distance between two pulleys for the peeling machine (m).

Power Requirement

Total power required for effective operation of the peeling machine was obtained from Equation 5

(Khurmi and Gupta, 2005). The power required was calculated to be approximately 1.4 hp although a 2 hp electric motor was selected for the machine.

$$P = F \times V \quad (5)$$

where P is power required to operate the machine (calculated to be 1,052.87 W), F is force required to power the machine (59.15 N), which was obtained from the sum of weights of pulley (3.92 N), weight of cylinder with cocoyam cormels to be peeled (6.18 N), and shaft (49.05 N) and V is speed of rotation of the shaft (17.8 m/s), calculated from $\pi DN/60$ where D is the diameter of driver shaft (0.241 m) and N is the rotational speed (1,410 rpm) assuming low speed operation. The exploded view and the orthographic projection of the designed peeling machine are presented in Figures 2a and 2b, respectively.

S/N	PART
1	WATER INLET
2	HOPPER
3	PEELING DRUM/ CHAMBER COVER
4	PEELING DRUM
5	COCOYAM TUBER OUTLET
6	INTERNAL PEELING DRUM
7	ROTATING DISC
8	FRAME
9	PULLEY SHAFT
10	PEELS OUTLET
11	ELECTRIC MOTOR

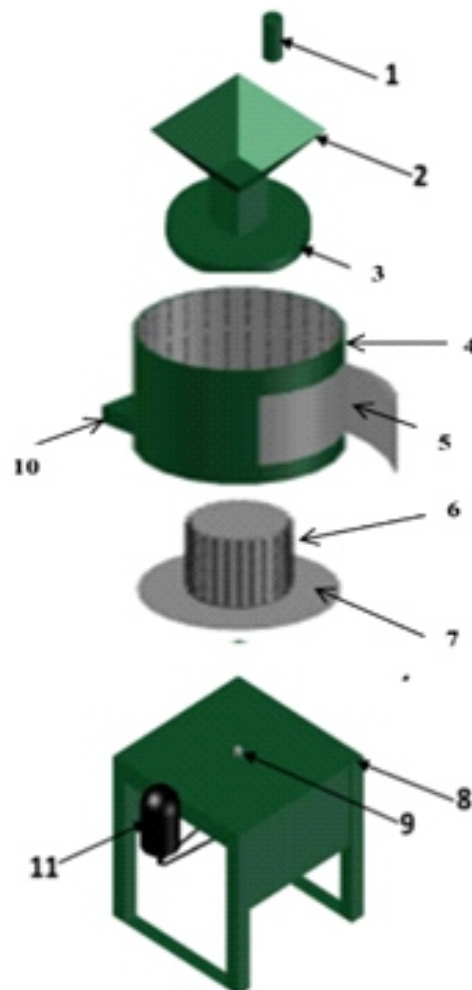


Figure 2(a): Exploded view of the machine

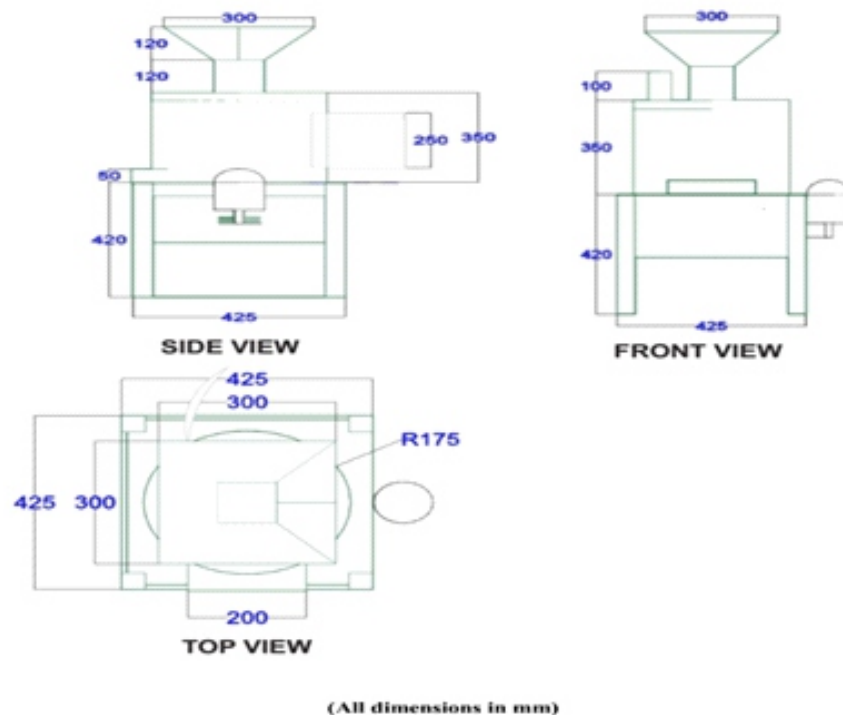


Figure 2(b): Orthographic projection of the machine

Principle of Operation of the Machine

The cocoyam cormels were fed into the peeling chamber through the hopper with an incorporated sliding gate to control the feeding rate. The peeling machine consists of two abrasive concentric drums (inner drum rotates while the outer one is stationary) which were vertically positioned and made of punched galvanized steel sheets. The peeling was achieved by abrasion caused by the movement of the cormels within the clearance between the two abrasive concentric drums. As the inner drum rotates, the cormels move against the walls of the drums and the punched surfaces rub on the cormel surfaces and peel off their skin predominantly by abrasive action. The cormels were held within the peeling chamber for specified retention time until the peeling was satisfactory. The peels escaped through the peel outlet, created by the clearance between the rotating disc and the wall of the stationary drum. The radial blower beneath the rotating disc relatively cleared the peels out through the peel outlet while the peeled cormels were collected at the main discharge unit controlled by a sliding lock.

