Enhancement of pulp sheet from the waste of Kluai Hin banana (*Musa sapientum Linn.*) from Yala province by using composite latex for packaging

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Abstract. Kluai Hin (*Musa sapientum Linn.*) is a famous banana planted in Thailand's Southern region provinces of Yala. This study aims to enhance pulp sheets' physical and mechanical properties from the waste of Kluai Hin by using composite latex for investigating the possibilities of Kluai Hin's pulp to be developed for commercial innovation. The chemical pulp of Kluai Hin is made by using the soda pulping process. The results showed that acceptable physical and mechanical properties of pulp were at temperature, time, and concentrations as 120°C, 120 minutes, and 30% of soda concentration, respectively. These are the most suitable conditions for obtaining paper sheets. The pulp sheet from Kluai Hin's pulp could be improved by coating with composite latex. Three formulas of composite latex coating contributed to the mechanical properties, but the third formula provided the best appearance. The elongation at break of pulp sheet coated with composite latex was greater than that of pulp sheet has non-coating up to 75 times. The good flexibility of the pulp sheet with composite latex coating demonstrated its good impact resistance. It has high flexibility, durability, water resistance, non-toxic, and environmentally friendly to the potentiality for applied as a cushioning material for packaging.

Keywords: Kluai Hin (*Musa sapientum Linn.*), soda pulping, composite latex, environmentally, packaging

1. Introduction

Banana is a tropical fruit that is economically important compared to other crops. Banana is also one of the most popular fruit due to numerous nutrients, including non-nutrients and polyphenolic compounds. Although various polyphenolic compounds are non-nutritive value, intake of fruits or vegetables rich in polyphenols may have health benefits in the long run (Tohraman *et al.*, 2018).

The banana crop produces large quantities of post-harvest biomass wastes. Currently, 37,40,096 tons of waste are dumped annually as waste from which banana fiber can be extracted. The extraction of banana fiber has already been studied that can be used in banana fiber. Anaerobic digestion of soft tissues of banana wastes separated fibers (Wobiwo *et al.*, 2017). Yilmaz *et al.* (2017) extracted fibers from fruit and bunch stems of the banana plants by water retting and showed that bunch stem fibers were superior in terms of fineness, initial modulus, and breaking strength. Ganan *et al.* (2004) extracted banana fiber from stem and bunch of banana waste by alkalization and salinization followed by mechanical treatment.

The extracted banana fiber has been studied for reinforcing material for lignocellulosic composite materials (Alavudeen *et al.*, 2015; Joseph *et al.*, 2006; Srinivasababu *et al.*, 2009), the pulp (Rahman et *al.*, 2014), cellulose microfibrils (Cherian *et al.*, 2008; Elanthikkal *et al.*, 2010). The spin ability of banana fiber, fineness, and tensile strength makes it usable in a number of different textiles with different weights and thicknesses, based on what part of the banana stem the fiber was extracted from. Enzymatic treatment of extracted banana fibers spinning showed the suitability of yarns production (Ortega *et al.*, 2016).

Thailand has a large number of different banana species. However, the distinctive type of banana known as "Kluai Hin" originated in Yala, Thailand's southern province. Kluai Hin is a species of the *Musa genus*, which belongs to the *Sapientum* family. Kluai Hin is a type of banana that, similar to Kluay Nam Wa, has a nutty flavor when boiled or glazed (Tohraman *et al.*, 2018; Utaipan *et al*., 2018).

Furthermore, the chemical composition in the Kluai Hin banana (*Musa sapientum Linn*.) has never been studied before.

Kluai Hin is a favorite product of Yala province with numerous demands from consumers. Kluai Hin can be manufactured into other high-value products, help local farmers to earn around 40-41 million THB per year (Utaipan *et al*., 2018).

However, no studies have found that waste from Kluai Hin is used to produce handmade paper or packaging. Therefore, the researcher team was interested in transforming the waste of Kluai Hin to the pulp sheet in different patterns that might encourage a Thai farmer in the community to produce a handmade product to economic crop in general and sustainable.

Most of this research has been measured the mechanical properties of Kluai Hin's pulp under optimal conditions and producing the pulp sheet from Kluai Hin for the paper package. Kluai Hin's chemical pulp was made as a raw material for pulp sheets by the soda pulping process. Kluai Hin's pulp sheets were coated with composite latex to improve their mechanical properties.

2. Objectives

1. To study and select the optimal conditions for producing pulp sheets of pulp from Kluai Hin by the soda pulping process.
2. To enhance Kluai Hin's pulp sheet production process by using composite latex, an environmentally friendly biomaterial.

