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Preliminary Evaluation of Banana Fiber Opening Performance using a Multi-Axis Air-Injected Rotary Arm Fiber Opening Machine (MAIRA-FOM)

Nur Suhailah Khamis[1], Muhammad Farid Shaari[1*], Norhaidah Mohd Asrah[2], Mohd Azim Faris Roslee[1]

[1] *Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, KM1 Jalan Panchor, 84600Muar, Johor, Malaysia*

[2] *Department of Statistics, Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia, KM1 Jalan Panchor, 84600 Muar, Johor, Malaysia*

*Corresponding Author: mdfarid@uthm.edu.my
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Abstract

Breaking of fibers during the fiber opening process has led to the development of a novel fiber opening technique that utilizes an air injection–assisted rotational beater. However, the full potential of this technique is still under investigation, particularly in terms of optimizing its process parameters. Hence, this research was conducted as a preliminary evaluation of a newly developed machine known as the Multi-Axis Air Injection Rotary Arm Fiber Opener Machine (MAIRA-FOM). The aim of this study was to investigate the correlation between fiber load and processing time on fiber opening efficiency. Two different raw, unopened fiber loads of 50 g and 150 g were processed at three processing durations of 5 minutes, 10 minutes and 15 minutes. The weights of both opened and unopened fibers were measured to determine the fiber opening efficiency. The results indicate that both fiber load and processing time significantly affect the opening efficiency, exhibiting a linear relationship. The highest efficiency achieved was 52% at a processing time of 15 minutes, which was significantly higher than the 28% efficiency obtained at 5 minutes. Additionally, a higher fiber load of 150 g resulted in improved separation efficiency compared to the lower fiber load of 50 g.

1. Introduction

Natural fibers are increasingly used in the production of non-woven fabrics as substitutes for synthetic fibers due to growing environmental awareness [1][2]. Natural fibers are preferred because synthetic fibers have a negative impact on the environment, contributing to the accumulation of non-biodegradable waste primarily plastics and the release of harmful chemicals during their production and disposal processes [3]. Among various natural fibers, banana fiber has been widely utilized in product development due to its favorable mechanical properties, biodegradability and sustainability [4]. Banana fibers are extracted from the pseudo-stem of the banana plant, which is an abundant agricultural waste, making them an attractive alternative to synthetic fibers [5]. However, one of the critical stages in processing banana fibers is the fiber opening process after extraction from the pseudo-stem.

The fiber opening process remains challenging because conventional opening techniques rely heavily on mechanical forces, which often cause fiber breakage and degradation, thereby reducing fiber quality [6].

Excessive fiber length reduction during opening adversely affects the quality of final textile products such as yarns and non-woven fabrics. To address this limitation, a fiber opening machine known as the Multi-Axis Air Injection Rotary Arm Fiber Opener Machine (MAIRA-FOM), incorporating a novel opening mechanism, was developed to minimize fiber damage during the opening process. Although the MAIRA-FOM has demonstrated the ability to open banana fibers effectively, further investigation is required to optimize its process parameters. Therefore, this study aims to evaluate the performance of the MAIRA-FOM by examining the correlation between fiber quantity and processing time on banana fiber opening efficiency. The findings from this preliminary investigation are expected to provide fundamental insights for optimizing the fiber opening process and supporting the development of high-quality banana fiber–based non-woven products.

2. Materials and Methods

The banana fiber used in this study was sourced from Bambusoideae Technology Sdn. Bhd. extracted from the pseudo stem of Abaca banana plants (Musa textilis) as shown in Fig. 1. The central 3 to 5 layers of the pseudo stem were chosen for fiber extraction due to their stronger and thicker nature which is beneficial for mechanical processing [7],[8]. The outer skins and inner core (pith) were discarded as they were either damaged or lacked the necessary fibrous structure. The fibers were then cut into 8 cm segments and stored at room temperature for compatibility with the fiber opener machine. To protect the fibers from moisture changes, they were sealed in airtight plastic bags ensuring uniform quality and reliable processing for the subsequent tests [9].