Performance Evaluation of the Machine

The performance of the peeling machine was evaluated at three operational speed levels namely 426, 539 and 917 rpm using fresh, wholesome cocoyam cormels at average moisture content (wet basis) of 65%. The duration for different batches introduced were recorded. Performance indices such as peeling efficiency and peel-cormel weight proportion were determined.

Capacity of the Machine

Machine peeling capacity was calculated as the ratio of batch load of the cormel to the total peeling time. It was determined according to Equation 6 (El-Ghobashy *et al.*, 2016).

$$C_p = \frac{L_b}{T_l + T_r + T_u} \times 60 \quad (6)$$

where C_p is machine peeling capacity (kg/h), L_b is batch load (kg), T_l is loading time (min), T_r is peeling resident time (min) and T_u is unloading time (min).

Machine Peeling Efficiency

The peeling efficiency of the machine was determined as the ratio of weight of peel removed by the machine to the total weight of peel on the cormel. The expression is as presented in Equation 7 (Adegbehingbe, 2010).

$$\eta_p = \frac{M_{po} \times 100}{T_{wp}} \quad (7)$$

where η_p is machine peeling efficiency (%), M_{po} is weight of peel collected through the peel outlet of the machine (kg) and T_{wp} is total weight of peel on the cormel (kg), which was obtained from the sum of weight of peel removed by the machine and the peel manually removed from the partially peeled cormel.

Peel-cormel weight proportion

The peel-cormel weight proportion was determined using Equation 9 (Balami *et al.*, 2012).

$$P_w = \frac{M_{pc} \times 100}{M_s} \quad (9)$$

where P_w is peel-weight proportion (%), M_{pe} is mass of peel collected (kg) and M_s is mass of the sample (kg).

Results and Discussion

Pictures of the fabricated peeling machine are shown in Figures 3a and 3b. Soaked and unsoaked cocoyam cormels were used in evaluating the performance of the machine to determine the effect of soaking as a form of pretreatment on the peeling efficiency and peel-cormel weight proportion.