3. Research Methodology

3.1 Raw material and chemical analysis

The waste of Kluai Hin (*Musa sapientum Linn*.) (WKH) was used as raw material for the preparation of banana pulp obtained from the banana plantation in Yala, Thailand. NaOH was purchased from Merck, Germany and other chemicals were purchased from L.B. Science Limited Partnership, Songkhla, Thailand.

Chemical composition of WKH was analyzed such as cellulose (Applied from Van Soest and Wine, 1967), lignin (Applied from Van Soest and Wine, 1967), ash (TAPPI T211 om-85), moisture content (TAPPI T264), pentosans (TAPPI T223 om-84), solvent extractive of wood (TAPPI T204 om-88), solubility in hot and cold water (TAPPI T207 om-88) and solubility in 1% NaOH (TAPPI T212 om-88).

3.2 Preparation of pulp sheet from the waste of Kluai Hin by the soda pulping process

The waste of Kluai Hin (WKH) was cleaned with water at least 5 times before chopped into small pieces, and then dried in a hot air oven for at least 72 hours. The WKH with 20% and 30% NaOH solution (1:15 w/v) was cooked at 120ºC for 120 minutes. After cooling, the fibers were separated by a wire mesh test sieve. The screened pulp yield of soda pulping was calculated and then the pulp sheets were made by a laboratory papermaking machine at a final grammage of 140 g/m^2.

3.3 Preparation of pulp sheet coated with composite latex

The composite latex was prepared by mixing SBR rubber with 50% of china clay and 50% of wood resin for 30 minutes after that added 50% of sulphur dispersion and then stirred for 30 minutes.

The Kluai Hin's pulp sheets, grammage of 320 g/m^2 and dipped to the composite latex for 30, 60 and 90 seconds. They were cured at room temperature (25-27ºC) and dried in hot air oven at 105ºC for 5 minutes. Physical and mechanical properties of coated and uncoated specimens were investigated. Ten specimens were used for testing of tensile strength test (TAPPI T494 om-88), and elongation test (TAPPI T403 om-91).

3.4 Statistical data analysis

All mechanical properties of Kluai Hin's pulp sheets were determined at least six replicates. The mean and standard deviations were calculated and reported. Analysis of variance (ANOVA) was operated by using Duncan's new multiple range test (DMRT) to decide the significant differences of Kluai Hin's pulp sheets properties. All significant values were expressed at 95% confidence level.

4. **Result and Discussion**

4.1 Raw material and chemical analysis

The chemical composition of WKH and compared with other fiber sources, as shown in Table 1.

Table 1: Some chemical composition of WKH and other fibers. (% base on dry weight)

Items	WKH	Rice straw (Wannapeera *et al.*, 2008)	Bamboo (Sharma *et al.*, 2015)	OPEFB (Sathawong *et al.*, 2018)	Wheat straw (Jiménez *et al.*, 2006)
Moisture	8.06	5.32	5.63	4.86	8.57
Ash	1.12	16.61	2.61	5.12	7.22
Cold water solubility	11.41	10.74	3.74	14.35	11.44
Hot water solubility	21.05	16.23	6.68	19.80	13.80
1% soda solubility	39.85	41.22	24.70	42.40	30.04
Cellulose	58.11	48.25	47.67	34.62	59.04
Lignin	4.62	17.27	23.97	25.10	18.94
Pentosan	6.32	-	-	12.18	20.48
Ethanol-benzene extractables	6.28	-	-	3.76	11.49

Table 1 demonstrated the chemical composition of WKH compared to those previously obtained for rice straw, bamboo, and various nonwood raw materials (viz. OPEFB, and wheat straw) (Jiménez *et al.*, 2006; Sathawong *et al.*, 2018). The moisture content of WKH was higher than rice straw, bamboo, and OPEFB but lower than wheat straw. The ash content was lower than those of the other raw materials. The ash contents of the nonwood fiber were still high for industrial processing, especially given higher ash than in wood. The nonwood fibers generally have higher silicon, nutrient, and hemicelluloses contents than wood fibers (Hunter, 1988). Hot and cold water solubility materials of WKH were higher than rice straw and bamboo. Both hot and cold water for those of the other raw materials suggested higher contents of inorganic compounds, tannins, gums, sugars, coloring matter, or starches in the sample.

Wood and nonwood fibers were extracted with 1% sodium hydroxide solution for 1 hour. Alkali solution removes low molecular weight carbohydrates in pulps. The solubility of WKH in the alkali solution was similar to rice straw and OPEFB but higher than bamboo and wheat straw. The solubility of fibers indicates an extent of cellulose degradation during pulping processes, and it has been related to the strength and other properties of pulps.

