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Research Article

Process Parameters Optimization for Quality Banana Fiber Extraction Using Mechanical Decorticator

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Abstract

Natural fibers can be spun into threads and can be used for various applications, as these are more sustainable than synthetic fibers. Banana pseudo-stem is considered agricultural waste after harvest and is left to rot in the fields that can be used as a valuable natural fiber source for composite as well as textile industries. Looking at the current extraction processes, the quality of fibers is observed to be inferior in the case of mechanical extraction when compared with manual traditional methods. This study focuses on this problem and investigates the banana fiber extraction machine and its process parameters optimization. The effect of blade profiles in the fiber extraction was evaluated using an after designing decorticator-type fiber extraction machine. The effective resistive force was observed to be 22.194 N, and the power was 174.308 W. It is observed that the optimum speed is 640 rpm and 2mm clearance for sharp-edged blades and 1mm for chamfered edged, with chamfered edges being able to produce high-quality fiber that is close to manual fiber quality.

Keywords: Banana Fiber, decorticator, blade profile, clearance.

Introduction

Natural fibers are seen as the sustainable alternative and have gained significant attention as an environmentally friendly alternative in packaging, textile, and composite industries due to their renewability, bio-degradability, and their mechanical properties (Ramesh et al., 2017). Among all the natural sources of fibers, the banana plant and its Musa species are selected as the study fiber source, as they are cultivated in more than 150 countries in the world.

In Nepal, the compound annual growth rate of banana is observed to be 6.38% for output (Ghimire et al., 2024), with 5,158 hectares of land covered with banana fields (Ghimire et al., 2023). Historically, banana pseudo-stems are left to rot in the fields after harvesting banana. Despite their potential as natural fiber sources, they are discarded as waste. These fibers have strength comparable to jute and sisal fibers with additional properties like high moisture absorption potential, biodegradable, and also being lightweight (Shrivastava et al., 2023).

The primary banana fiber extraction methods are mechanical and the traditional extraction process. The traditional process is primarily used in Nepal and Japan, where the manual scraping is followed by the retting process, which is time-consuming, more labor-intensive, and the production rate is low (Sinha & Devnani, 2023). Mechanical extraction process, on the other hand, uses decorticator machines that have a higher production rate, but the fiber qualities are often observed to be inferior to manual processing. This disparity in quality has limited the commercial adoption of the mechanical decorticator machine for banana fiber extraction.

Past research has shown that parameters like roller speeds, clearance, and feed angle affect the quality of fiber produced (Vishnu et al., 2023). The gap between the decorticator and breast plate in sisal has also been seen to be affecting the quality of the natural fiber, and observed the gap of 2mm produce optimal result (Ahmad et al., 2017). It is also observed that the sharpness of the blade affects quality, thus chamfered edges are seen as a better alternative in this case (Shambhu et al., 2023). Also, the pulling has to be done at a force of approximately 250 N in order to get better quality banana fiber from pseudo-steam (Onyenanu et al., 2024). Observing this literature, it is observed that the combined effect of these factors affect the banana fiber quality. It is thus necessary in context of Nepal to locally develop and optimize the banana fiber extraction machine.

This study is focused on optimizing the banana fiber extraction process in the context of Nepal by selecting key design parameters that affect the fiber quality. Along with developing and testing the blade profile, decorticator speed, and roller clearance in terms of fiber.

Materials and Methods

Load Determination

Using Izod impact testing in the material science lab, the resistance force was obtained to separate the fiber from pseudo steam, which is then used as the force required. The force required is then used in determining motor sizing and the machine design process. The stem sample of standard 72 mm width and thickness, ranging from 10-12 mm were used. The moisture content was taken to be 66.67%. The relation used is;

$$Energy\ absorbed\ = WR\,(-cos\alpha\ + cos\beta) \qquad (1)$$

Here, Alpha (α) = Angle of fall= 90° and Beta (β) = Angle of rise

Design of Machine and Fabrication

SolidWorks was used to develop the CAD model, where different parts were modelled, changed, and studied.

Testing

Taking a constant width of 70mm while varying the moisture content, decorticator rpm, blade profile, and clearance, the test was carried out.

