WOOD RESEARCH doi.org/10.37763/wr.1336-4561/70.2.273285
e-ISSN 2729-8906
70(2): 2025 273-285 pp.

PREPARATION OF ECO-FRIENDLY COMPOSITE PAPER WITH GINKGO LEAF AND BIO-BASED FIBERS

ZIXING MA, MENG ZHOU, YANGYI WANG, QIYUE WANG, HELAN XU, XIULIANG HOU
JIANGNAN UNIVERSITY
CHINA

(RECEIVED FEBRUARY 2025)

ABSTRACT

Ginkgo leaf was treated with deep eutectic solvents and then mixed with bio-based fibers, willow catkins or kapok fibers as reinforcing materials to prepare *ginkgo leaf* composite paper. The effects of the papermaking process conditions and the proportion of *ginkgo leaf* on the properties of the composite paper were studied. The results showed that the properties of the composite paper were better when the proportion of *ginkgo leaf* was within the range of 70-90%, with a smooth surface, high strength, and flexibility, which can meet the needs of daily packaging. The higher the proportion of *ginkgo leaf*, the better the anti-ultraviolet property and the higher the strength. When the proportion of willow catkins or kapok fibers was higher, the water resistance and flexibility were better. Among them, when the proportion of *ginkgo leaf* was 90%, the ultraviolet protection factor (UPF) could reach 128, showing excellent anti-ultraviolet property. When the proportion of *ginkgo leaf* was 70%, the water contact angle to composite paper was 144.2°, indicating water resistance.

KEYWORDS: Ginkgo leaf, deep eutectic solvent, willow catkin, kapok fiber, composite paper.

INTRODUCTION

Developing low-cost, novel materials for the preparation of composite paper can address not only the current issue of resource scarcity but also broaden the application scope of paper, offering promising development prospects (Fan et al. 2023). *Ginkgo* leaf, a resource-rich and cost-effective plant material, contain various bioactive compounds beneficial to human health, including polyphenols (approximately 68.9 mg/g), flavonoids (approximately 16.6 mg/g), and terpenoids (approximately 4.2 mg/g) (Patrycja et al. 2023, François et al. 2019, Chen et al. 2021, Lin et al. 2022). China has a long history of the development and utilization of *ginkgo* leaf, which has been used for a long time to treat bronchitis, asthma and other diseases, and also has been used to lower blood pressure and blood lipid diseases. Recently, plant resource utilization have expanded to novel material engineering. Zhou et al. (2022) extracted flavonoids from *ginkgo* leaf for dyeing and antimicrobial finishing of wool fabrics, demonstrating that the combination of *ginkgo* leaf extract and ampicillin can significantly improve antimicrobial ability. However, there are few studies on *ginkgo* leaf extract as materials for functional paper (Li et al. 2023, Guo et al. 2021).

Some researchers have used *ginkgo* leaf and chitosan to prepare an antioxidant and anti-ultraviolet bio-based composite film, but chitosan is expensive. A willow tree can produce between 280,000 and 1,485,000 willow catkins annually (Nissim et al. 2021), primarily composed of α-cellulose (approximately 94%), along with minor components such as pentosans (1.51%), nitrogenous substances (0.87%), water-soluble substances (3.30%) and lipids (0.60%) (Wan et al. 2020). Due to the short length, smooth surface, and lack of crimp in willow catkins, the cohesion between fibers is reduced, making yarn spinning challenging. Although the willow catkins are widely distributed in the world, their utilization has not been general so far (Wu et al. 2019). In addition, kapok fibers contain flavonoids and triterpenoids, which gives it natural antibacterial and anti-mite properties, and can be used as a raw material for papermaking (Zhang et al. 2024). If these fibers can be used effectively, they can not only produce economic benefits, but also reduce the environmental pollution.

