DOI: 10.19884/j.1672-5220.202412005

Utilization of Ecological Resources: Preparation and Application of Composite Paper Made from *Mikania Micrantha* and Waste Paper

LU Xinyan[1*], KAEWBUCHA Manus[1], APIWATHNASORN Chalisa[2*]
1. Chakrabongse Bhuvanarth International College of Interdisciplinary Studies, Rajamangala University of Technology Tawan-Ok, Bangkok 10400, Thailand
2. Faculty of Fine and Applied Arts, Rajamangala University of Technology Thanyaburi, Khlong Luang, Pathum Thani 12110, Thailand

Abstract: This study aims to explore the potential of using a blended pulp from *Mikania micrantha* (*M. micrantha*) and waste paper for producing composite paper. The effects of the mass ratio of *M. micrantha* stem to waste paper (MRMW), the beating time (BT), the water-to-pulp mass ratio (WPMR) and the times of pulp suspension screening (TPSS) on the paper's basic structural, optical and mechanical properties are investigated. It is found that MRMW primarily affects the grammage (mass per unit area), density, bulkness and whiteness; WPMR mainly affects the thickness and density; TPSS mainly affects the thickness and grammage. When MRMW is 3∶7, the composite paper shows higher values for thickness, grammage, density and whiteness; whereas when MRMW is 7∶3, these values are lower. Extending BT can increase paper density. The tensile strengths of all prepared samples fall in the range of 1.5 to 4.1 kN/m, indicating their excellent strength properties that meet the demands of many paper applications. The artistic bags and lampshades crafted from this composite paper exhibit a more natural texture compared to conventional packaging paper. This research demonstrates the feasibility of papermaking by using *M. micrantha*, while showcasing the potential for synergistic integration of waste resources with traditional hand papermaking techniques.

Keywords: *Mikania Micrantha* (*M. micrantha*); cellulose fiber; waste resource utilization; handmade paper; orthogonal experiment

CLC number: TB484.1 **Document code**: A

Article ID: 1672-5220(2025)03-0273-10

Open Science Identity (OSID)

0 Introduction

As global environmental issues intensify, efficient resource utilization and recycling have become crucial topics for sustainable development worldwide[1]. With the acceleration of industrialization, the overexploitation of natural resources and environmental pollution have become increasingly severe, and thus searching for sustainable resource management strategies is particularly important[2]. Against this backdrop, the management and utilization of invasive alien plants have become one of the hot research topics[3]. *Mikania Micrantha* (*M. micrantha*), a tenacious tropical vine from the Americas, has become a global nuisance with its swift growth and prolific reproduction, leading to significant ecological and economic damage[4]. This plant not only quickly covers other plants, hindering their growth, but also inhibits the growth of neighboring plants through its allelopathic effects, leading to the loss of biodiversity and a decline in ecosystem service functions[4]. Traditional control methods, such as physical removal and chemical control, are often costly and limited in effectiveness, and may also cause secondary environmental pollution[5]. In recent years, the transformation of *M. micrantha* into valuable resources, such as biomass energy and biomaterials, has become a new research direction[6]. This reuse not only mitigates the environmental harm caused by this invasive species but also supplies resources for the circular economy, yielding ecological and economic advantages.

The quest for sustainable development in the paper industry has become increasingly pressing. As a resource-intensive industry, its sustainability hinges on the sustainable sourcing of fiber raw materials. Non-wood fibers such as bamboo, wheat straw, sugarcane bagasse and reeds along with waste paper, are important sources for the paper industry[7-8] because these materials are rich in cellulose, a key component in papermaking[9]. Scholars have proved that *M. micrantha* also contains a high proportion of cellulose[10]. It is found that the cellulose mass fraction of *M. micrantha* is 56.42%[10]. Besides, it has good morphology and mechanical properties like common fibers and is suitable for manufacturing fiber-reinforced composites[10-12]. This indicates that preparing paper from *M. micrantha* stem cellulose is technically feasible. However, current research mainly focuses on its medicinal properties[13-14],

---

Received date: 2024-12-04

* Correspondence should be addressed to APIWATHNASORN Chalisa, email: chalisa_a@rmutt.ac.th; LU Xinyan, email: xinyan.lu@rmutto.ac.th

Citation: LU X Y, KAEWBUCHA M, APIWATHNASORN C. Utilization of ecological resources: preparation and application of composite paper made from *Mikania Micrantha* and waste paper [J]. *Journal of Donghua University (English Edition)*, 2025, 42(3): 273-282.

pesticidal properties[15-16] and application to dye wastewater treatment[17-19]. Studies have also investigated the application of antibacterial components from *M. micrantha* in textile spinning[20] and antibacterial finishing[21]. Nonetheless, there is a noticeable gap in research regarding the use of *M. micrantha* for papermaking.

From the perspective of papermaking technology, traditional "wet papermaking" techniques are commonly adopted in most regions worldwide. This process involves utilizing water as a medium to disperse fibers, enabling them to interweave on a screen, followed by the removal of excess water to form wet sheets that are ultimately dried to produce paper[22]. Although industrial papermaking dominates in most cases, handmade paper still maintains its vitality in specific fields due to its unique value, which is manifested in the diversity of artistic creation and the continuity of cultural traditions.

In this study, the feasibility of utilizing *M. micrantha* for papermaking is explored. Cellulose fibers are extracted from its stems and blended with waste paper to produce pulp. The pulp is then used to create paper through traditional hand papermaking techniques. Key manufacturing parameters are examined by using orthogonal experiments, and the properties of the obtained paper are tested and characterized. Finally, the potential application of the handmade composite paper is analyzed.