The solubility of WKH in ethanol-benzene solutions was 6.28% d.b., lower than wheat straw but it was higher than OPEFB. The solubility of fibers in ethanol-benzene solution indicates an extractable content of wood consists of certain other dichloromethane-insoluble components, such as low molecular-weight carbohydrates, salts, waxes, fats, resins, non-volatile hydrocarbons during pulping processes. The cellulose of WKH was slightly high compared to other raw materials. Cellulosic fibers have various features which fulfill the requirement of papermaking for paper manufactures.

Lignin contents of WKH were lower than those of the other raw materials. Lignin is one of the main components of wood cell walls and it has a critical effect on the mechanical properties of paper pulp and wood fiber-based composites.

The pentosans content of WKH was 6.32%. It was lower than wheat straw and OPEFB. The pentosans contents indicate the retention or loss of hemicelluloses during pulping processes, and since hemicelluloses contribute to the strength of paper pulps, high pentosans content is acceptable. Frequently, pentosans content in softwood and hardwood were 6-9% and 17-25%, respectively (TAPPI, 1984).

4.2 Preparation of Kluai Hin's pulp sheets and testing to discover the optimal condition

The pulp yield and tensile strength of Kluai Hin's pulp sheets were the most important aspects of optimal pulping (shown in Figure 1 and Figure 2). The highest Kluai Hin's pulp yield was 43.43% (d.b.), which was obtained from the soda pulping condition of 30% (w/w) NaOH solution, cooking time 120 minutes, and cooking temperature of 120°C (30/120/120). Moreover, this condition contributed to the highest tensile index is illustrated in Figure 2. The tensile strength of the Kluai Hin's pulp sheets was the range of 48.71-61.82 MPa. Tensile strength is a measure of material resistance under fracture stress. It depends on the strength, length, and surface area of the fibers and the strength of bonding between them (Sathawong *et al.*, 2018, and Aisyah *et al.*, 2013). The results demonstrated a maximum the tensile strength of Kluai Hin's pulp sheets obtained from the soda pulping condition of 30% (w/w), cooking time 120 minutes, and cooking temperature of 120°C (30/120/120) was 61.82 MPa.

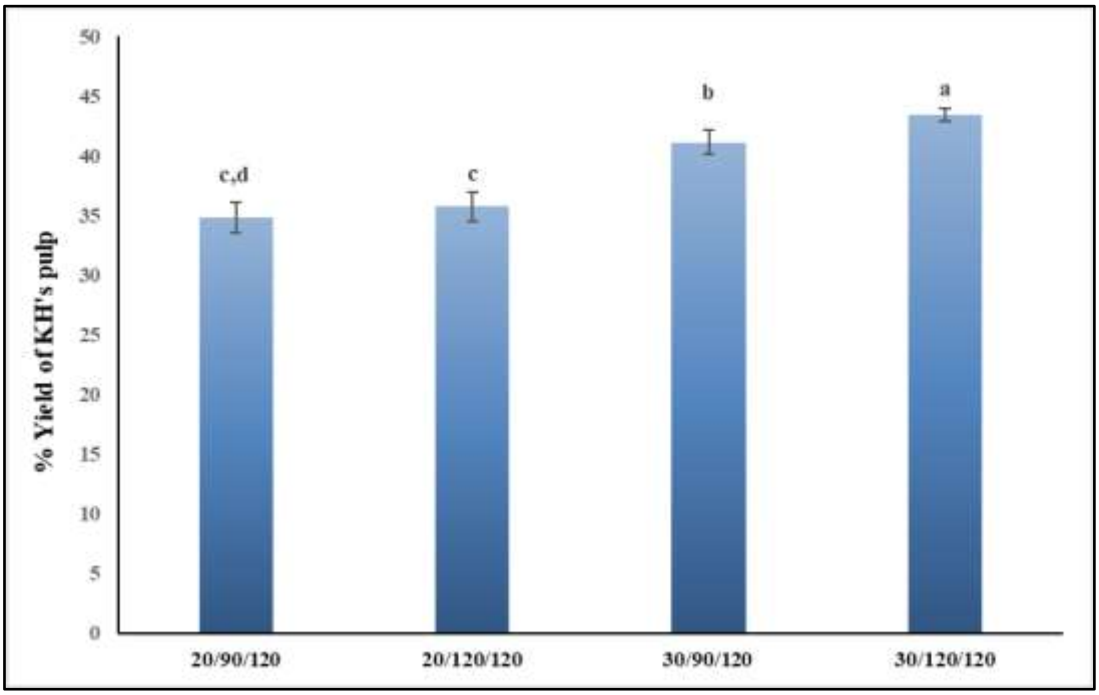

Figure 1. Pulp yields of Kluai Hin's pulp obtained from soda pulping conditions.