This paper describes the preparation of composite paper made with *ginkgo* leaf and willow catkins, with good mechanical strength, ultraviolet resistance, and biodegradability. The process involves treating *ginkgo* leaf (GL) with deep eutectic solvents (DES) and incorporating a small amount of willow catkins (WC) or kapok fibers (KF). The method of in-situ lignin regeneration through DES treatment is simple, fast, and environmentally friendly. The used chemicals can be recycled, and the resulting composite paper can be degraded in the natural environment.

MATERIAL AND METHODS

Ginkgo leaf (collected in Jiangnan University campus on November), willow catkins (collected in Jiangnan University campus on February), kapok fibers (purchased from Pengcai Home Textiles, China). Choline chloride and oxalic acid are both analytical grades, and purchased from Sinopharm Chemical Reagent Co. Ltd. China.

Preparation of DES

The solution was prepared by heating choline chloride and oxalic acid in a 1:1 molar ratio at 80°C until a homogeneous liquid was obtained. Consequently, DES was prepared, which was then sealed and stored for further experimental use (Zhou et al. 2024).

Preparation of eco-friendly composite paper

The dried *ginkgo leaf* was ground into powder and passed through a 50-mesh sieve. The powder was then mixed with DES in a mass ratio of 1:15 and heated at 120°C for 2 h to obtain a brown liquid. After cooling, an equal volume of distilled water was added for washing. Since lignin is hydrophobic, it can be rapidly precipitated and separated. Following filtration and additional washing steps to remove the DES, a high-solid-content and high-viscosity ginkgo cellulose-lignin slurry was obtained. The slurry was subsequently stirred and filtered again. The filtrate was evaporated to recover DES and can be reused.

Willow catkins were pulverized for 2 min at 7000 rpm, and the desired fiber length was 5-10 mm. Ginkgo cellulose-lignin slurry and willow catkins were mixed in different proportions, uniformly dispersed, and then pressed and dried at 110°C for 5 min using a paper sample press to obtain ginkgo leaf /willow catkins (GL/WC) composite paper. The experiment was repeated, with willow catkins replaced by kapok fibers, to prepare ginkgo leaf /kapok fibers (GL/KF) composite paper.

Morphological characterization

The morphological characteristics of willow catkins, kapok fibers, GL before and after treatment with DES were observed using scanning electron microscopy (SEM) (SU1510, Hitachi Limited, Japan). The samples were subjected to gold sputtering treatment prior to SEM analysis.

FTIR analysis

The chemical structures of GL and before and after treatment with DES, willow catkins and kapok fibers, were characterized by a Fourier Transform Infrared Spectrometer (FTIR) (Nicoletis, Thermo Fisher Scientific, USA) at room temperature, with a scanning range 4000~500 cm^{-1}.

TG analysis

The thermal property of willow catkins, kapok fibers were analyzed using a thermogravimetric analyzer (TG) (Q500, TA Instruments, USA) under a nitrogen atmosphere, from room temperature to 800 °C at a heating rate of 10 °C/min.

Fluorescence properties

The fluorescence effect of GL/WC or GL/KF composite paper was observed using an inverted fluorescence microscope (Nikon Ti-S, Nikon Corporation, Japan), and all images were taken in a dark field at room temperature.

Water repellency

The dynamic changes in the contact angles of water droplets on the surface of GL/WC or GL/KF composite paper were measured using a contact angle measurement system (SL200KS, Beijing Dataphys Instruments Co, China). The water contact angles at the initial state and after 60 seconds of contact were compared to characterize the paper's water resistance.

Anti-ultraviolet properties

The anti-ultraviolet property of the GL/WC or GL/KF composite paper was measured by a textile ultraviolet tester (YG(B), Wenzhou Darong Textile Instrument, China), following the standard "Textiles-Evaluation for solar ultraviolet radiation protective properties" (GB/T 18830-2009). The lower the T_{UVA} and T_{UVB} and the higher the *UPF* value, the better the anti-ultraviolet property of the sample.