1 Materials and Methods

1.1 Materials

M. micrantha was gathered in Guangzhou, Guangdong Province, China. The waste paper sample was obtained by processing printed waste paper through a shredder. Other routine chemicals were obtained from Anhui Mycelium Initiating Health Technology Co., Ltd., China.

1.2 Cellulose fibers extraction of *M. micrantha* and waste paper

Upon harvesting fresh *M. micrantha*, the leaves were removed, leaving only the stems. These stems were then thoroughly washed and cut into segments of approximately 3 cm in length. They were subsequently immersed in a pot of water, to which 5% (mass fraction) sodium bicarbonate was added. This alkaline solution, in conjunction with elevated temperatures, facilitated the denaturation of soft tissues and the separation of fibers. The mixture was heated at 100 ℃ for 60 min to degrade and dissolve non-cellulosic matter. After that, the segments were taken out and subjected to multiple rinses in water to remove residual alkali. If necessary, 2% (mass fraction) citric acid was added to neutralize the solution until the pH stabilized around 7. The waste paper samples were similarly treated through alkali boiling and rinsing.

1.3 Preparation of composite paper

Traditional hand papermaking begins with the preparation of the pulp, which is thoroughly mixed with water, and filtered through a mold (wooden frame with mesh) to create a layer of randomly interwoven fibers. This layer dries naturally or through heating to form paper sheets, whose size is dictated by the wooden frame.

Figure 1 illustrates the papermaking process employed in this study.

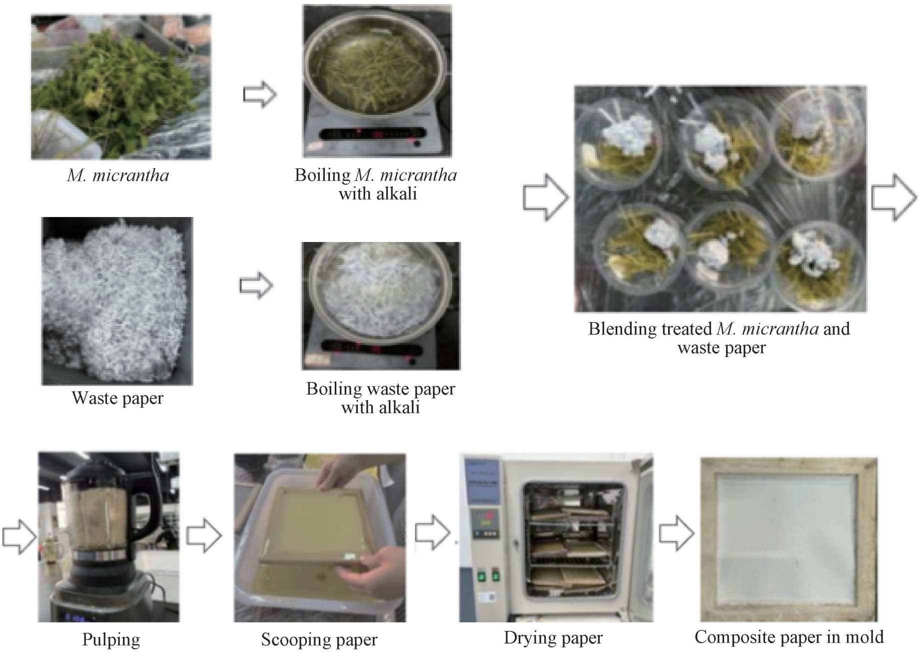


Fig. 1 Preparing process of composite paper from *M. micrantha* and waste paper

Initially, both *M. micrantha* and waste paper samples were treated as described in Section 1.2. Subsequently, these treated materials were blended in a specific mass ratio to create a uniform mixture using a high-speed blender with a 2 200 W power output and an 8 L capacity. During this stage, water was introduced at a water-to-pulp mass ratio of 200∶1. For papermaking, the paper mold was used to scoop the pulp suspension from the edge of the basin, and then moved horizontally with an outward motion to form a uniform sheet. The thickness of the composite paper was adjusted by the number of scoops, and more scoops yielded a thicker sheet. The sheets were dried in an oven at 60–70 ℃, as temperatures above this range could lead to warping. The oven drying time was adjusted based on the paper's thickness and frame size to ensure uniform drying. After complete drying, the composite paper was carefully peeled off from the mold to obtain the final product.

1.4 Orthogonal experiment

Through extensive literature review and analyses, four key factors that influence the morphology and performance of paper were identified: the mass ratio of *M. micrantha* stem to waste paper (MRMW), the beating time (BT), the water-to-pulp mass ratio (WPMR) and the times of pulp suspension screening (TPSS)[23-24]. Before determining the orthogonal experimental design, pre-experiments were conducted to determine the levels corresponding to these four factors. On this basis, the corresponding $L_9(3^4)$ orthogonal table was selected for experimental design (Table 1). The total mass of the mixed materials used for papermaking was set to 20 g, the selected sheet-forming frame size was 20 cm × 20 cm, and the size of the paper after detaching from the frame was 15 cm × 15 cm. The corresponding composite paper was named WZi, ($i = 1, 2, \cdots, 9$).