Figure 3: (a) The assembled peeling machine



(b) Peeling machine showing internal peeling drum

Effect of Operational Speed on Machine Performance

Average capacities of the peeling machine for the soaked cocoyam cormels were 192.7, 191.3 and 181.3 kg/h at 426, 539 and 917 rpm, respectively, while for fresh (unsoaked) cormels, the capacities were 191.9, 189.6 and 185.3 kg/h at 426, 539 and 917 rpm, respectively. The average machine capacities were 188.4 and 188.9 kg/h for soaked and unsoaked cormels, respectively. Low-speed operation is therefore, recommended for improved peeling machine capacity.

Variations in machine peeling efficiency at different operational speed levels for soaked and unsoaked cormels are presented in Figures 4 and 5, respectively. It was observed that the peeling efficiency increased predominantly as the operational speed increased for the soaked cormels, indicating that more peels were removed from the cormels as the speed level increased for a specified retention period. Peeling efficiencies for soaked cormels increased for all the three retention periods as the speed increased from 426 to 539 rpm. However, as the speed increased from 539 to 917 rpm, the peeling efficiency remained constant (73.6%) for 40 s retention, increased from 72.2 to 80.5% for 50 s retention period and reduced from 87.5 to 75.0% for 60 s retention period. The highest peeling efficiency (87.5%) for soaked cormels was obtained for 60 s retention period at 539 rpm while the lowest peeling efficiency (69.4%) was obtained for 40 s retention period at 426 rpm speed level. Increasing efficiency with increasing operational speed was reported by Balami *et al.* (2016) for peeling fresh taro tubers.

The peeling efficiencies of the fresh, unsoaked cormels decreased consistently as the operational speed increased for the range of retention periods considered. This is similar to the results reported by Oluwole and Adio, (2013) and Ezeanya, (2020) for peeling fresh cassava tubers and taro cormels, respectively. The highest peeling efficiency (72.2%) was obtained for 60 s retention period at 426 rpm while the lowest peeling efficiency (55.5%) was obtained for 40 s retention period at 917 rpm speed level.

Increase in the peeling efficiencies as the speed level increased could be attributed to the softness of the cortex of the soaked cormels which made it possible for the abrasive surfaces of the peeling drums to engage the peels and therefore, improving the efficiency at higher speeds. However, it could be observed that the outer skin of the fresh (unsoaked) cormels was quite hard and therefore, the cormels slip off the abrasive surfaces at higher operational speed levels.