Banana fiber is sourced from the pseudo-stem which is cut, dried and conditioned before being processed. The proposed work uses a MAIRA-FOM which uses a combination of mechanical beating and air-jet pressure for banana fiber opening. The machine consists of a rotary spiked arm that uses a motor and an air compressor that provides 0.8 MPa pressure to separate fibers. Key parameters such as fiber quantity and processing time are adjusted to evaluate their effects on fiber opening efficiency, mass loss and fiber quality. Supporting tools include a digital scale (±0.1g accuracy) for measuring fiber mass, a digital tachometer for verifying rotational speed. This setup allows the evaluation of fiber opening efficiency, mass loss and fiber quality under various conditions. The experimental methods and procedures include adjusting the fiber amount and processing time, as well as analyzing the data using conventional analysis methods. The experimental apparatus enables analysis of the efficiency of fiber opening, mass and quality of the fibers at different settings illustrating the effect of processing factors on the fiber opening process.

Fig. 1 *Banana pseudo stem fibre*

2.1 Experimental setup

The machine as shown in Fig. 2 is powered by a DC motor which powers a spiked rotating arm provided with metal spikes for combing the fiber. The speed & power controller controls the running of the DC motor. A speed & power controller regulates the motor's operation. The fiber is processed in a clear fiber holding chamber for easy observation with 0.8 MPa air pressure used to clean and separate the fiber. The system includes a metal support structure for stability during operation.

The testing process involves setting the rotational speed of the machine and then verify this speed with a tachometer (HABOTEST HT671). The air pressure is set to 0.8MPa to properly separate fibers. Fiber sample weight at 50g and 150g of fiber samples is measured and subjected to processing. The fiber opener is also set to operate for either 5 min or 15 min depending on the experimental setting. Weight is measured again to determine mass loss, opening efficiency and observed for cleanliness and separation. This experimental process carried out according to set parameters to ensure the results are consistent and reliable. Table 1 shows that experimental process is conducted according to the predefined factors and levels for the fiber opening process to ensure reliable and consistent results

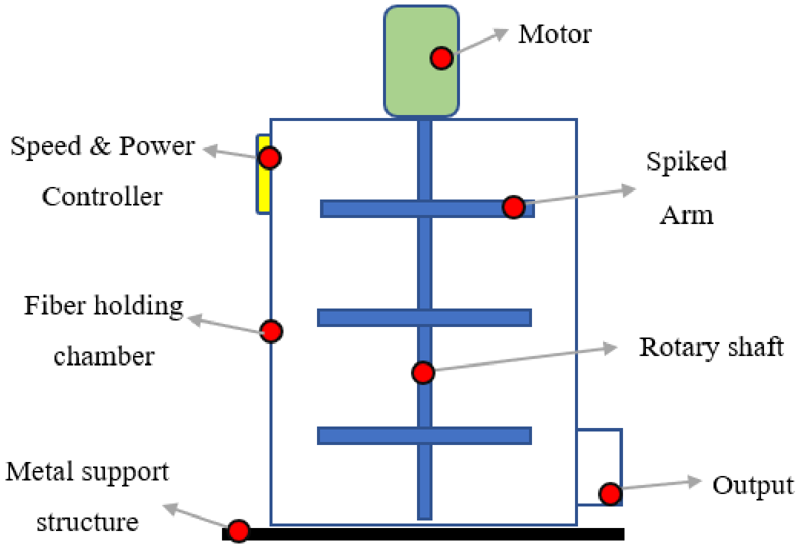

Fig. 2 *System Configuration*

Table 1 *Factors and Levels for Fiber Opening Process*

Factor	Parameter	Unit	Low (-1)	High (+1)
A	Fiber Quantity	g	50	150
B	Processing Time	min	5	15

3. Result and Analysis

This section presents the experimental results and analysis of the banana fiber opening process using the MAIRA-FOM. The main purpose was to evaluate the performance of the fiber opener by considering the efficiency of the opening, mass loss, opening efficiency and quality of fibers obtained for different processing conditions. The influence of some key parameters was examined such as the fiber quantity and processing time of treatment to find which one has the greatest influence on the general performance of fiber separation. The results are discussed based on the experimental data showing relationships among these parameters and fiber quality obtained focusing on the improving of the process to obtain the maximum efficiency and least fiber damage.