Table 1 Orthogonal experimental factor level for *M. micrantha* and waste paper composite paper

Sample	MRMW	BT/min	WPMR	TPSS
WZ1	3∶7	6	150∶1	2
WZ2	3∶7	9	200∶1	3
WZ3	3∶7	12	250∶1	4
WZ4	5∶5	6	200∶1	4
WZ5	5∶5	9	250∶1	2
WZ6	5∶5	12	150∶1	3
WZ7	7∶3	6	250∶1	3
WZ8	7∶3	9	150∶1	4
WZ9	7∶3	12	200∶1	2

1.5 Characterization and measurement of composite paper

1.5.1 Thickness, grammage, density and bulkiness

The thickness of the composite paper was determined using a fabric thickness tester (YG141D, Nantong Sansi Mechanical and Electrical Technology, China; precision: 0.01 mm). The grammage of the composite paper is its mass per unit area. The sample was cut into strips with a width of 1.5 cm and a length of 15 cm, and 10 strips were weighted by a high-precision electronic balance (Yingheng YHM, Wuxi Yingheng Electronic Co., Ltd., China). The grammage of the composite paper was calculated as

$$G = \frac{M}{A}, \tag{1}$$

where G is the paper grammage; M is the total mass; A is the total area.

The paper density reflects the compactness of its structure, influenced by factors such as fiber arrangement, internal structure and production processes. According to the specifications of GB/T 451.3—2002, the density of the sample was calculated as

$$D = \frac{G}{\delta}, \tag{2}$$

where D is the density; δ is the thickness of the paper.

Bulkiness reflects the relationship between the volume and mass of the sample and significantly influences the opacity and stiffness of the sample[26]. The paper bulkiness V was calculated as

$$V = \frac{\delta}{G}. \tag{3}$$

The five-point sampling method was used here to calculate the paper thickness, grammage, density and bulkiness, and the average value was taken.

1.5.2 Whiteness

According to GB/T 7974—2013, a whiteness meter (N-WSB-1, Shanghai Shangpu Instrumentation Equipment Co., Ltd., China) was used to measure paper whiteness. Before testing, a working standard whiteness plate (R457) with a calibration value of 79.4 was selected for calibration. Each sample was tested five times, and the average value was calculated.

1.5.3 Tensile strength

Tensile strength test was conducted according to GB/T 12914—2018. The samples with a width of 1.5 cm and a length of 15 cm were cut from the paper specimen along the longitudinal direction and transverse direction, respectively. A compression/tension testing machine (ZP-100 N, Shenzhen Aiguli Instrument Co., Ltd., China) was used to perform the tensile strength test on these samples. The tensile strengths in both directions were calculated as

$$S = \frac{F}{w}, \tag{4}$$

where S is the tensile strength; F is the measured maximum tensile force; w is the width of the sample.

1.6 Data analysis

One-way analysis of variance (ANOVA) was performed using SPSS (SPSS v. 22.0, IBM Corp., USA) to examine whether there were significant differences in the whiteness and tensile strength of the nine samples. If there were significant differences, paired samples *t*-tests were conducted to find the pairs of dependent variables that were significantly different. The significance level was set as $p<0.05$, marked as " * " in Figures.

1.7 Fabrication of artistic bag and lampshade with composite paper

To verify the aesthetic appearance of the handmade composite paper, the artistic bags and lampshades were fabricated by using WZ1 and WZ4. They were cut into the designed patterns for the bags and lampshades via laser cutting, and then the bags and lampshades were manually assembled.

The dyed paper samples were made following the process similar to that shown in Fig. 1. The main difference was that the dye solution replaced water during the pulping process. To prepare the dye solution, 500 g sappan wood was added to 5 000 mL water and the mixture was heated by using an electric induction cooker until it reached the boiling point. The temperature was then maintained at 90 ℃ for 90 min. After heating, the solution was cooled to room temperature and was used to replace water during the pulping process. The resulting red-dyed pulp was thoroughly mixed and transferred to the papermaking basin containing a 3% (mass fraction) alum solution, in which it was soaked for 30 min to promote color fixation and enhance dye adhesion. Finally, the dyed pulp was used to sheet formation and produce the dyed paper samples.

2 Results and Discussion

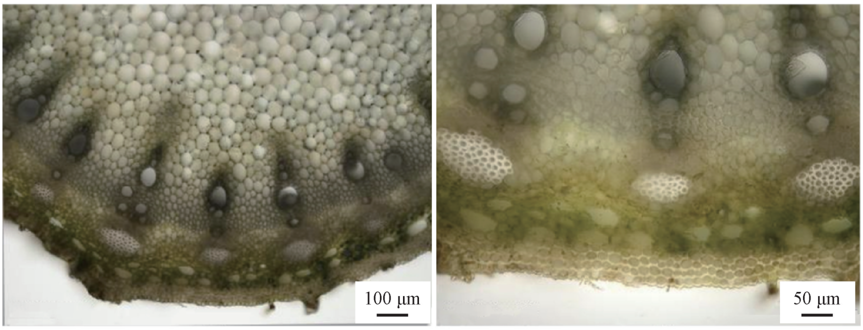
2.1 Morphology of *M. micrantha*

M. micrantha was harvested during the periods optimal for high-quality cellulose[25] to ensure the natural properties and integrity of cellulose fibers. Figure 2 shows the images of the freshly collected *M. micrantha*.


(a) (b)

Fig. 2 Photographs of *M. micrantha*: (a) full view; (b) stem sample

The cross-section of the stem from *M. micrantha*, measuring 0.02 mm in thickness, was examined by using an Olympus BX 53 fluorescent microscope at magnifications of 10 and 20. The resulting morphology is depicted in Fig. 3. The findings reveal that the cellulose fibers in *M. micrantha* are concentrated in distinct bundles and are present in significant quantities.