Mechanical properties

The tensile strength, tensile elongation, and tensile index of the GL/WC or GL/KF composite paper was determined using a tensile strength tester (YG028, Ningbo Textile Instrument Factory, China) with a sample of 15x1 cm, following the standard "Paper and board. Determination of tensile properties. Constant rate of elongation method" (GB/T 12914-2018); the softness of the composite paper was determined using the heart-shaped method with a sample size of 20 x 2 cm, following the standard "Textiles. Determination of bending behavior. Part 2: Heart loop method" (GB/T 18318.2-2009).

RESULTS AND DISCUSSION

The properties of raw materials

Reaction mechanism of DES with *ginkgo* leaf is shown on Fig. 1. Chloride ions and hydroxyl groups between choline chloride and oxalic acid can form weaker hydrogen bonds, which reduce the compound's crystallization ability and keep DES in a liquid state at lower temperatures. These hydrogen bonds can also affect the ether bonds, reducing the required energy for cleavage of the ether bond (β-O-4). After the ether bonds (β-O-4) are broken, lignin with depolymerize into monomers in the DES (Maninder et al. 2023, Xia et al. 2021) and dissolve in the solvent. The acidic DES also helps to break down hemicellulose, amorphous cellulose, and other non-crystalline components. However, cellulose with higher crystallinity is insoluble.

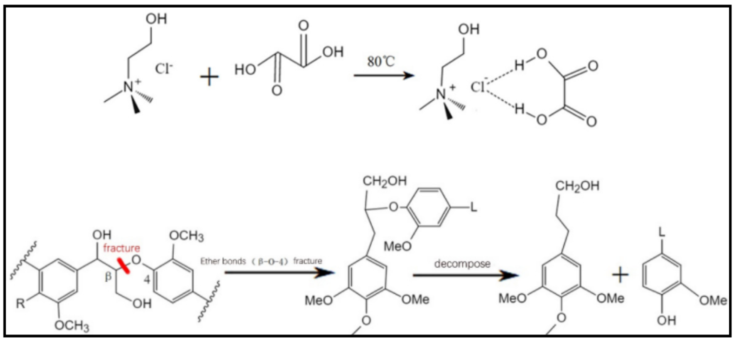

Fig. 1: Reaction mechanism of DES with ginkgo leaf (Maninder et al. 2023, Xia et al. 2021).

Surface morphology

The morphology of GL before and after DES treatment is shown in Fig. 2. It can be seen that the ground GL is irregular in shape with a diameter ranging from 20 to 70 µm and has a relatively rough surface. After DES treatment, the GL particles adhere to each other, forming a compact and fine overall structure with particle diameters ranging from 5 to 20 µm. After DES treatment, the surface of the GL becomes loose and rough, leading to the dissolution of hemicellulose and lignin and the exposure of internal fibers.

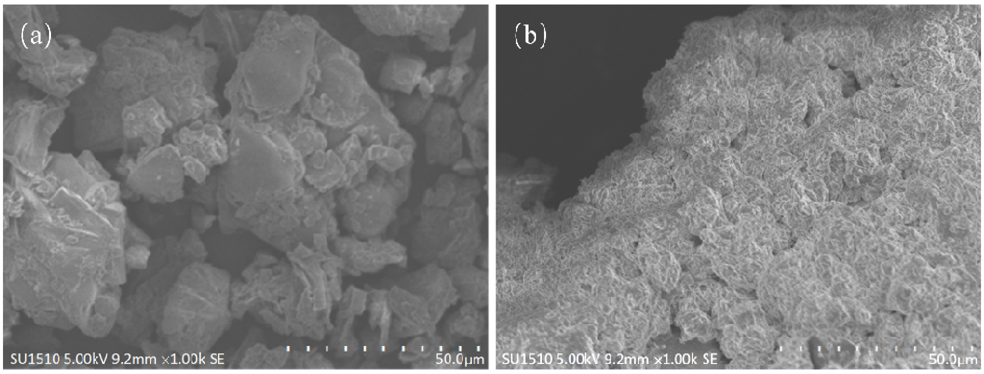

Fig. 2: SEM images of (a) GL before DES treatment and (b) GL after DES treatment.

