Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 26 (2015) 756 – 760

www.elsevier.com/locate/procedia

12th Global Conference on Sustainable Manufacturing

Novel technology for sustainable pineapple leaf fibers productions

Yusri Yusof[a*], Siti Asia Yahya[a], Anbia Adam[a]

[a] *Faculty of Mechanical Engineering Universiti Tun Hussein Onn Malaysia (UTHM) 86400, Parit Raja, Batu Pahat, Johor, Malaysia*

*Corresponding author. *E-mail address:* yusri@uthm.edu.my

Abstract

Recently, there is a critical issue on crop waste management from agricultural sectors in Malaysia. Due to the rapid development in agricultural sectors, there are approximately 1.2 million tons of agricultural wastes being disposed annually in Malaysia. This kind of waste is usually eliminated by burned or decomposed and lead to the arising of some environmental issues. Regarding to environmental and sustainability awareness, concerns on the long term effect of burning crop waste have been expressed including pineapple leaves burning. Responding to this emerging issue, there are emphases on transformation of crop waste to wealth in order to create a sustainable agriculture industry. In pineapple cultivation, the pineapple leaves can be further processed to produce value-added products. Pineapple waste is no longer something that is unwanted. Recently, it is regarded as resources for economy development. Turning pineapple leaves into wealth not only makes good environmental sense, but also turns "trash" into "cash". In Malaysia, several initiatives have been done in order to extract fiber from pineapple leaves and convert into commercial products. However, the process involved in pineapple leaves fiber productions is still lag behind technologies development in this era. The proposed technology involved in sustainable pineapple leaf fibers (PALF) productions practicing the process that will reduce the environment pollution, minimize the waste, conserved energy and natural resources. This sustainable manufacturing will maximize the productions of pineapple leaf fibers and develop green environment as well as boost the economy growth.

Peer-review under responsibility of Assembly Technology and Factory Management/Technische Universität Berlin.

Keywords: pineapple leaf fiber (PALF); sustainable agriculture; waste to wealth; green environment; economy development

1. Introduction

Recently, the concerns of sustainable development have encouraged efforts toward increasing the efficiency utilization of raw resources and reduce the waste productions. In this context, utilization of agricultural byproducts as an alternatives fiber resource has been highlighted. Reuse of these wastes will lead to significant reduction of generated waste hence decreased environmental impact. Apart from that, reuse of these byproducts for value-added products manufacturing will become one of an additional revenue source for farmers and developed the diversification of agricultural industry.

Pineapple is one of the most familiar tropical fruits widely cultivated around the world for its fruits. Pineapple leaves, the major part of the plant that is currently unused needs global attention for its commercial exploitation. After fruit harvesting, the leaves are disposed by burning or decomposed. This happened due to the outdated technology involved for this purpose and ignorance from farmers and local communities regarding the existence of commercial uses of pineapple leaves.

A comprehensive studies must be done in order to figure out the potential of these beneficial agricultural wastes since the practices of decomposing and burning the leaves *in-situ* will effect plantation yield improvement [1]. There are numerous studies done by researchers on various aspects of pineapple leaf fibers (PALF). Several authors analyzed the properties of PALF included physical, mechanical, and chemical properties from various pineapple species [2, 3].

Furthermore few research have been done on the surface treatments effects towards PALF's tensile properties [4, 5]. All the research findings showed that surface treatments will enhance PALF's mechanical properties. All the previous work done regarding to PALF only focusing on PALF compositions, PALF properties, and PALF utilizations in

Peer-review under responsibility of Assembly Technology and Factory Management/Technische Universität Berlin.
doi:10.1016/j.procir.2014.07.160

several applications such as particleboard, composites reinforcement agent, and papermaking [6].