(a) (b)

Fig. 3 Cross-section image of stem from *M. micrantha* at two different magnifications: (a) 10; (b) 20

2.2 Thickness, grammage, density and bulkiness of composite paper

Figure 4 presents the images of the nine prepared composite paper samples.

Figure 5 presents the thickness, grammage, density and bulkiness of composite paper samples. Table 2 shows the range analysis results of the experimental data. It can be observed that paper thickness is primarily related to TPSS, followed by WPMR and MRMW, while BT has the least significant effect. The grammage of the paper is most closely related to MRMW, followed by TPSS and WPMR, with BT having the least significant impact. Paper density and bulkiness are most influenced by MRMW, followed by BT and WPMR, while the TPSS has a relatively minor influence.

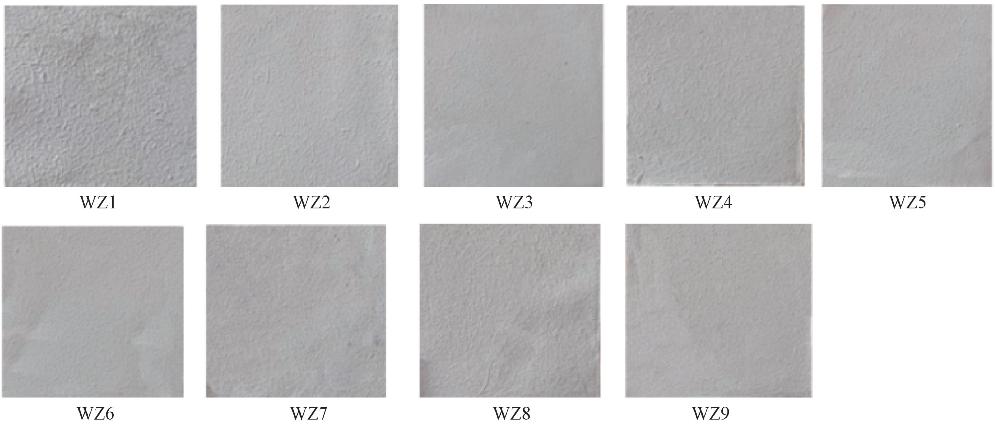
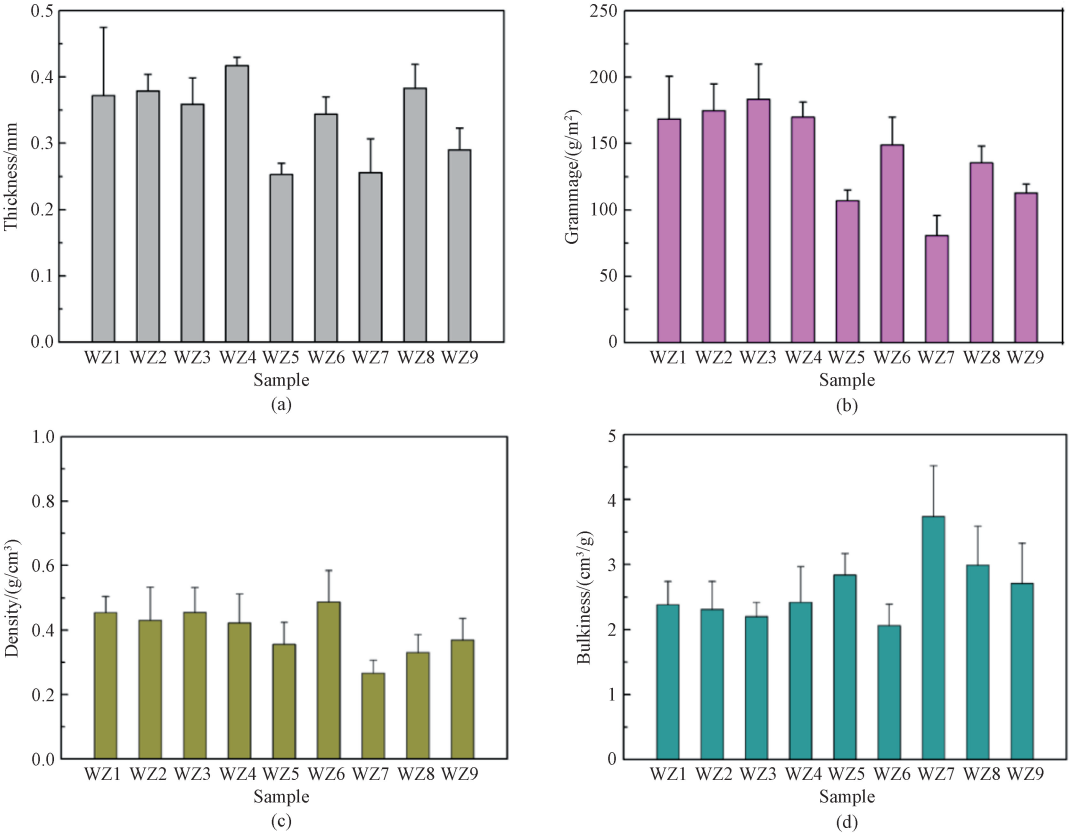


Fig. 4 Nine composite paper samples



(a)

(b)

(c)

(d)

Fig. 5 Properties of composite paper: (a) thickness; (b) grammage; (c) density; (d) bulkiness

The greater paper thickness, higher grammage and density occur when MRMW is 3∶7, while the lower values are observed at a ratio of 7∶3. This suggests that increasing the mass ratio of waste paper can enhance paper thickness, grammage and density. This is likely due to the fact that *M. micrantha* fibers are relatively coarse and long[9-11], whereas waste paper fibers are finer and shorter[24]. As a result, an increase in the mass fraction of waste paper leads to an increase in these paper properties. Prolonging BT increases the paper density, possibly because the extended BT makes the pulp finer and more uniform, thereby enhancing the paper density. A decrease in WPMR also increases paper thickness, grammage and density as a higher pulp mass fraction leads to an increase in these properties. An increase in TPSS primarily increases paper thickness and grammage, as it results in the increased material accumulation.