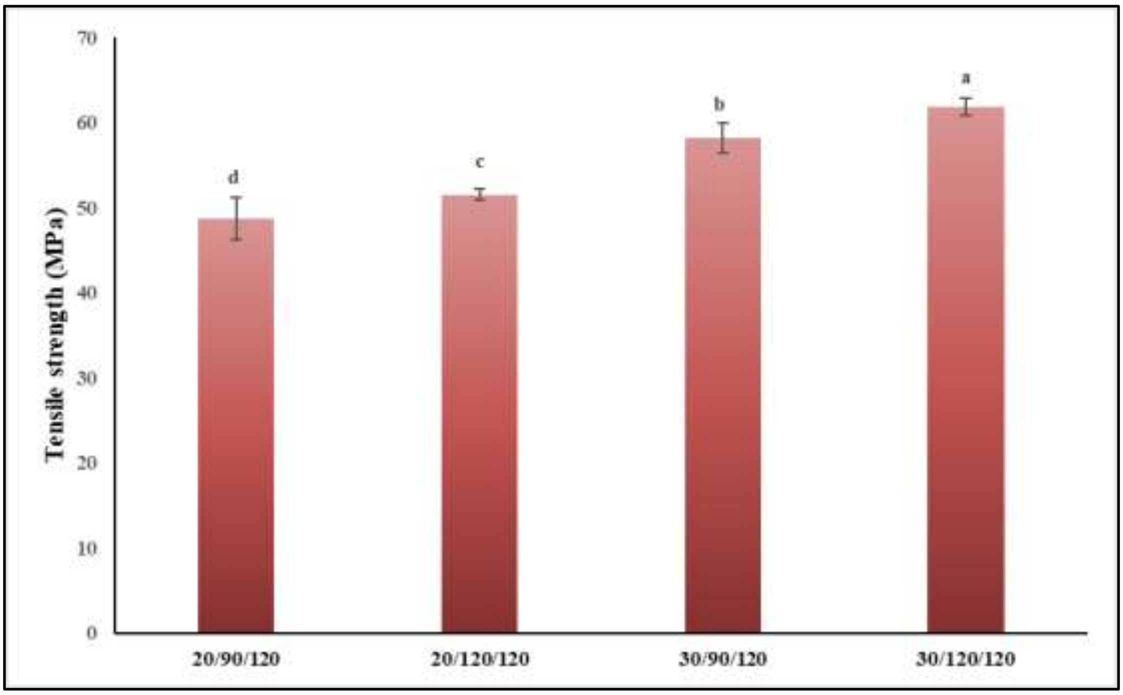

Figure 2. Tensile strength of Kluai Hin's pulp sheets obtained from soda pulping process.

The trend of the burst index (BI) was found similar to the tensile index. Burst testing is the method to evaluate the behavior of paper when the perpendicular forces to the surface. It can indicate the rupture resistance of paper materials (Sathawong *et al.*, 2018). The Kluai Hin's pulp sheets of the soda pulping condition of 30% (w/w) NaOH solution, cooking time 120 minutes, and cooking temperature of 120°C (30/120/120) revealed the greatest burst index (BI) of 2.02 kPa.m^2/g. Nevertheless, the results similar to that of burst index (BI) obtained from the soda pulping condition of 30% (w/w) NaOH solution, cooking time 90 minutes, and cooking temperature of 120°C (30/90/120), shown in Figure 3.