In our endeavor to develop pineapple leaf fiber diversifications, we have discovered a new technology for sustainable pineapple leaf fibers productions. This work will present the initial phase of larger-scale study on the innovations involved in PALF productions. In this preliminary study, PALF obtained from local pineapple cultivar will be extracted, scoured, and drying by using new technology invented. Then, the produced PALF was characterized in terms of physical and mechanical properties hence compared with PALF produced by conventional method.

2. Experimental details

2.1. Materials

Pineapple leaves used in this study is obtained from residues after harvesting pineapple collected from Muzium Nanas, Pontian, Johor. The plant variety used was *Josapine* belonging to Spanish cultivar. Josapine leaves are long and wide. The leaves are about 30-60cm long and 4-6cm wide.

Other reagent employed in this study was sodium carbonate (Na_2CO_3).

2.2. Pineapple leaf fiber (PALF) productions

In conventional methods, PALF is extracted on a long bench by using a scrapping tool called *'ketam'* [7]. There are about six main steps involved as shown in Figure 1. The scrapped PALF is then washed under running tap and dried directly under the sun.

In this work, PALF is produced by novel technology invented as illustrated in Figure 2. PALF is extracted by a decortication machine named Pineapple Leaf Fiber Machine 1 (PALF M1). When most of the extractor or decorticator out there using crusher-like technology to extract PALF, this machine used blades to remove the waxy layer on the pineapple leaf instead of forcing it out by crushing [8]. Furthermore, the blades' designs were unprecedented. The number of blades used, sizes and certain angle of the two blades needed to ensure that the leaf will not snap during the process plays crucial part of the extraction process.

As shown in Figure 3, pineapple leaf is inserted between the two blades, blade 1 and blade 2. Upon entering the blades, the leaf will be sort of 'grind' and the outer waxy layer will be removed during this first step. During second step, when the leaf was being pulled off, yet again, the leaf will be grind for the second time that will remove the entire waxy layer, which was left during the first step.

The extracted PALF is then being scoured and dried by using Pineapple Leaf Fiber Machine 2 (PALF M2) as in Figure 2(b). At this stage, the remaining green debris accumulated at PALF will be further cleaned and removed. Apart from green debris removal, this machine also will dry the fiber at the same time. Difference from PALF M1, PALF M2 only has one rotating drum with blades attached to it.