In each test, initial weight, stump weight, final fiber weight, and processing time were recorded, and the decortication % was calculated.

$$Decortication\% \ = \frac{Initial\ - Stump\ weight}{Initial\ weight} * 100\% \qquad (2)$$

Here different 5-point visual range was used as a visual ranking scale;

Rank 5: Very good to Rank 1 bad;

Table 1: Visual ranking scale of fiber

Ranks	Status	Condition
Rank 1	Bad	Severely damaged, unusable fiber
Rank 2	Poor	Significant damage and short fibers
Rank 3	Average	Moderate, with some breakage
Rank 4	Good	Mostly clean fiber and slight damage
Rank 5	Very good	Clean, continuous fibers, minimal damage

Result and Discussion

Resistance Force Calculation

Different thicknesses of 10.45,10 and 12 mm were used, and the average yielding force can be seen in the range of 16.04 to 22.3 J in Table 2. The most prominent value is observed to be 20.91J which is selected as the minimum energy required.

Table 2: Izod test result

Thickness	Angle reached	Energy Absorbed (J)	Average energy (J)
10.45	86, 85, 85	16.74, 20.91, 20.91	19.52
12	85, 85, 84	20.91, 20.91, 25.09	22.3
10	85, 86, 87.5	20.91, 16.74, 10.47	16.04

Taking the energy equation as,

$$E = \int \omega . r . F(t) dt \quad (3)$$

Using the mean value theorem, the equation (3) changes to;

$$\frac{1}{\Delta t} * \int F(t) = Fe$$

Taking ω = 52.36 rad/sec, r = 0.15m and = 0.12,

Average force (Fe) = 22.194N

Now, the average power requirement for decortication is calculated to be 174.308 watts.

Blade Profile Effect on Fiber Quality

At 640 RPM and 2mm clearance, the comparative analysis of the sharp and chamfered blades was performed, and the fiber quality was assessed.

Sharp-Edged Blades:

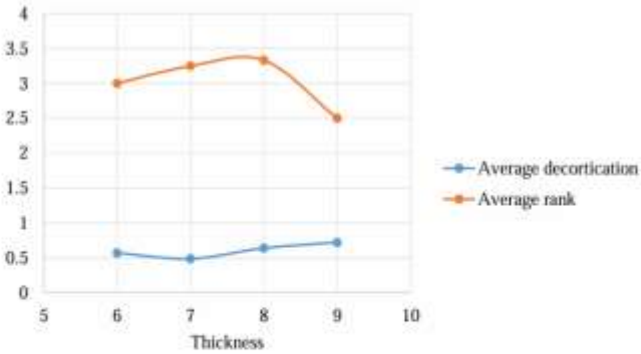

Fig. 1: Thickness vs Average Decortication and average rank for 1 mm clearance sharp edge

In the case of sharp-edged blades at 1mm clearance, it is observed that the optimal performance range is at 6-8 mm thickness, where the average decortication was 57-64% with the average rank that hovers between 3.25-3.33, as shown in Fig. 1. The thickness below 5 mm has excessive breakage of fiber, whereas the thickness above 9 mm was under decorticated and has reduced quality (Table 3).

Table 3: Performance summary of sharp-edged blades at 2mm clearance and 640 RPM

Thickness	Average Decortication %	Average Rank	Quality Assessment
4	44.92	1.67	Poor
5	53.62	3	Average
6	64.93	4.29	Good – Very good
7	64.08	4.33	Good – Very good
8	76.55	2	Average
9	64.08	1	Bad

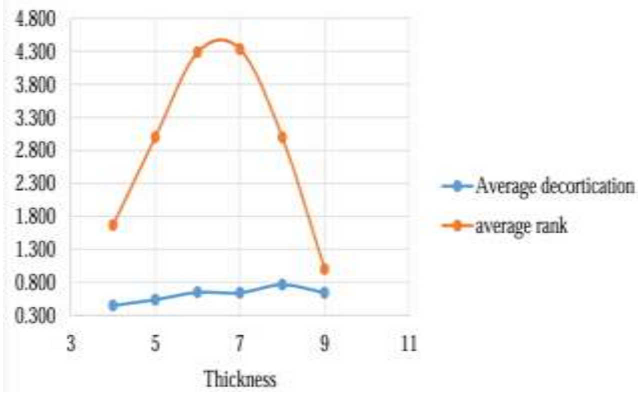

Fig. 2: Thickness vs Average Decortication and average rank for 2 mm clearance sharp edge

At 2mm clearance, the better quality fiber was seen in 6-7 mm thickness, and the average decortication was between 64-65%. The quality was in the range of good and very good, showing the range of 4.29-4.33 as shown in Fig. 2. This finding is consistent with (Ahmad et al., 2017), where the 2mm clearance had optimal quality for sisal fiber at a thickness of 5-8 mm at 640 rpm.