The SEM images of willow catkins and kapok fibers is shown in Fig. 3. The willow catkins have a diameter of about 5-15 μm and a length of about 5-15 mm (Fig. 3a). They are fine, soft, and light, with high bulkiness. The fibers are straight, and their surface is smooth. The kapok fibers have a diameter of about 20-45 μm and a length of about 8-32 mm, with a morphology similar to that of willow catkins (Fig. 3b). Both willow catkins (Fig. 3c) and kapok fibers (Fig. 3d) have distinct circular lumens in cross-section, with thin tube walls and large hollow spaces. This hollow structure is one of the main reasons for their hydrophobic properties, and they have good application prospects in fields such as thermal insulation materials, oil absorption materials, biomass carbon micropipes, and conductive aerogels (Li et al. 2016, Pan et al. 2024).

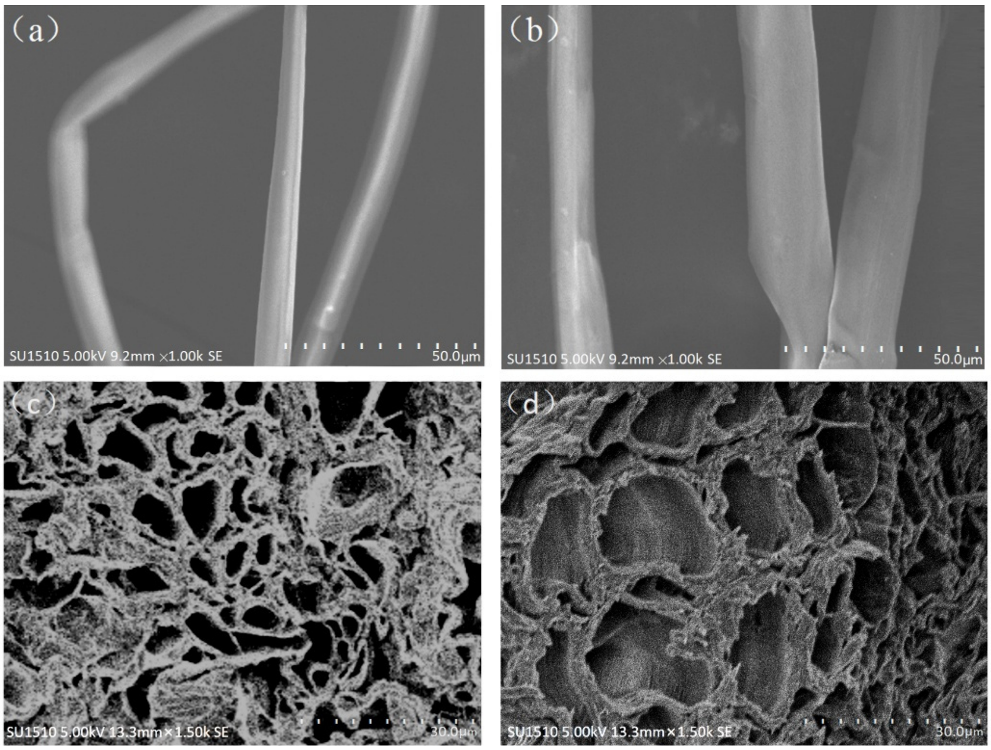

Fig. 3: SEM images of longitudinal profile of (a) WC, (b) KF and cross-section of (c), WC (d) KF.