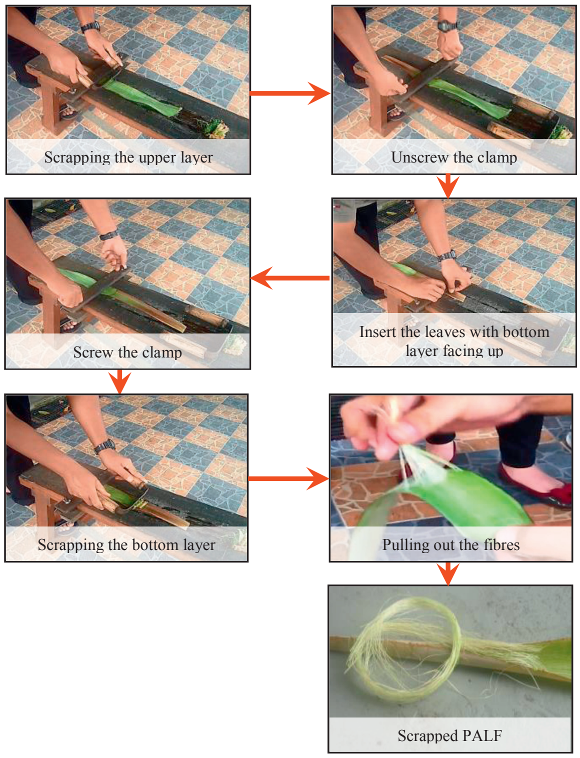


Fig.1. Hand scrapping method

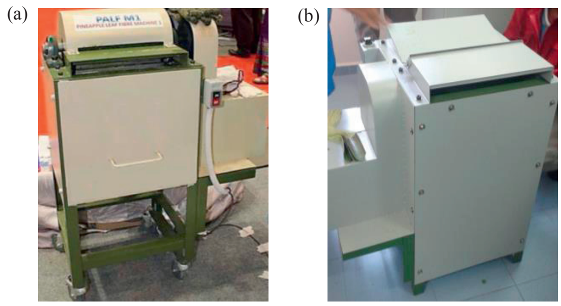


Fig.2. (a) PALF M1; (b) PALF M2

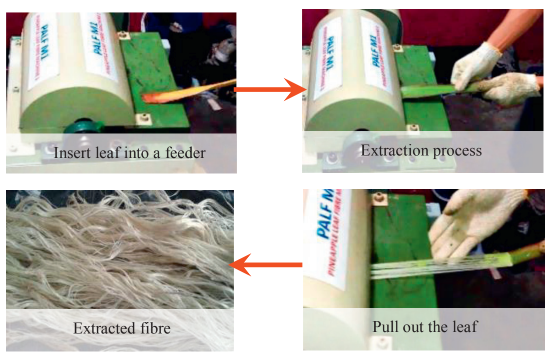


Fig.3. PALF M1 mechanism

2.3. Degumming of PALF

Degumming is one of the process done in order to eliminate the gummy matters in pineapple leaves including pectin's, pentosan, and lignin [9]. All these gummy matters make the fiber steep in natures. Degumming can be carried out by using silane, alkaline, or acids. This work will cover for alkaline treatment only. For alkaline treatment, the extracted PALF was immersed in 3% of sodium carbonate (Na_2CO_3) for 1 hour at room temperature. After that, the fibres were washed, rinsed several times with distilled water in order to neutralize remaining alkali, and then dried directly under the sun.

In addition, heat treatment also applied in this study. PALF was boiled at 100°C for approximately 1 hour, and then sun-dried. Apart from that, there are combination of treatment that applied both heat and alkaline treatment. The entire surface treatments applied on PALF in this study is summarized in Table 1.

Table 1. PALF surface treatments.

Sample	Treatments
Untreated	-
Alkali treatment	3% Na_2CO_3
Heat treatment	Boiling water@ 100°C
Alkali + Heat treatment	3% Na_2CO_3 + Boiling water@ 100°C

2.4. Characterizations

Diameter of PALF was measured under video analyzer. The diameter was measured at four different points and the average was calculated.

A JEOL model field emission-scanning electron microscope (FE-SEM) was used to observe PALF imaging surface at nano-scale. The samples were observed in the FE-SEM using a voltage of 5.0kV with working distance 8mm.

On the other hand, tensile test was carried out according to ASTM C1557-03: Standard Test Method for Tensile Strength and Young's Modulus of Fibers [10]. Fibers with diameter in range from 70.0µm-90.0µm are selected for tensile test. The tensile tests were performed using Lloyd Instruments Universal Testing Machine model LR30K with crosshead speed of 1mm/min at room temperature. The gauge length was set at 50mm.

3. Results and discussion

3.1. Effectiveness of PALF M1

It is apparent that by using PALF M1, both upper and bottom of leaves surface will be scrapped at same time while when hand scrapping is applied, only one side of the leaves surface will be scrapped. As a result, less time is taken to extract a piece of leaves using PALF M1 than hand scrapping.

Table 2 presents the comparison of PALF productions between hand scrapping and PALF M1 by assuming 8 hours working per day. PALF M1 manage to extract about 5760 pieces of leaves per day with average time taken 5 seconds per pieces while hand scrapping took about 50 seconds to extract one piece of leaves. Productions rate of PALF M1 is approximately 10 times of hand scrapping.

Table 2. Comparison between PALF M1 and hand scrapping.

	PALF M1	Hand scrapping
Time	≈5 sec/piece	≈50 sec/piece
Productions rate	≈5760 pieces/day	≈576 pieces/day
Time & labor management	Efficient	Less efficient
Yield fiber	Uniform fiber length	Less uniform fiber length

This new invention also being compared with conventional method in term of pineapple leave wastes management. Figure 4 showed the graph of pineapple leave wastes management from 2008-2013. All the data collected showed is based on the estimated value given by one of the pineapple's farmer at Pineapple Museum, Pontian Johor [7].