Table 2 Range analysis of thickness, grammage, density and bulkiness results

Factor	Thickness/mm				Grammage/(g/m^2)			
	k_1	k_2	k_3	R	k_1	k_2	k_3	R
MRMW	0.369	0.333	0.305	0.064	174.820	140.740	108.150	66.670
BT	0.347	0.334	0.327	0.020	139.260	137.780	146.670	8.889
WPMR	0.360	0.359	0.286	0.074	149.630	151.110	122.960	28.150
TPSS	0.301	0.324	0.383	0.082	128.890	133.330	161.480	32.592

Factor	Density/(g/cm^3)				Bulkiness/(cm^3/g)			
	k_1	k_2	k_3	R	k_1	k_2	k_3	R
MRMW	0.447	0.422	0.323	0.124	2.290	2.408	3.150	0.860
BT	0.381	0.374	0.438	0.064	2.828	2.707	2.314	0.515
WPMR	0.425	0.408	0.360	0.066	2.473	2.461	2.916	0.455
TPSS	0.393	0.396	0.404	0.010	2.627	2.700	2.522	0.178

Notes: k_1, k_2 and k_3 are the average values of level 1, 2 and 3, respectively, under a certain factor; R is the range analysis results.

2.3 Whiteness of composite paper

Figure 6 presents the whiteness of nine composite paper samples. Table 3 shows the results of the variance analysis. The results indicate that the MRMW has a significant impact on the whiteness ($p < 0.05$), while other factors such as WPMR, BT and TPSS have insignificant effects on the whiteness ($p > 0.05$).

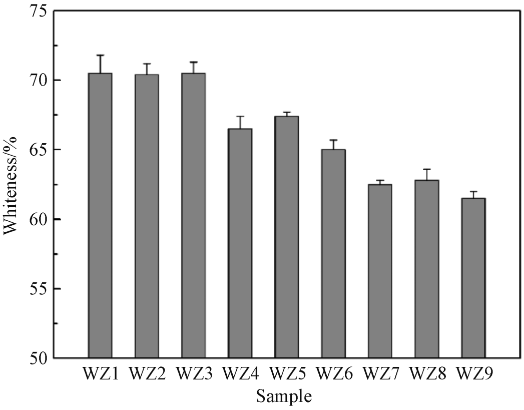


Fig. 6 Whiteness of samples

Table 3 ANOVA results of whiteness of samples

Factor	Square sum	Freedom	Mean square	F	p
MRMW	500.65	2	250.33	538	0.000
BT	9.42	2	4.71	0.39	0.681
WPMR	2.31	2	1.15	0.09	0.911
TPSS	3.34	2	1.67	0.14	0.873

Note: the value of 0.000 is approaching zero, but not zero.

Figure 7 displays the whiteness values of the nine samples at different mass ratios of *M. micrantha* stem to waste paper (MRMWs). There are significant differences in the whiteness among the samples at the three MRMWs ($p < 0.05$). Specifically, the whiteness is the highest when MRMW is 3∶7, followed by 5∶5, and lowest at 7∶3. This suggests that as the mass fraction of *M. micrantha* increases, the whiteness decreases. This is because *M. micrantha* contains chlorophyll, which lowers the whiteness of the prepared composite paper. In practical applications, the natural color of *M. micrantha* adds visual aesthetics to the paper, making it more suitable for artistic creations.

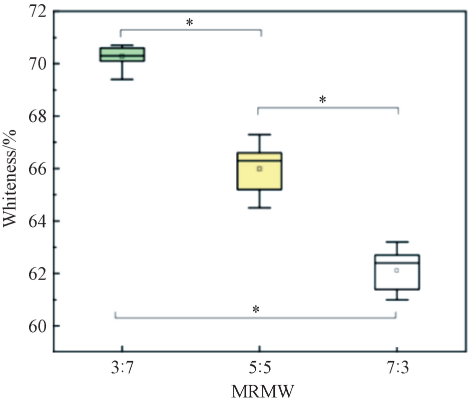


Fig. 7 Whiteness of composite paper samples at different MRMWs

2.4 Analysis of tensile strength

Figure 8 presents the tensile strength for nine composite paper samples. It can be observed that the longitudinal tensile strengths of most samples are higher than their transverse tensile strengths ($p < 0.05$). This occurs primarily because the pulp is filtered and formed into paper in the longitudinal direction, resulting in a relatively high density in this direction compared to that in the transverse direction. Additionally, the tensile strengths of all samples fall in the range of 1.5 to 4.1 kN/m. This range of the tensile strength is sufficient to meet the requirements of writing and printing, ensuring that the paper is resistant to normal tearing or damage during use.