3.1 Effect of Fiber Quantity on Opening Efficiency

The ability of a mechanism to effectively open natural fibers is evaluated by evaluating its ability to consistently produce high-quality fibers with minimal defects. The results of the study shows that the mechanism is capable of achieving a high level of reliability where this fiber opener can not only be used on banana fiber, but it can also be applied to other plant-based fibers, making it a versatile tool for sustainable fiber processing. This adaptability further enhances its potential for industrial-scale applications offering an efficient and eco-friendly alternative to traditional fiber opening methods.

Fig. 3 shows the Opening Efficiency vs. Fiber Quantity using different processing times which 5 min is represented by a blue line and 15 minutes is represented by an orange line. Opening efficiency increases in line with an increase in fiber quantity for both processing times. It should be noted that for all values of fiber quantity, the 15 minutes processing time results in higher opening efficiency than that of the 5 minutes processing time. In contrast, the 5 min processing time show a slower rate of improvement in efficiency as the fiber quantity grows. Overall, the graph suggests that a longer processing time enhances opening efficiency but both processing times benefit from an increase in fiber quantity. Table 2 shows the Comparison of Fiber Condition at Different Processing Times and Weights.

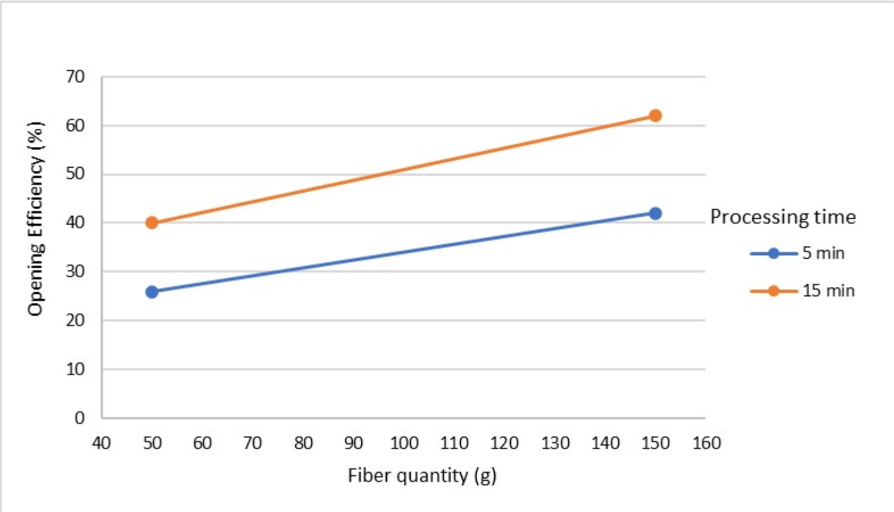

Fig. 3 *Opening efficiency vs speed for different fiber quantities*

Table 2 *Comparison of Fiber Condition at Different Processing Times and Weights*

	Fiber Quantity	
Processing Time	50g	150g
5 min	 The fiber was not fully opened. Big fiber clumps were visible.	 More fiber were opened than the 50g sample.
15 min	 More fibers were opened compared to the 5 min sample. Less and smaller clumps appear.	 The fiber is fully opened.