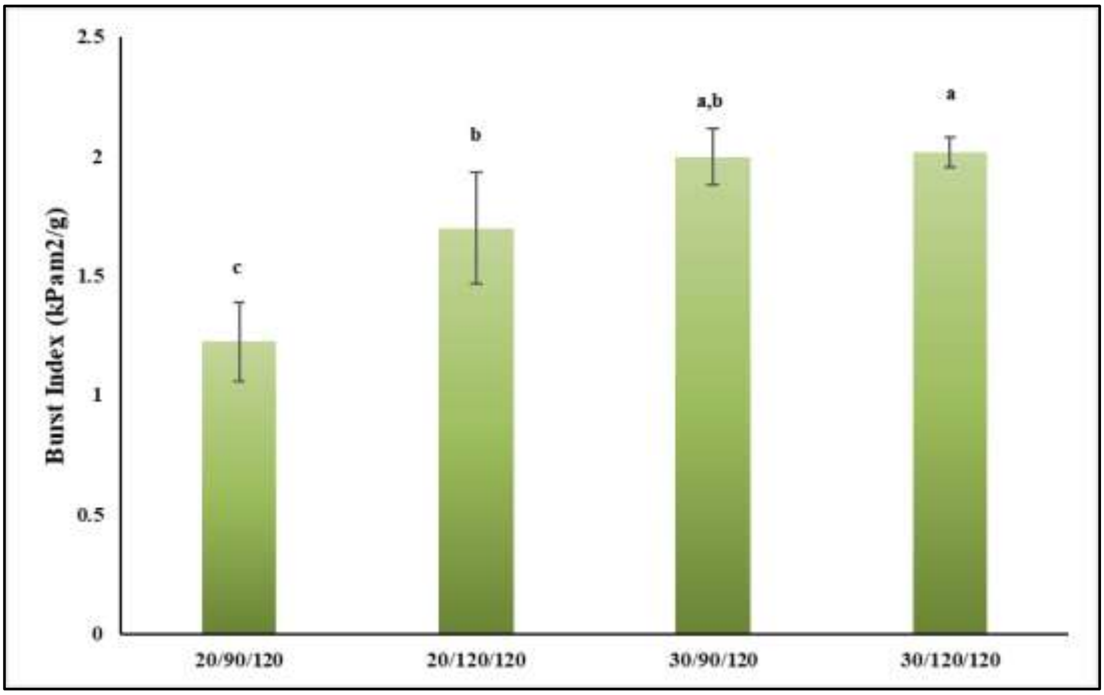

Figure 3. Burst index of Kluai Hin's pulp sheets obtained from soda pulping process.

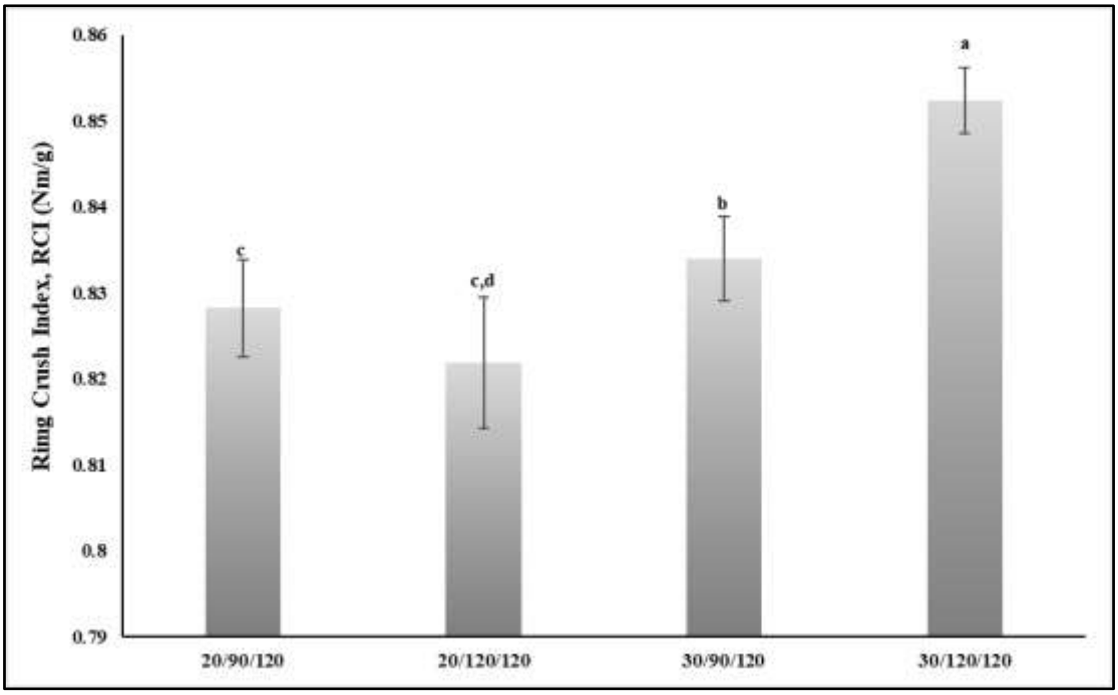

Figure 4. Ring crush index of Kluai Hin’s pulp sheets obtained from soda pulping process.

The ring crush test is a standard method of compressive strength tests of corrugated containers (Nordstrand, 2004). The strongest compressing force was produced from the soda pulping condition of % (w/w) NaOH solution, cooking time 120 minutes, and cooking temperature 120°C (30/120/120), as shown in Figure 4. They contributed the highest RCI, which was about 0.821-0.852 Nm/g. Figures 1, 2, 3, and 4 illustrates the correlation between Kluai Hin’s pulp yields and the mechanical properties of Kluai Hin’s pulp sheets obtained from the soda pulping process. The condition of 30% (w/w) NaOH solution, cooking time 120 minutes, and cooking temperature of 120°C (30/120/120) had better mechanical properties than other conditions. Therefore, it was chosen to prepare Kluai Hin's pulp sheets for coating with composite latex in the next stage.