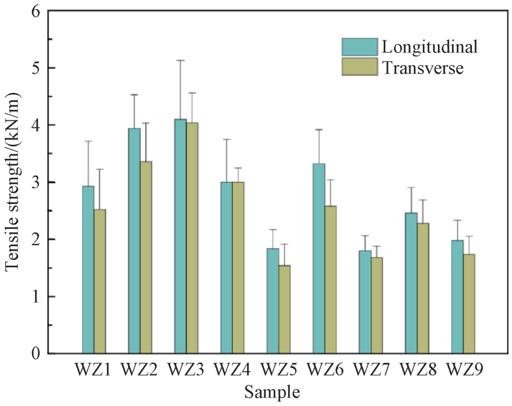


Fig. 8 Tensile strengths of composite paper samples

Table 4 presents the results of the variance analysis on the influence of various factors on the tensile strength of paper (the average of the longitudinal and transverse tensile strengths). MRMW has a significant effect on the tensile strength ($p<0.05$), while WPMR and TPSS have insignificant effects on the tensile strength ($p > 0.05$).

Table 4 ANOVA results of tensile strength of samples

Factor	Square sum	Freedom	Mean square	F	p
MRMW	4.034	2	2.017	5.486	0.044
BT	0.392	2	0.196	0.201	0.823
WPMR	0.293	2	0.146	0.148	0.866
TPSS	1.453	2	0.726	0.910	0.452

Figure 9 illustrates the tensile strengths of composite paper samples at different MRMWs. It can be observed that the tensile strength of the paper at an MRMW of 3∶7 is significantly higher than that at MRMWs of 5∶5 and 7∶3 ($p < 0.05$), while there is no significant difference in the tensile strength between the paper at MRMW of 5∶5 and 7∶3 ($p > 0.05$). This suggests that as the mass fraction of *M. micrantha* increases, the tensile strength of the paper decreases. Conversely, a higher mass fraction of waste paper results in higher tensile strength. This is because when MRMW is 3∶7, the paper has a greater grammage and density, which enhances its tensile strength. Additionally, the fiber length of *M. micrantha* is around 20 mm[10], whereas the wood pulp fibers used in conventional papermaking are typically 1–2 mm long. Longer fibers tend to form a loose arrangement during the flow and settlement of the pulp, resulting in more voids in the paper structure and consequently lower tensile strengths. Furthermore, there are numerous hydrogen bonds between the cellulose molecules in the waste paper fibers. Especially in the waste paper pulp, water molecules interact with the cellulose hydrogen bonds, causing the molecular chains to arrange more closely[26], thereby enhancing the intermolecular compactness.

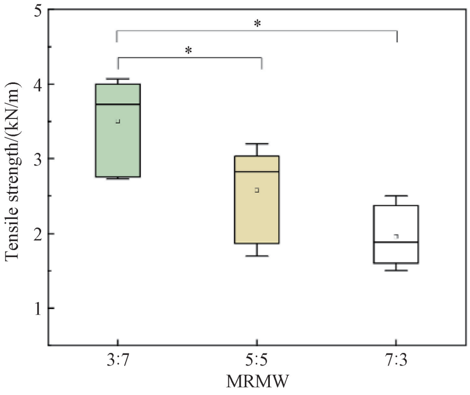
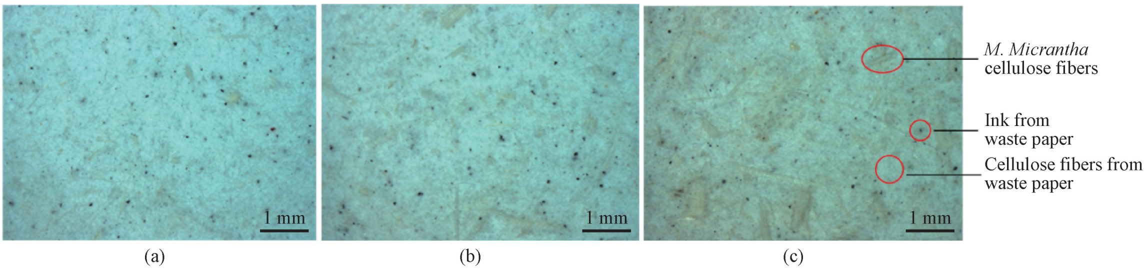


Fig. 9 Tensile strengths of composite paper samples at different MRMWs

2.5 Microscopic observation of samples

To further investigate the microscopic morphological structure of the composite paper, samples were observed by using a stereo microscope (ZEISS Stemi 2000-C, Photometrics Ltd., USA). This allowed for the observation of the distribution of *M. micrantha* cellulose fibers, waste paper cellulose fibers, and ink on the composite paper samples at different MRMWs. Figure 10 shows the microscopic morphological structures of WZ1, WZ5 and WZ7. It is evident that the *M. micrantha* cellulose fibers are coarse and long, while the waste paper cellulose fibers are finer and shorter.



(a) (b) (c)

Fig. 10 Microscopic morphological structure of different samples: (a) WZ1; (b) WZ5; (c) WZ7

Simultaneously, the distribution of different components in the composite paper was measured by using the above microscope. The principle behind this measurement is the utilization of different absorption characteristics of different materials towards various wavelengths. The optical density images shown in Fig. 11 reveal that as the mass fraction of *M. micrantha* fibers increases, the structure became looser, with fewer interlacing between the fibers. These characteristics result in lower density, higher bulkiness and reduced tensile strength when the mass fraction of *M. micrantha* fibers are high.