3.2 Effect of Processing Time on Opening Efficiency

The air-jet assisted mechanism helps improve the quality of the opened fibers by reducing the force required to open the fiber and minimizing damage. Fig. 4 shows the graph for opening efficiency vs fiber capacity for different speeds. The graph illustrates how processing time influences the removal rate with longer exposure leading to a higher percentage of dirt removal while balancing the risk of fiber damage.

The rotary spiked arm impacts the fibers more frequently as processing time increases which allows the loosening and better separation of the fiber bundles. Efficiency is consistently highest at 250 rpm reaching 52% after 15 minutes as opposed to 28% at 150 rpm. These findings suggest that longer processing times are more effective at higher rotational speeds. In general, improving fiber separation is largely dependent on processing time and speed.

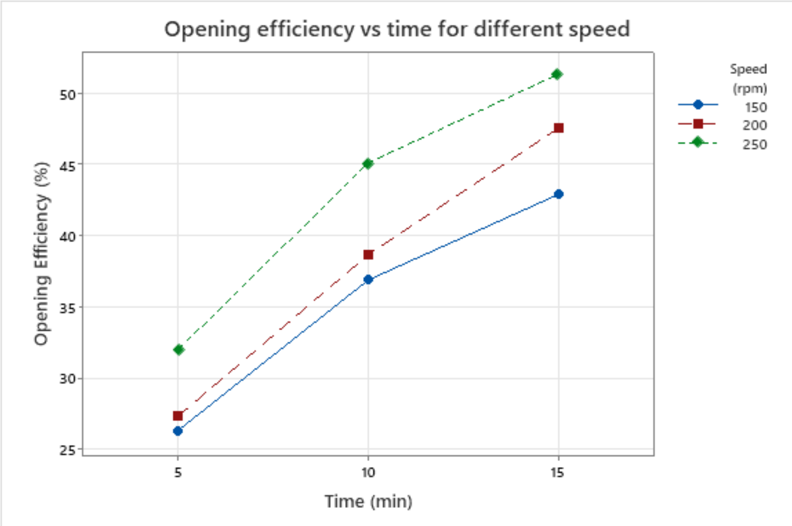

Fig. 4 *Opening efficiency vs fiber quantity for different speeds*

4. Conclusion

A vertical rotation-assisted natural fiber opening mechanism has been successfully designed, fabricated and validated. This mechanism has demonstrated reliability and efficiency in its function making it a promising solution for natural fiber processing. This design provides an efficient and effective solution for opening natural fibers while minimizing fiber damage and improving the overall quality of the opened fibers. In conclusion, the performance of the MAIRA-FOM machine used for opening banana fibers was successfully analyzed using the performance equation based on the interaction of the main factors like fiber quantity and processing time. The analysis proved that both factors significantly influenced the efficiency of opening with a majorcontribution from processing time and the fiber quantity. Increased processing time and the fiber quantity positively increased the efficiency of opening. The ideal combination of parameters for the highest opening efficiency was found to be 15 minutes and 150g of fiber. With these parameters, the optimal opening efficiency was realized that MAIRA-FOM is an effective sustainable tool for opening banana fibers with little damage. The research confirms that MAIRA-FOM can significantly enhance fiber quality making it a promising method for sustainable banana fiber processing in the textile industry. In summary, processing time and amount of fiber are main factors in efficient opening of fibers and MAIRA-FOM is an eco-friendly efficient method for using banana pseudo-stems as raw material for textile production by transforming them into natural textile products.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contributions to the paper as follows: the study conception and design were carried out by Nur Suhailah Khamis and Muhammad Farid Shaari, with data collection conducted by Nur Suhailah Khamis and Mohd Azim Faris Roslee. Analysis and interpretation of results were handled by Nur Suhailah Khamis, Muhammad Farid Shaari, Norhaidah Mohd Asrah and Mohd Azim Faris Roslee while the draft manuscript preparation was done by Nur Suhailah Khamis and Muhammad Farid Shaari. All authors reviewed the results and approved the final version of the manuscript.

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