FTIR analysis

FTIR spectra of GL before and after DES treatment are shown in Fig. 4a. The peak at 3400 cm^{-1} is attributed to the -OH vibration. After DES treatment, the hydroxyl groups associated with hydrogen bonds are reduced, and new phenolic hydroxyl groups are generated due to the cleavage of β-O-4 ether bonds. The peak at 2920 cm^{-1} corresponds to the C-H stretching vibration of methyl and methylene groups in methoxy and side chains. The characteristic absorption bands of lignin are mainly between 1750 and 1500 cm^{-1}, with the peak at 1720 cm^{-1} corresponding to the acetyl groups in hemicellulose and the carbonyl ester bonds in lignin. The peak intensity decreases significantly after treatment, indicating that DES removes certain amounts of hemicellulose and lignin. The peaks at 1610 cm^{-1} and 1520 cm^{-1} are related to the vibration of the aromatic nucleus of lignin, and the peak at 1460 cm^{-1} is associated with the side chain hydrogens on the benzene ring, corresponding to the characteristic of the lignin backbone. The peak intensity does not change significantly after DES treatment, indicating that the aromatic structure of lignin is not obviously destroyed. The peak at 1240 cm^{-1} represents the stretching vibration of C-O in phenylpropanoids, resulting from the stretching of ether bonds between lignin and hemicellulose. The peak intensity decreases significantly after treatment, indicating that lignin is solubilized by breaking the ether bonds between lignin and hemicellulose. The peak at 1160 cm^{-1} is due to the asymmetric stretching vibration of C-O-C in cellulose, and the peak at 1110 cm^{-1} corresponds to the vibration of the C-C-C backbone of cellulose macromolecules. These two peak intensities remain almost unchanged after DES treatment, indicating that DES does not destroy the structures of cellulose (Wu et al. 2020).

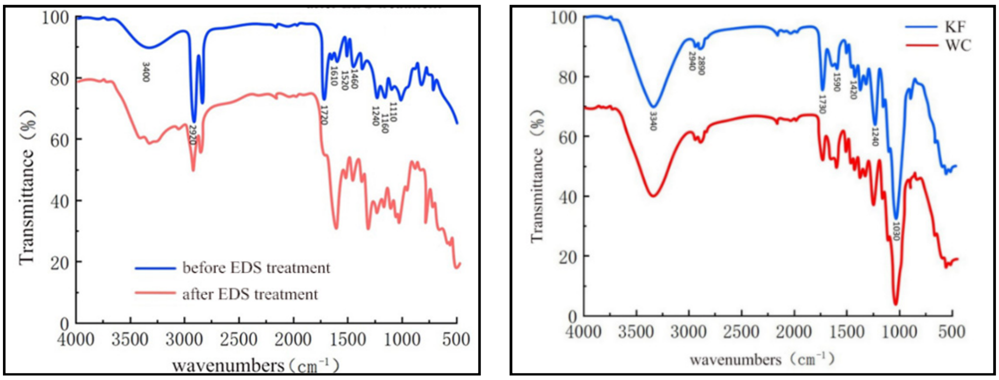

Fig. 4: a) FTIR spectra of GL before and after DES treatment, b) FTIR spectra of WC and KF.

FTIR spectra of willow catkins and kapok fibers are shown in Fig. 4b. The absorption peak at 3340 cm^{-1} is attributed to the stretching vibration of -OH groups involved in hydrogen bonding. The peaks at 2940 cm^{-1} and 2890 cm^{-1} correspond to the asymmetric and symmetric stretching vibrations of aliphatic $–CH_2$ and $–CH_3$ groups, respectively. The characteristic absorption bands of lignin are mainly between 1700 and 1500 cm^{-1}, with a peak at 1730 cm^{-1} for non-conjugated carbonyl groups and a peak at 1590 cm^{-1} for the aromatic ring skeleton vibration of lignin molecules. The absorption peak at 1420 cm^{-1} is a doublet for C-H bending vibration, the peak at 1240 cm^{-1} is for C-C skeletal vibration, and the peak at 1030 cm^{-1} is a significant C-O absorption peak from the cellulose skeleton. Studies have shown that kapok fibers contain 64% cellulose, 13% lignin, 8.6% moisture, 1.4-3.5% ash, 4.7-97% water-soluble substances, 2.3-2.5% xylan, and 0.8% wax (Li et al. 2023, Zheng et al. 2021), and these compositions similar to those of willow catkins.