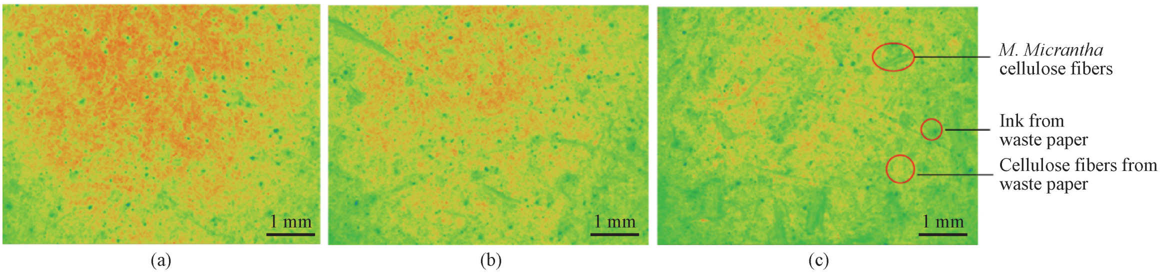


Fig. 11 Optical density images of different samples: (a) WZ1; (b) WZ5; (c) WZ7

2.6 Application of handmade composite paper

Figure 12 shows the bag and lampshade crafted from WZ1 and WZ4 respectively, which were made by preparing colored composite paper, cutting and hand-shaping. Compared to common packaging paper, the handmade composite paper provides a more natural texture, resulting in vibrant colors and fine details. Additionally, its eco-friendly nature and durability make it an excellent choice for artistic expression. The integration of *M. micrantha* into handmade composite paper enables a variety of sustainable and ecologically friendly applications. It can be applied in furniture decoration, lighting fixtures and cultural products, offering a unique aesthetic appeal and connection to tradition.

(a) (b)

Fig. 12 Bag and lampshade crafted from WZ1 and WZ4: (a) application of WZ1 on bag; (b) application of WZ4 on lampshade

While *M. Micrantha* handmade paper offers a wide range of applications, it is essential to take specific precautions to ensure its longevity and safety. The paper's flammability necessitates adherence to stringent fire prevention protocols, especially in applications where it encounters heat sources or open flames. To extend its utility in various settings, waterproofing treatments may be required, as the paper's natural fibers are not inherently resistant to water damage. Additionally, the delicate nature of the handmade paper demands careful handling to prevent mechanical damage, such as tearing or creasing, which can compromise its structural integrity and aesthetic appeal.

3 Conclusions

This study explores sustainable ecological waste treatment and resource utilization by conducting papermaking experiments with composite pulp of *M. micrantha* and waste paper. Using orthogonal experimental methods, the research systematically assessed the impact of four key factors, i. e., MRMW, BT, WPMR and TPSS, on the basic structural, optical and mechanical properties of the composite paper. The results demonstrate that MRMW significantly affects paper grammage, density, bulkiness and whiteness. An MRMW of 3∶7 produces higher thickness, grammage, density and whiteness, while an MRMW of 7∶3 yields lower values for these parameters. Increasing BT can enhance the paper's density. The paper with an MRMW of 3∶7 exhibits the highest whiteness. Regarding mechanical properties, the tensile strengths of all prepared samples fall in the range of 1.5 to 4.1 kN/m, indicating their excellent strength properties. This study demonstrates the feasibility of sustainable ecological papermaking with *M. micrantha* and provides a basis for optimizing papermaking process parameters.

References

[1] CHENG C B, AHMAD S F, IRSHAD M, et al. Impact of green process innovation and productivity on sustainability: the moderating role

of environmental awareness[J]. *Sustainability*, 2023, 15(17): 12945.

[2] HERMAWAN A N, MASUDIN I, ZULFIKARIJAH F, et al. The effect of sustainable manufacturing on environmental performance through government regulation and eco-innovation [J]. *International Journal of Industrial Engineering and Operations Management*, 2024, 6(4): 299-325.

[3] VRABIČ-BRODNJAK U, MOŽINA K. Invasive alien plant species for use in paper and packaging materials[J]. *Fibers*, 2022, 10(11): 94.

[4] ZHOU S, WANG M, YUAN L L, et al. Local grasses for the control of the invasive vine *Mikania micrantha* [J]. *Journal of Plant Ecology*, 2022, 15(4): 844-853.

[5] UDDIN M N, MOHEBBULLAH M, ISLAM S M, et al. Preparation and characterization of *Mikania micrantha* (MM)/chitosan (CS) nanocomposites with polyvinyl alcohol (PVA) back layer[J]. *Journal of Sol-Gel Science and Technology*, 2023, 108(1): 84-97.

[6] BORA A R, BABU D S, CHETRY S, et al. Management options of *Mikania micrantha*: a review [J]. *Agricultural Reviews*, 2023, 44: 393-396.

[7] ABD EL-SAYED E S, EL-SAKHAWY M, EL-SAKHAWY M A. Non-wood fibers as raw material for pulp and paper industry[J]. *Nordic Pulp & Paper Research Journal*, 2020, 35(2): 215-230.

[8] ZHU B J, LI Z, CHEN S Y, et al. Bacterial cellulose nanofibers as reinforcement for preparation of bamboo pulp based composite paper [J]. *Journal of Donghua University (English Edition)*, 2023, 40(3): 247-254.

[9] YANG G H, MA G G, HE M, et al. Application of cellulose nanofibril as a wet-end additive in papermaking: a brief review [J]. *Paper and Biomaterials*, 2020, 5(2): 76-84.

[10] KARIM F E, ISLAM M R, AHMED R, et al. Extraction and characterization of a newly developed cellulose enriched sustainable natural fiber from the epidermis of *Mikania micrantha* [J]. *Heliyon*, 2023, 9(9): e19360.