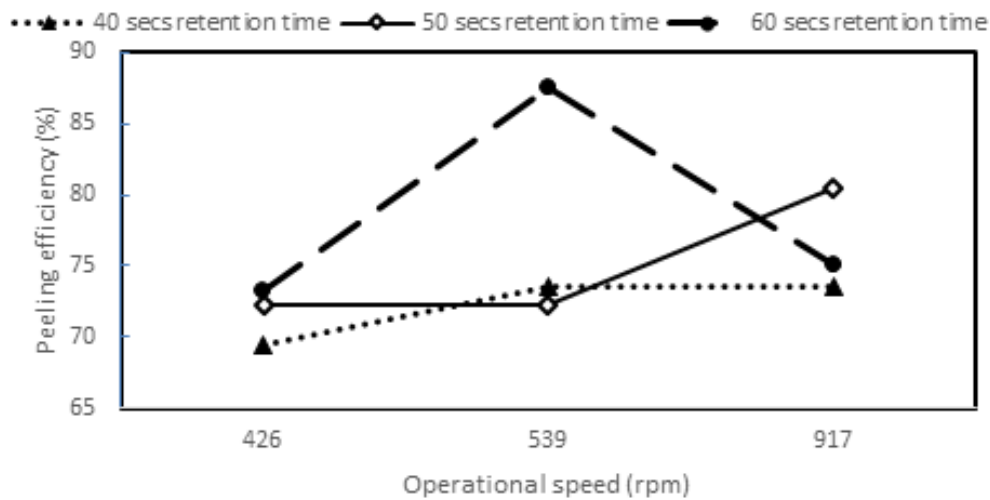


Figure 4: Peeling efficiency of soaked cormels

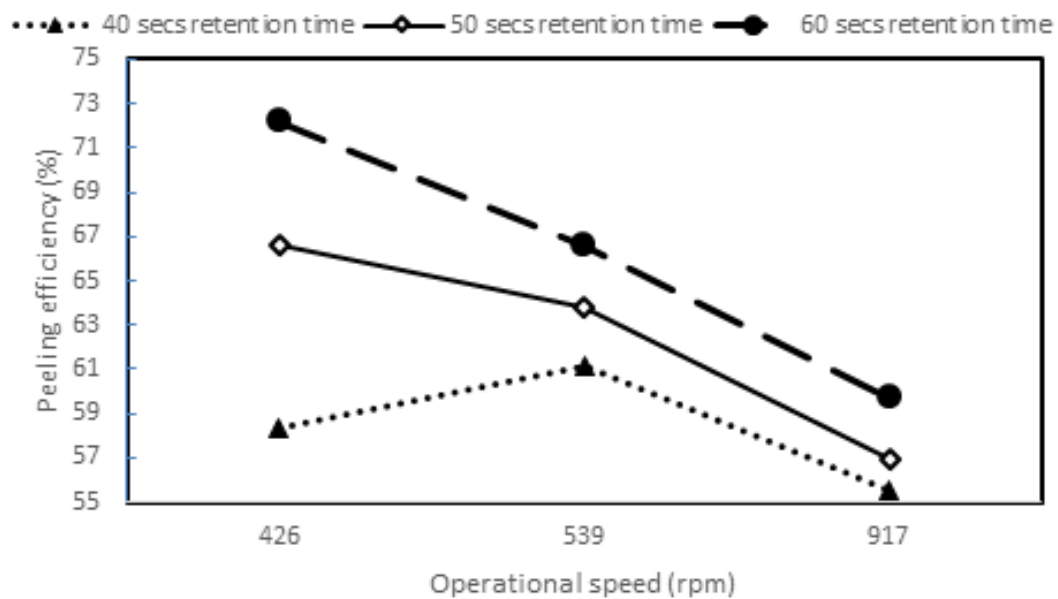


Figure 5: Peeling efficiency of unsoaked cormels

Variations in peel-cormel weight proportion at different operational speed levels for soaked and unsoaked cormels are presented in Figures 6 and 7, respectively. It was observed that the peel-cormel weight proportion increased predominantly as the operational speed increased for the soaked cormels. A similar trend was reported by Oluwole and Adio (2013) for fresh cassava tubers. The highest (22.91%) and lowest (18.38%) peel-cormel weight proportions for soaked cormels were obtained for 60 s retention period at 539 rpm and 40 s retention period at 426 rpm speed level, respectively.

The highest (19.55%) and lowest (15.27%) peel-cormel weight proportions for unsoaked cormels were obtained for 60 s retention period at 426 rpm and 40 s retention period at 917 rpm speed level, respectively. The peel-cormel weight ratio of the fresh, unsoaked cormels decreased consistently as the operational speed increased for the range of retention periods considered. This could be attributed to less contact between the cormels and abrasive surfaces of the concentric drums as the operational speed increased. The hardness of the cormel peel (without soaking) may also contribute to the reduction in the peel-cormel

weight proportion of the unsoaked cormel as the operational speed increased. Soaking as a form of pre-tre

the cortex (outer peel) of the cocoyam cormels and this resulted in better machine performance in terms of 1 weight