Method of hand scrapping seems not very practical since it does not contribute significant impact towards reductions of pineapple leaves waste after harvesting. From year 2008 until 2010, there are about 85-88% of pineapple leaves have been wasted. After the PALF M1 has been introduced, the percentage is drastically decreased to 2-8%. This low percentage indicates that invention of PALF M1 offered practical management of pineapple leaves wastes towards developing sustainable pineapple industry.

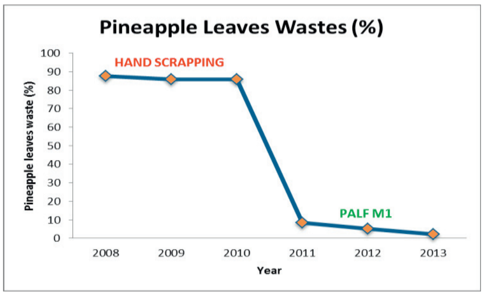


Fig. 4. Percentage of pineapple leaves wastes at Pineapple Museum

Basically, after scrapping process there will be amount of green debris waste accumulated. Those green debris waste are defined as pulp waste as shown in Figure 5. This kind of waste can be further utilized for several purposes included vermicomposting and animal pellets.

Fig.5. Pulp waste

As showed in Figure 6, graph of number of extracted leaves versus pulp waste produced (gram) is plotted. It is obvious that hand scrapping generated large pulp waste compared to PALF M1. For every five pieces of scrapped leaves, hand scrapping method produced about one and a half gram (1.5 g) pulp waste, while PALF M1 generated one gram (1.0 g) waste. PALF M1 managed to reduce the pulp waste produced after scrapping process up to 33%.

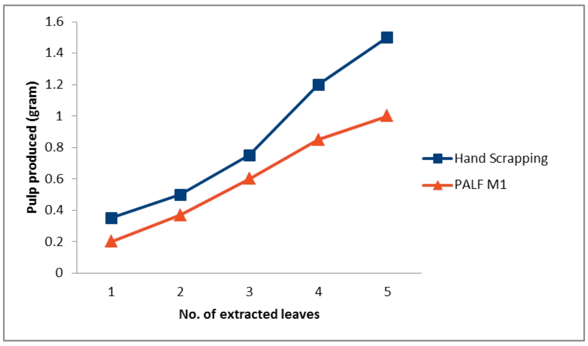


Fig.6. Pulp waste generated after scrapping process

In summary, PALF M1 offered better approach in both wastes management; pineapple leaves wastes and pulp wastes. This proposed novel technology can be better alternative in order to reduce pineapple wastes towards developing sustainable pineapple industry as well as agriculture industry.

3.2. PALF's physical properties

PALF processed by conventional methods and new invented machines are shown in Figure 7. Final PALF processed using PALF M1 and PALF M2 look more clean, soft, and bright compared to conventional method. In term of color, PALF extracted by hand is brownish, while PALF extracted using PALF M1 is more attractive in creamy white.

(a) (b)