[11] LIM C J, ARUMUGAM M, LIM C K, et al. Mercerizing extraction and physicochemical characterizations of lignocellulosic fiber from the leaf waste of *Mikania micrantha* kunth ex H. B. K [J]. *Journal of Natural Fibers*, 2020, 17(5): 726-737.

[12] VIJAYAN S, JOY C M. Properties of natural fibers separated from *Chromolaena odorata* and *Mikania micrantha* [J]. *Journal of Natural Fibers*, 2018, 15(3): 396-405.

[13] MA Q, WANG Z G, YANG X, et al. Study on chemical composition and antibacterial activity of the leaves of *Mikania micrantha* H. B. K[J]. *Natural Product Research and Development*, 2020, 32(12): 2061-2065. (in Chinese)

[14] SHEAM M, HAQUE Z, NAIN Z. Towards the antimicrobial, therapeutic and invasive properties of *Mikania micrantha* Knuth: a brief overview [J]. *Journal of Advanced Biotechnology and Experimental Therapeutics*, 2020, 3(2): 92.

[15] DAS G, FARHAN M, SINHA S, et al. *Mikania micrantha* extract enhances cutaneous wound healing activity through the activation of FAK/Akt/mTOR cell signaling pathway[J]. *Injury*, 2023, 54(8): 110856.

[16] SAIKIA S, TAMULI K J, NARZARY B, et al. Chemical characterization, antimicrobial activity, and cytotoxic activity of *Mikania micrantha* Kunth flower essential oil from North East India [J]. *Chemical Papers*, 2020, 74(8): 2515-2528.

[17] INDRAYANI Y, ALKHADI A. Activity of *Mikania micrantha* leaf extract against subterranian termite and wood decay[J]. *Berkala Penelitian Hayati*, 2021, 26(2): 53-59.

[18] AL MAHMOOD A, BIN SYED S, HASAN Z, et al. Structural, morphological, optical, and antimicrobial study of *Mikania micrantha* (leaf) extract treated zinc doped cobalt ferrite nanoparticles and antibacterial clothing applications [J]. *Results in Surfaces and Interfaces*, 2024, 17: 100303.

[19] YANG X Z, DUAN C L, TIAN X J, et al. Study on absorption of methylene blue by *Mikania micrantha* [J]. *Journal of Weed Science*, 2016, 34(4): 12-17. (in Chinese)

[20] ISLAM M A, BEGUM H A, SHAHID M A, et al. Antibacterial electrospun nanofibers from poly (vinyl alcohol) and *Mikania micrantha* with augmented moisture properties: formation and evaluation [J]. *The Journal of the Textile Institute*, 2021, 112(10): 1602-1610.

[21] NEOG R, KOLA N. An *in vitro* analysis of antibacterial property of *Mikania micrantha* leaves extract as a textile finish with crosslinking agent and its washing efficacy [J]. *Fibers and Polymers*, 2024, 25(7): 2569-2583.

[22] WANG C C. Preparation of micro/nanocellulose pretreated with NMMO and its application in papermaking [D]. Guangzhou: South China University of Technology, 2017. (in Chinese)

[23] ZHAO X D. A Research on impact of waste paper recycling and utilization to Chinese papermaking industry [D]. Beijing: Beijing Forestry University, 2020. (in Chinese)

[24] HE B H. Principle and engineering of papermaking [M]. Beijing: China Light Industry Press, 2010. (in Chinese)

[25] DAY M D, CLEMENTS D R, GILE C, et al.

Biology and impacts of Pacific islands invasive species. 13. *Mikania micrantha* Kunth (Asteraceae) [J]. *Pacific Science*, 2016, 70 (3): 257-285.

[26] PRIETO-GARCÍA F, JIMÉNEZ-MUÑOZ E, OTILIO A, et al. Obtaining and optimization of cellulose pulp from leaves of *agave tequilana* weber var. *blue*. Preparation of handmade craft paper [J]. *Waste and Biomass Valorization*, 2019, 10(8): 2379-2395.

生态资源利用：基于薇甘菊与废纸制备复合纸及其应用

卢新燕[1*], KAEWBUCHA Manus[1], APIWATHNASORN Chalisa[2*]

1. 东方皇家理工大学 国际跨学科研究学院，曼谷 10400，泰国
2. 塔亚武里皇家理工大学 美术与应用艺术学院，空銮县，巴吞他尼府 12110，泰国

摘　要：该研究旨在探索薇甘菊（*M. micrantha*）和废纸复合纸浆在手工造纸中的潜力。研究了薇甘菊杆与废纸质量比（MRMW）、打浆时间、水与浆的质量比（WPMR）及浆液抄纸次数（TPSS）对纸张基本结构、光学和力学性能的影响。研究发现，MRMW 主要影响复合纸的定量（单位面积质量）、密度、蓬松度及白度；WPMR 主要影响复合纸的厚度和密度；TPSS 主要影响复合纸的厚度和定量。当 MRMW 为 3∶7时，复合纸的厚度、定量、密度和白度值较高；MRMW 为 7∶3时，这些性能值较低。延长打击时间可提高纸张密度。所制备样品的抗张强度为 1.5~4.1 kN/m，表明其具备优良的强度特性，可满足多种纸张应用需求。相比传统包装纸，用这种复合纸制作的艺术包和灯罩具有更自然的质感。研究证实了利用薇甘菊造纸是可行的，体现了废弃资源与传统手工造纸技术协同整合的潜力。

关键词：薇甘菊；纤维素纤维；废弃资源利用；手工造纸；正交试验