At 3mm clearance, it is observed that the optimum rank is at 10 mm thickness and observed to have decortication ranging from 59% to 82%, as shown in Fig. 3:

Thus, the clearance of 2mm has better quality fiber when the thickness is taken as 6-7 mm in the case of sharp-edged blades.

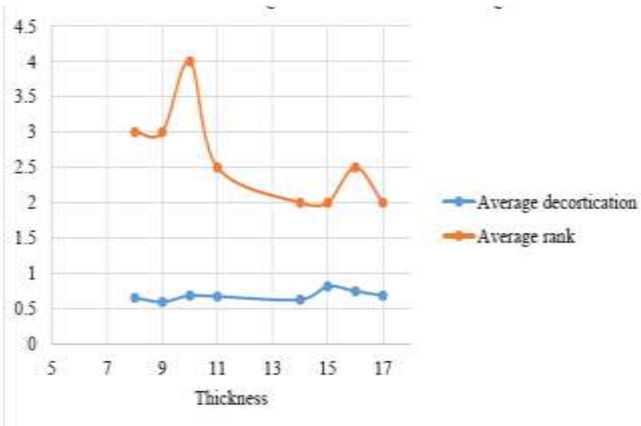

Fig. 3: Thickness vs Average Decortication and average rank for 3 mm clearance sharp edge

Chamfered Blade:

In the case of chamfer-edged blades, the study is performed on different clearance ranges of 0.635 mm, 1mm, and 2mm clearance range. It is seen that the chamfered-edged blades have superior performance across a wide range of different thicknesses. At 0.63m mm, it is observed that the good quality fiber was observed at a range of 5-10 mm thickness, where the rank ranges from 3.5-4 and average decortication ranging from 20.78% - 76.68% as shown in Fig. 4.

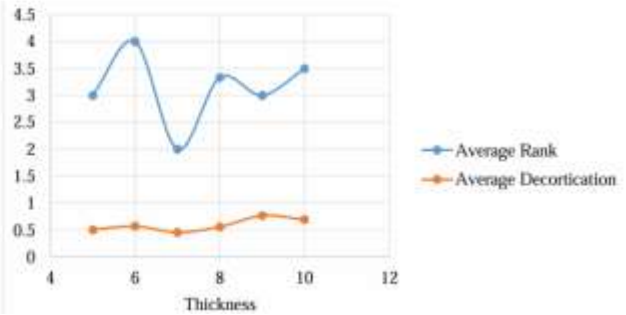

Fig. 4: Thickness vs Average decortication and average rank for 0.635mm clearance chamfer edge

At 1mm clearance, the optimum performance is observed at the range of 5-10 mm thickness with a rank ranging from 3.4-4.4 and an average decortication of 59-71% as shown in Fig. 5.

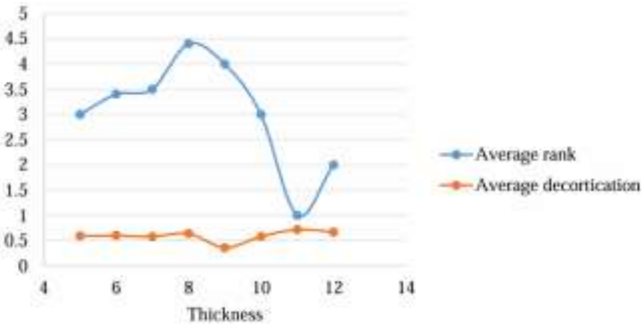

Fig. 5: Thickness vs Average decortication and average rank for 1 mm clearance chamfer edge

At a 2mm clearance chamfer-edged blade, it is observed that the optimum performance is observed in a thickness range of 9-12 mm, where the average rank is below other options, where the average rank is 2-2.75, and average decortication ranging from

Table 4: Performance summary of chamfered- edged blades at 1mm clearance and 640 RPM

Thickness (mm)	Average Decortication (%)	Average Rank	Quality Assessment
5	59.25	3.00	Average-Good
6	59.92	3.40	Good
7	57.85	3.50	Good
8	63.80	4.40	Very Good
9	35.82	4.00	Good
10	58.10	3.00	Average
11	71.75	1.00	Bad