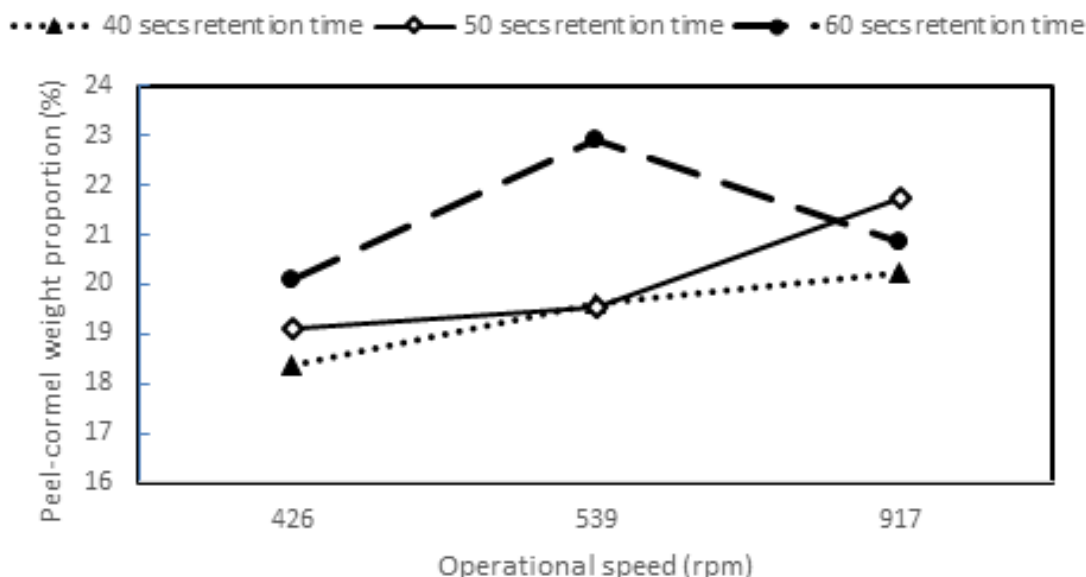


Figure 6: Peel-cormel weight proportion for soaked cormels

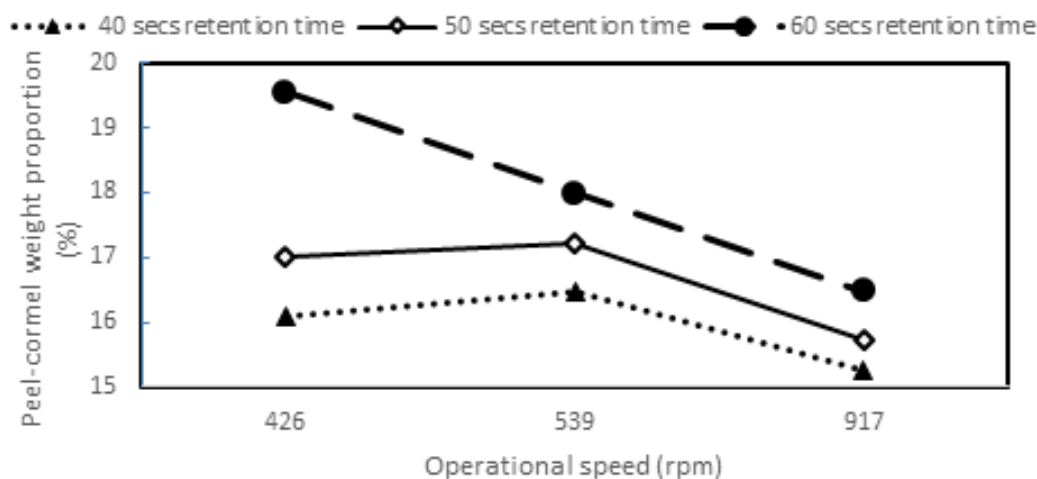


Figure 7: Peel-cormel weight proportion for unsoaked cormels

Effect of resident Time on Machine Performance

Variations in machine capacity with retention period are shown in Figure 8 while those of peeling efficiency and peel-cormel weight ratio at different operational speed levels are presented in Figures 9 and 10, respectively. The machine capacities for both soaked and unsoaked cormels at different speed levels considered decreased as the retention period increased from 40 s to 60 s. The machine capacities were highest for 40 s retention period while they were lowest for 60 s