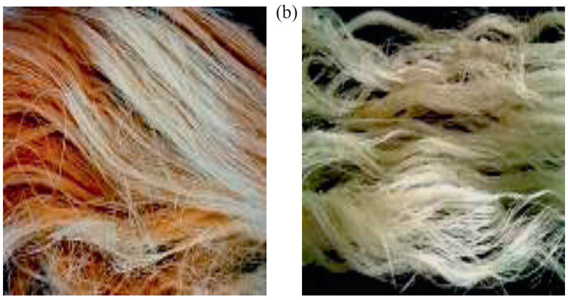


Fig.7. PALF processed by (a) conventional method; (b) PALF M1 and PALF M2

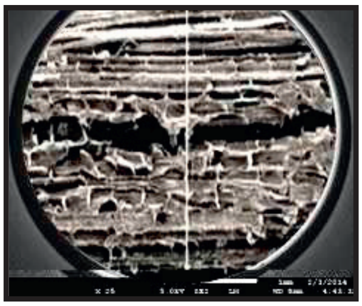
For diameter measurement, PALF is assumed to be cylindrical in shaped, so the fibre width is defined as fibre diameter. The results are statistically presented in Table 3. Average diameter of PALF bundles extracted by hand scrapping was 90.7µm, meanwhile diameter of PALF bundles extracted from PALF M1 was 75.7µm approximately. Those values obviously showed that PALF M1 manage to produce more refined fibre compared to hand scrapping.

Table 3 Diameter of PALF

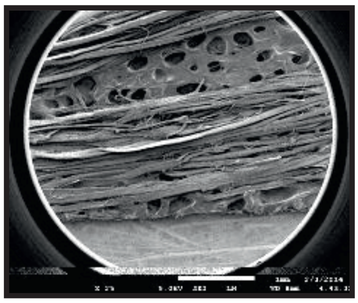
Extraction methods	Sample	Diameter (µm)				
		Pt. 1	Pt. 2	Pt. 3	Pt. 4	Ave.
PALF M1	1	69.75	71.55	73.05	71.65	71.50
	2	76.72	77.17	77.47	68.64	75.00
	3	77.56	76.15	79.58	85.76	79.76
	4	67.56	73.23	87.05	65.90	73.43
	5	78.05	76.54	84.30	76.87	78.90
	Average :					**75.70**
Hand scrapping	1	79.86	84.77	92.03	86.50	85.79
	2	90.47	91.72	87.45	87.80	89.36
	3	88.73	99.82	92.65	96.87	94.52
	4	95.67	92.35	89.58	83.40	90.25
	5	99.80	91.78	90.08	92.44	93.58
	Average :					**90.70**

Besides that, the FE-SEM (field emission scanning electron microscope) micrographs taken from the different method of PALF extractions are shown in Figure 8. Both PALF extracted by hand scrapping and PALF M1 exhibit multi-fibrillar structure and the fibrils were bound together by lignin as well as hemicellulose.

However, it is apparent that the PALF extracted using PALF M1 exhibits parallel fiber arrangement, more fine and delicate structured compared to hand scrapping PALF. This showed that PALF M1 do not contribute high damage to PALF structure compared to conventional method.



(a)



(b)

Fig.8. SEM photomicrographs of PALF (a) hand scrapping; (b) PALF M1

3.3. PALF's mechanical properties

There are several factors that affected mechanical properties of PALF have been studied in this work, included effect of extraction methods and effect of surface treatment.

Tensile properties of PALF that have been extracted by hand scrapping and PALF M1 are showed in Table 4. From this comparison, it is obviously showed that PALF M1 produced better fibre with higher tensile properties compared to hand scrapping. PALF extracted using PALF M1 recorded tensile strength with 613.75MPa which is rather high than hand scrapping with only 393.70MPa.

This might due to the mechanism used during extraction process. During hand scrapping, some forces are being applied continuously at same point in order to scrap the fibre. The force applied is not evenly distributed along the fibre's length which can lead to fibre damage and broken at certain point. As a result, fibre's tensile properties will be affected.

Table 4. Tensile properties of extracted PALF

	Tensile strength (MPa)	Young's modulus (GPa)	Strain to failure (%)
Hand scrapping	393.70	7254.2	3.24
PALF M1	613.75	1379500.0	6.67

Besides that, tensile properties of degummed PALF also been analyzed. In this test, only PALF extracted using PALF M1 will be analysed. From Table 5, it is obvious that surface treatments will increase PALF tensile strength. In addition, PALF treated with both heat treatment and alkaline treatment exhibit the highest tensile strength (1088.60MPa).