TG analysis

The TG analysis curves of kapok fibers and willow catkins are shown in Fig. 5. It can be seen that the two curves both show a stable and slow mass loss process below 200°C, which are mainly due to the release of adsorbed water and the degradation of polysaccharides. The main thermal mass loss occurs between 250°C and 350°C, during which cellulose in fibers begin to decompose significantly, and the final mass loss is due to the oxidation and decomposition of carbon, forming gaseous products with smaller molecular masses (Sangalang et al. 2021). Ultimately, at 600°C, the mass residue percent of kapok fibers is 15.23%, and that of willow catkins is 2.32%. Both fibers show minimal mass loss before 120°C, indicating good thermal stability to meet the required temperature in papermaking process.

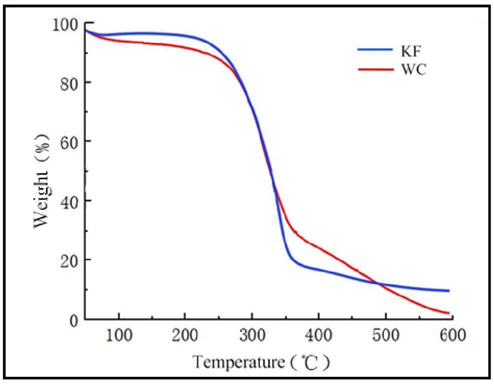

Fig. 5: TG curves of WC and KF.

Surface morphology of composite paper

From Fig. 6a, the blending of the *ginkgo* leaf without DES treatment and willow catkins cannot form into paper, which resulted that the *ginkgo* leaf without DES treatment has not bonding ability. From Fig. 6b, the GL slurry after DES treatment without willow catkins can form paper. However, due to the lack of reinforcing fibers, it is brittle and easy to break. Neither of these methods is suitable for preparing composite paper. From Fig. 6c, the GL/WC composite paper which prepared from *ginkgo* leaf treated with DES and willow catkins is flat, soft, and has a thickness of about 0.1 mm and a weight of about 50 g/m². The blended composites can be changed according to actual needs to obtain thicker or thinner composite paper. The selected fiber length should be between 5 and 10 mm. If the fibers are too long, it will lead to poor dispersibility and easy tangling during papermaking, resulting in uneven thickness or even holes. If the fibers are too short, it will lead to insufficient fiber intertwining and resulted in lower tensile strength of the composite paper.

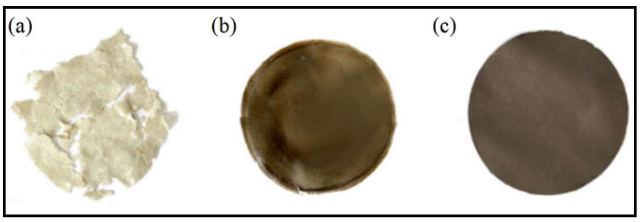

Fig. 6: a) GL/WC composites without DES, b) GL paper, c) GL/WC composite paper.

Surface morphology under the optical microscope

The surface morphology of the composite papers prepared from different proportions of materials is shown in Fig. 7. under an optical microscope. The fibers intertwine with each other to form a compact structure. There is no significant difference in the surface characteristics of the GL/WC and the GL/KF composite papers. As the proportion of GL increases, the color of the composite paper deepens, and the fibers become closer to each other, making the smoother surface. However, if the proportion of GL is too high, the composite paper will become brittle and lose the characteristics of paper. Overall, the proportion of GL should be 70-90% for composite papers.