retention period. Longer retention periods reduced the machine capacity at different operational speed levels for both soaked and unsoaked cormels. Maximum machine capacity (232.5 kg/h) was obtained at 40 s retention period for soaked cormels peeled at 539 rpm while the minimum capacity (145.2 kg/h) was obtained at 60 s retention period for soaked cormels peeled at 917 rpm. Shorter retention periods are thereby recommended when larger capacities are required as long as the peeling efficiency of the machine is not adversely affected.

In most of the cases considered, longer retention periods resulted in higher peeling efficiencies and peel-cormel ratios for both soaked and unsoaked cormels. The 60 s retention period gave the highest efficiency (87.5%) for soaked cormels operated at 539 rpm while the lowest peeling efficiency was obtained for 40 s retention period for fresh (unsoaked) cormels

peeled at 917 rpm. This implied that the longer the cormels were retained in the peeling chamber, the more the amount of peel removed by the abrasive surfaces of the concentric drums within the chamber. However, it should be noted that increased retention period results in increased loss of cormel flesh during the peeling operation.

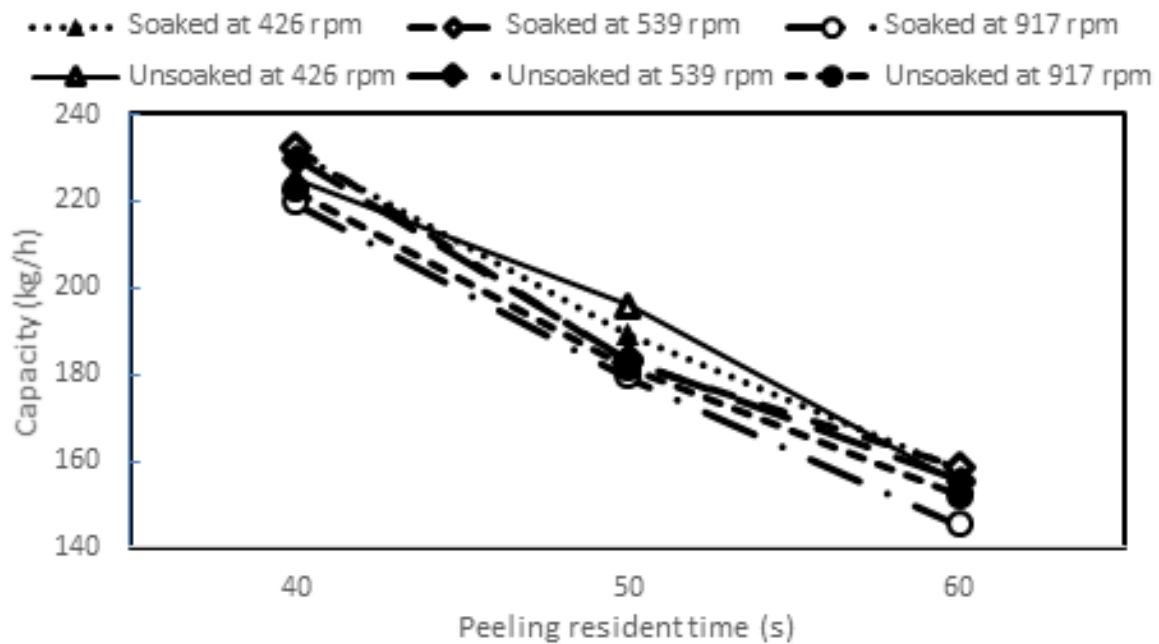


Figure 8: Effect of resident time on machine peeling capacity

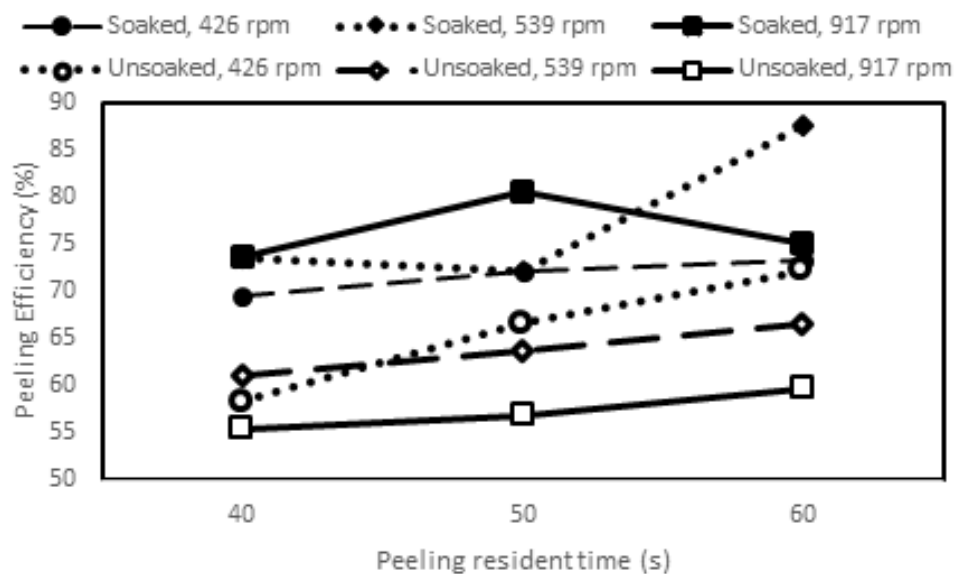


Figure 9: Effect of resident time on peeling efficiency

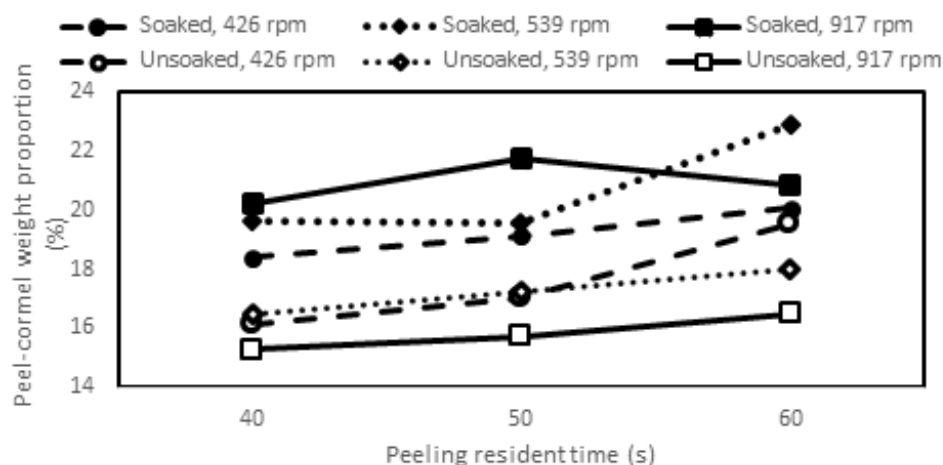


Figure 10: Effect of resident time on peel-cormel weight proportion

Conclusion

The cocoyam cormel peeling machine was designed, fabricated and evaluated with soaked and unsoaked cormels at three operational speed levels and three retention periods. It could be recommended that the machine should be run at a medium speed of 539 rpm which gave better performance in terms of peeling efficiency (87.5%) and peel-cormel weight proportion (21.6%). Soaking as a form of pre-treatment is also recommended before peeling cocoyam cormels so as to soften the cortex (outer peel) of the cocoyam cormels and obtain better machine performance in terms of higher peeling efficiencies.

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