4.3 Preparation and Testing of the coated Kluai Hin’s pulp sheets

Figure 5 illustrate the appearance of Kluai Hin's pulp sheets after being coated with the composite latex. The third composite latex formula has a better look than the others (smooth, while the others were rough). The ability of deaeration in each coating formula was different due to the amount of wood resin dispersion. The distribution of wood resin will help to increase the number of air bubbles in the latex coating. Each coating formula's wood resin dispersion is composed of bentonite, which is applied as a surfactant. Bentonite is responsible for the roughness of the coating surface.

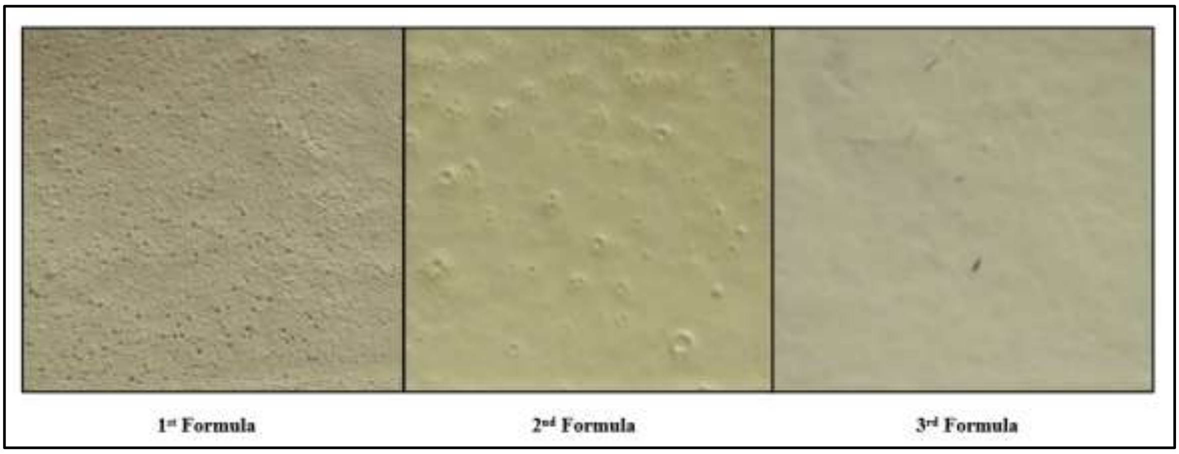

Figure 5. The appearance of Kluai Hin's pulp sheets coated with composite latex

The mechanical properties of Kluai Hin's pulp sheets, both coated and uncoated, were investigated. The tensile strength of all coated Kluai Hin's pulp sheets was lower than uncoated Kluai Hin's pulp sheets because the water content in composite latex has broken the H-bonding of the fiber network (shown in Figure 6). Furthermore, the study discovered that the tensile strength of coated Kluai Hin's pulp sheets was unaffected by various composite latex formulas or coating durations. The tensile strengths of coated Kluai Hin's pulp sheets were not considerably different due to the three composite latex formulas using the same soil level of china clay as reinforcement. The elongation at break of coated Kluai Hin's pulp sheets, on the other hand, was opposite to the tensile strength (shown in Figure 7). The Kluai Hin's pulp sheets coated had a greater elongation than the uncoated Kluai Hin's pulp sheets. The Kluai Hin's pulp sheets coated with the third formula of composite latex and 60-seconds coating duration (F3/S60) have the best elongation at a break of 220 mm. The composite latex coating provided Kluai Hin's pulp sheets elasticity and flexibility. However, the various formulas and duration of coating have not affected the elongation property of coated Kluai Hin's pulp sheets due to the same level of SBR rubber in all formulas.