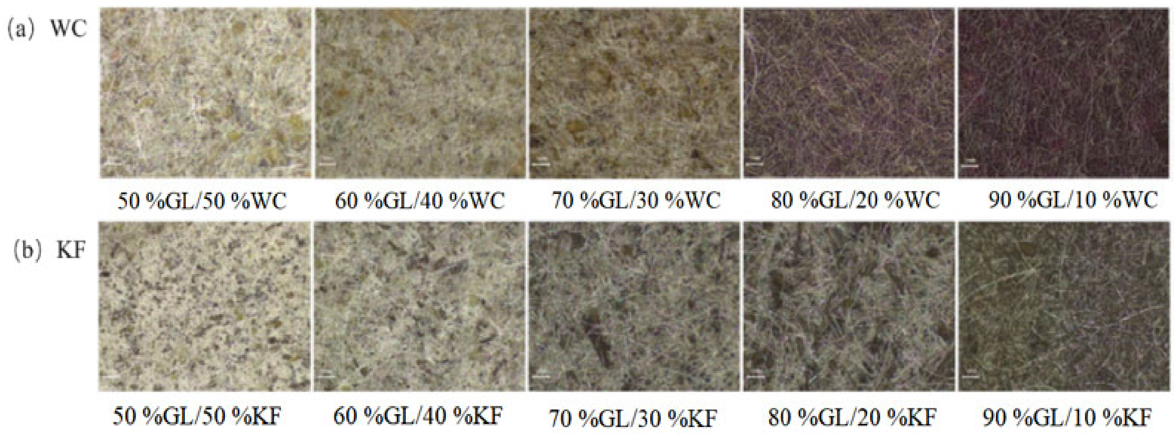

Fig. 7: Optical microscope images of GL/WC and GL/KF composite papers.

Surface morphology under fluorescence

The fluorescence effect of the prepared composite papers is shown in Fig. 8.

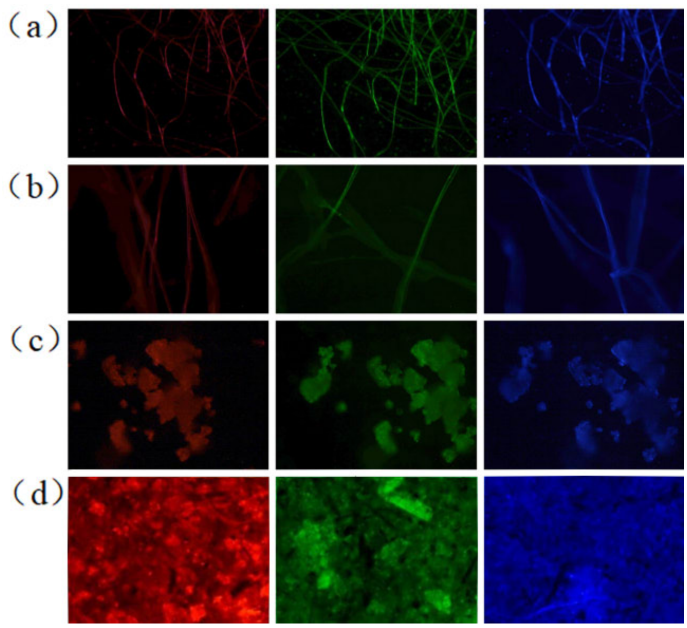

Fig. 8: Fluorescence images of (a) willow catkins (b) kapok fibers (c) ginkgo leaf treated with DES (d) composite paper.

It can be seen that the composite paper prepared from different materials exhibits a fluorescence phenomenon, which may be attributed to the presence of a large number of conjugated C=C double bonds on the benzene rings in the aromatic substances. These bonds allow the materials to absorb light energy, enter an excited state, and quickly return to the ground state, producing a fluorescence effect (Hu et al. 2017, Verenkar et al. 2020, Hou et al. 2017). The composite papers prepared from *ginkgo* leaf retains this characteristic, which can increase the recognizability of the composite papers and holds good application prospects in anti-counterfeiting fields.