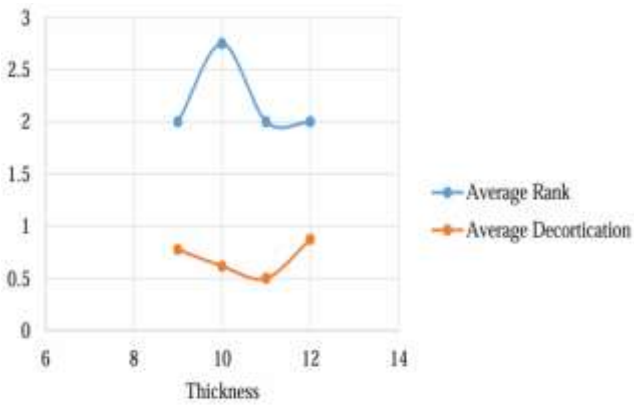

Fig. 6: Thickness vs Average decortication and average rank for 2 mm clearance chamfer edge

49.9% - 87.37% as shown in Fig. 6. The quality is very low in the case of a 2mm thickness chamfered-edged blade.

Thus, at 1 mm clearance, the chamfered-edged blades produce high-quality fibers with consistence performance at thickness 8mm and average rank of 4.4 mm and 9 mm thickness with average rank of 4, this shows that the quality of chamfer to handle pseudo-steam dimension with less damage to fiber. Sharp edges tend to cut the fiber, but chamfered edges are seen to promote gradual fiber separation.

Rpm and Its Effect on Fiber Quality

Observing different speeds ranging from 425 rpm to 640 rpm under constant clearance of 2mm and 6mm thickness, the optimum quality was observed in the range of 630-640 rpm, where the optimum being 640 rpm with average rank of 3-3.5 and average decortication ranging from 53-60% as shown in Fig. 7.

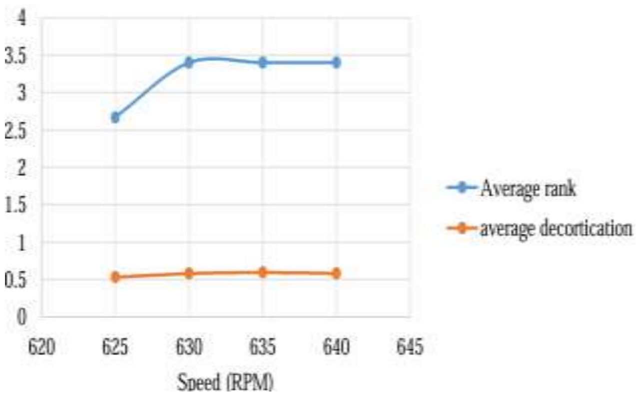

Fig. 7: Rpm and its effect on quality and decortication

Conclusion

From the above result, the resistance force of pseudo steam was found to be 22.194 N, and it required 174.308 Watts of power for effective extraction. It is observed that the clearance influences the efficiency of decortication and fiber quality, too. In the case of sharp-edged blades, the optimal clearance is 2mm, which is a balance between fiber preservation and effective material removal, whereas clearance above 3mm causes incomplete separation and below 1mm causes fiber breakage. Whereas the chamfered edges' optimum performance was at 1 mm clearance, which shows that the chamfered edges require tighter clearance due to altered dynamics when compared to sharp edges. Thus, the stem thickness of 5-10 mm is preferred, and chamfered edges are required for fiber making. Also, the speed of 630-640 provides a balance between fiber quality and decortication efficiency. Lower speed is caused by lower decortication, whereas higher speed increases fiber damage risk.

Thus, chamfered-edged blades at 1mm clearance approached the quality of manually extracted fiber. These findings can be guidelines for designing an efficient banana fiber extraction machine that can transform the waste from the pseudo-stem of the banana into a sustainable fiber source for textile and composite production.

Authors' Contribution

All authors contributed equally at all stages of research and manuscript preparation. Final form of the manuscript was approved by all authors.

Conflict Of Interest

The author(s) declare(s) that there is (are) no conflict(s) of interest.

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Annex:


Rank 5 fiber


Rank 4 Fiber


Rank 3 Fiber


Rank 2 Fiber


Rank 1 Fiber