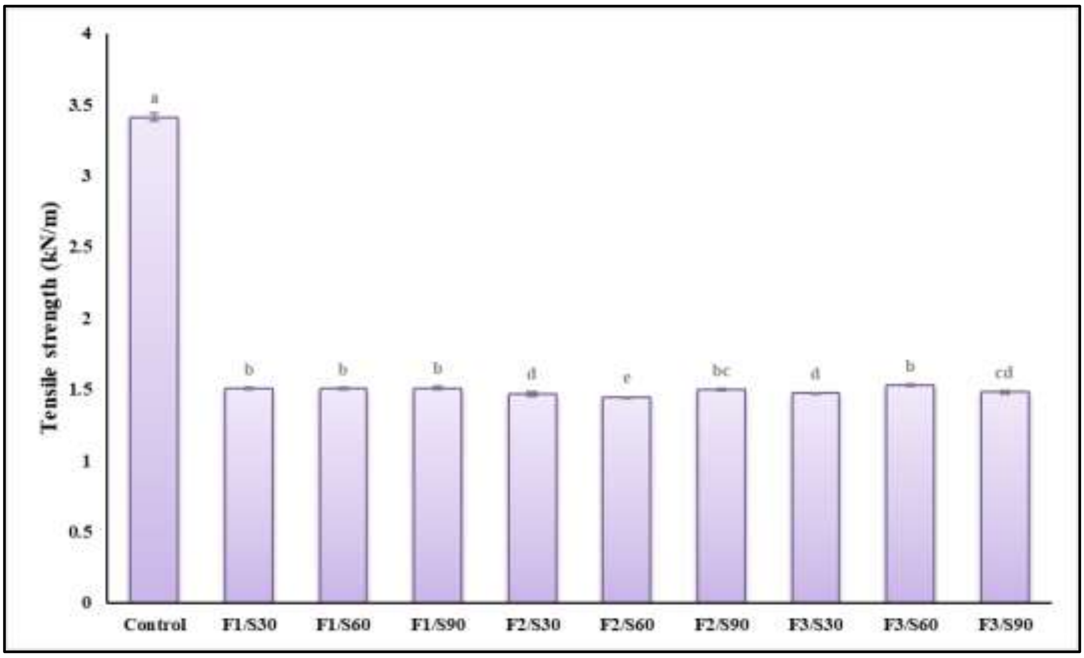

Figure 6. Tensile strength of the coated Kluai Hin's pulp sheets at different coating conditions.

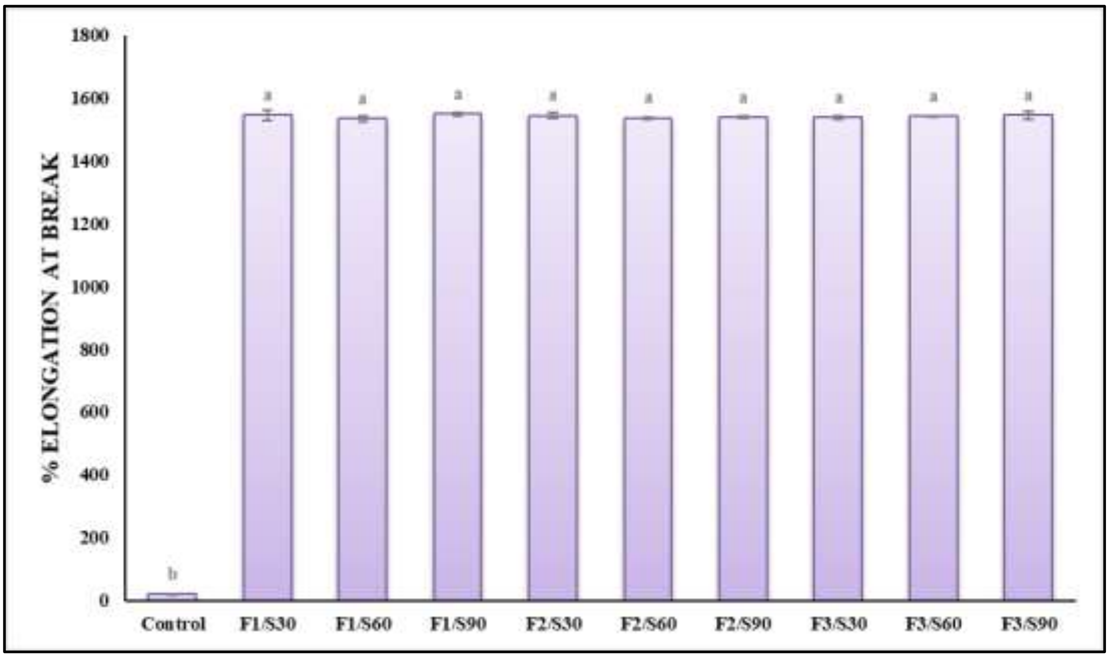

Figure 7. Elongation at break of the coated Kluai Hin's pulp sheets at different coating conditions.

5. Conclusion

Kluai Hin pulp had a high yield and good mechanical properties, according to the results. Kluai Hin achieved a pulp yield of 43.43 % (d.b.) with a soda pulping condition of 30% NaOH solution (w/w), 120 minutes cooking time, and 120°C cooking temperature. The mechanical properties of this soda pulping condition are superior to other situations.

Coating Kluai Hin's pulp sheets with composite latex could improve their mechanical properties. The appearance of the third formula, which had the least amount of wood resin, was the best. The elongations at break of Kluai Hin's pulp sheets with composite latex coating are approximately 75 times greater than those of Kluai Hin's pulp sheets without composite latex coating. The excellent resilience of pulp sheets produced of Kluai Hin's pulp with composite latex coating proved the potential for impact protection. Kluai Hin pulp can make low-cost handcrafted paper product packaging, reduce pollution, and provide rural communities jobs. It provides a perspective on potential future developments.