During alkaline and heat treatment, the binding materials that are hemicellulose and lignin were partially removed hence created less dense and less rigid interfibrillar region. As a result, the fibrils are able to rearrange themselves along the tensile deformation direction that results in better load sharing and higher stress fibers development.

Table 5. Tensile properties of untreated and treated PALF

	Tensile strength (MPa)	Young's modulus (GPa)	Strain to failure (%)
Untreated	613.75	1379500.0	6.67
Heat treated	671.64	6725.4	3.16
Alkali treated	763.60	2899.9	3.60
Heat + alkali treated	1088.60	6441.6	3.79

4. Conclusions

The present works shows that the innovation of PALF M1 and PALF M2 contribute significant effort towards pineapple leaf fiber (PALF) productions. Besides increasing the PALF productions rate, this innovation also do not alter too much PALF's originality in term of texture, physical properties, and mechanical properties. From SEM image, it is apparent that PALF M1 and PALF M2 produced more fine and delicate PALF compared to conventional methods. In addition, the chemical treatment and heat treatment do increase PALF's tensile strength. Na_2CO_3 treatment and boiling water treatment increased the tensile strength of the PALF's over those of untreated fibres

Furthermore, this works present the new finding of potential fibre in replacing glass fibre and man-made fibre. Besides that, the fibre productions from this kind of agricultural waste has great commercial application potential which can add value to pineapple cultivation, facilitate extra income for entrepreneurs or farmers, and lead to agricultural diversification.

Moreover, this works allows great significant reduction in the volume of waste accumulated and contributes in raw materials extraction. Comprehensive works need to be done in future in order to determine the potential area of utilizing PALF as commercial fibre.

Acknowledgements

This research is financially supported by the Science fund (MOSTI) with Vot No. S021, Knowledge Transfer Program (KTP) with Vot No. 1082 organized by Ministry of Higher Education Malaysia, and Universiti Tun Hussein Onn Malaysia, UTHM. A big appreciation to entire team members for cooperation and support provided.

References

[1] A.R. Mohamed SMS, A. Khalina. Selected Properties of Hand-Laid and Compression Molded Vinyl Ester and (PALF)-Reinforced Vinyl Ester Composites. International Journal of Mechanical and Materials Engineering (IJMME). 2010;5(1):68-73.
[2] Sena Neto AR, Araujo MAM, Souza FVD, Mattoso LHC, Marconcini JM. Characterization and comparative evaluation of thermal, structural, chemical, mechanical and morphological properties of six pineapple leaf fiber varieties for use in composites. Industrial Crops and Products. 2013;43:529-37.
[3] A.R. Mohamed SMS, M. Shahjahan, A. Khalina Characterization of pineapple leaf fibers from selected Malaysian cultivars. Journal of Food, Agriculture & Environment. 2009;7(1):235-40.
[4] J. P. Siregar SMS, M.Z.A. Rahman, H.M.D.K. Zaman. Effects of Alkali Treatments on the Tensile Properties of Pineapple Leaf Fiber Reinforced High Impact Polystyrene Composites. Pertanika Journal Science & Technology. 2012;20(2):409-14.
[5] Rahman MA. Study of Modified PALF. Journal of Textile and Apparel, Technology and Management. 2011;7(2):1-16.
[6] Siti Asia Yahya YY. Comprehensive Review on the Utilization of PALF. Advance Materials Research. 2013;701:430-4.
[7] Ahsik A. Pineapple Leaf Fibre Muzium Nanas, Pontian, Johor2013.
[8] Yusri Yusof AA. Review on PALF Extraction Machines for Natural Fibers. Advance Materials Research. 2013:781-4.
[9] Sunil Pardeshi MJM, Vijay Goud. Extraction of Pineapple Leaf Fiber and its Spinning: A Review. Textile Review. 2012.
[10] ASTM C1557-03 Standard Test Method for Tensile Strength and Young's Modulus of Fibers.