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References

[1] Aisyah, H.A., Peridah, M.T., Sahri, M.H., Anwar, U.M.K., & Astimar, A.A. 2013. Properties of medium density fibreboard (MDF) from kenaf (Hibiscus cannabinus L.) core as function of refining conditions. *Composites Part B: Engineering*. 44(1). pp. 592-596

[2] Alavudeen, A., Rajini, N., Karthikeyan, S., Thiruchitrambalam, M., & Venkateshwaren, N. 2015. Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: Effect of woven fabric and random orientation. *Materials & Design*. 66. pp. 246-257.

[3] Cherian, B.M., Pothan, L.A., Nguyen-Chung, T., Mennig, G., Kottaisamy, M., & Thomas, S. 2008. A novel method for the synthesis of cellulose nanofibril whiskers from banana fibers and characterization. *Journal of Agricultural and Food Chemistry*. 56(14). pp. 5617-5627.

[4] Elanthikkal, S., Gopalakrishnapanicker, U., Varghese, S., & Guthrie, J.T. 2010. Cellulose

microfibres produced from banana plant wastes: Isolation and characterization. *Carbohydrate Polymers*. 80(3). pp. 852-859.
[5] Ganan, P., Cruz, J., Garbizu, S., Arbelaiz, A., & Mondragon, I. 2004. Stem and bunch banana fibers from cultivation wastes: Effect of treatments on physico-chemical behavior. *Journal of Applied Polymer Science*. 94(4). pp. 1489-1495.
[6] Jiménez, L., Angulo, V., Ramos, E., De la Torre, M.J. & Ferrer, J.L. 2006. Comparison of various pulping processes for producing pulp from vine shoots. *Industrial Crops and Products*. 23. pp. 122-130.
[7] Hunter, A.M. 1988. Utilization of annual plants and agricultural residues for the production of pulp and paper. *Tappi pulping conf*., pp. 139-160.
[8] Nordstrand, T. 2004. Analysis and testing of corrugated board panels into the post-buckling regime. *Composite Structures*. 63(2). pp. 189-199.
[9] Ortega, Z., Morón, M., Monzón, M.D., Badalló, P., & Paz, R. 2016. Production of banana fiber yarns for technical textile reinforced composites. *Materials*. 9(5). pp. 370-377.
[10] Rahman, M.M., Islam, T., Nayeem, J., & Jahan, M. 2014. Variation of chemical and morphological properties of different parts of banana plant (*Musa paradisica*) and their effects on pulping. *International Journal of Lignocellulosic Products*. 1(2). pp. 93-103.

[11] Sathawong, S, Sridach, W., & Techato, K. 2018. Recovery of Kraft Lignin from OPEFB and Using for Lignin–Agarose Hydrogel. *Journal of Polymers and the Environment*. 26. pp. 3307–3315.
[12] Sharma, B., Gatoo, A., & Ramage, M.H. 2015. Effect of processing methods on the mechanical properties of engineered bamboo. *Construction and Building Materials*. 83. pp. 95-101.
[13] Srinivasababu, N., Rao, K.M.M., & Kumar, J.S. 2009. Experimental determination of tensile properties of okra, sisal and banana fiber reinforced polyester composites. *Indian Journal of Science and Technology*. 2(7). pp. 35-38.
[14] Tohraman, A., Bungaramphai, R., & Tongkeaw, P. 2018. Optimization of the Reversed-Phase High-Performance Liquid Chromatography Method Coupled with Diode Array Detection for Identification Polyphenols in Kluai Hin (*Musa Sapientum Linn.*). *The International Conference on Food and Applied Bioscience*. pp. 81-90.
[15] Utaipan, P., Chootong, C., & Najai, W. 2018. The Efficacy of Developed Product from KluaiHin Powder (Banana Powder) and Guidelines of Health Product Development. *Proceedings of the Universal Academic Cluster International Spring Conferences*. pp. 11-22.
[16] Wannapeera, J., Worasuwannarak, N., & Pipatmanomai, S. 2008. Product yields and characteristics of rice husk, rice straw and corncob during fast pyrolysis in a drop-tube/fixed-bed reactor. *Songklanakarin Journal os Science and Technology*. 30(3). pp. 393-404.
[17] Wobiwo, F.A., Alleluya, V.K., Emaga, T.H., Boda, M., Fokou, E., Gillet, S., Deleu, M., & Gerin, P.A. 2017. Recovery of fibers and biomethane from banana peduncles biomass through anaerobic digestion. *Energy for Sustainable Development*. (37). pp. 60-65.
[18] Yilmaz, N.D., Sulak, M., Yilmaz, K., & Khan, G.M. 2017. Effect of chemical treatments on physico-chemical properties of fibres from banana fruit and bunch stems. *Indian Journal of Fibre & Textile Research*. 42(1). pp. 111-117.