Functional and mechanical properties of composite papers

Water repellency

The front side of the natural *ginkgo* leaf is hydrophilic, while its back side is hydrophobic. After treatment with DES, GL possesses both polar hydrophilic side chains, such as phenolic hydroxyl groups, which can cross-link with cellulose to provide mechanical strength, and non-polar hydrophobic main chains, such as alkyl groups, which prevent water penetration (Wang et al. 2022, Hu et al. 2023). On the other hand, the surfaces for kapok fibers and willow catkins are both hydrophobic (Winges et al. 2024, Asyraf et al. 2023), and the higher the proportion in the composite paper is, the larger the water contact angle is. As shown in Tab. 1, the surface water contact angles of the composite papers made from *ginkgo* leaf are all greater than 90°, indicating hydrophobicity, and the hydrophobicity-maintained within 60 s. Among them, 70% GL /30% WC composite paper exhibits the largest water contact angle of 144.2°.

Tab. 1: Water contact angles of composite papers.

Materials	0s Contact angle/°	60s Contact angle/°
GL	96.9	88.6
90 %GL/10 %WC	119.7	118.4
80 %GL/20 %WC	127.1	125.5
70 %GL/30 %WC	144.2	143.6
WC	150.6	150.6
90 %GL/10 %KF	112.3	111.7
80 %GL/20 %KF	120.3	119.2
70 %GL/30 %KF	130.7	129.8
KF	135.0	134.7

Anti-ultraviolet properties

The UV resistance of the composite paper is presented in Tab. 2. It is evident that for composite paper made from the same raw material, the higher the proportion of GL, the better the UV resistance of the composite paper becomes. When the proportion of GL exceeds 70%, the UPF value of the composite papers can reach above 100, indicating excellent UV resistance. Compared with general printing paper with similar thickness (approximately 0.1 mm thick, approximately 70 g/m² in weight per square meter). The UPF value of the composite papers is significantly higher.

Tab. 2: UV resistance properties of the composite papers.

Composite paper	T_{UVA} (%)	T_{UVB} (%)	*UPF*
90 %GL/10 %WC	0.08	0.09	1928
80 %GL/20 %WC	0.10	0.14	806
70 %GL/30 %WC	0.27	0.22	482
90 %GL/10 %KF	0.11	0.11	850
80 %GL/20 %KF	0.17	0.20	493
70 %GL/30 %KF	1.66	0.58	244
general printing paper	2.32	2.00	52

Mechanical properties

The mechanical properties of the composite papers are detailed in Tab. 3. The photo images of composite papers showing softness are shown in Fig. 9. It is observed that the 80% GL/20%WC composite paper exhibits the highest strength. At this ratio, the tensile strength, tensile elongation, and softness of the composite paper made from willow catkins are slightly greater than those made from kapok fibers. This difference may be attributed to the finer and softer characteristics of willow catkins, which contribute to a denser structure in the composite paper. The softness of the packaging paper was assessed using the heart-shaped method. It is noted that the higher the fiber content, the greater the hanging height, and consequently, the softer the packaging paper is.

Tab. 3: Mechanical properties of the composite papers.

Composite paper	Breaking force (N)	Elongation at break (%)	Tensile strength (N/mm^2)	Softness (cm)
90 %GL/10 %WC	2.79±0.27	1.33±0.10	0.19	5.62
80 %GL/20 %WC	2.94±0.25	1.40±0.16	0.20	5.85
70 %GL/30 %WC	2.54±0.30	1.43±0.18	0.17	6.03
90 %GL/10 %KF	2.18±0.25	0.45±0.06	0.15	4.77
80 %GL/20 %KF	2.17±0.28	0.56±0.08	0.14	5.36
70 %GL/30 %KF	2.04±0.32	0.67±0.11	0.14	5.80

Fig. 9: The photo images of composite papers showing softness.

CONCLUSIONS

(1) A mixture of oxalic acid and acetylcholine can form DES, and it can be utilized to treat lignin from *ginkgo* leaf and obtain a cellulose-lignin slurry with a high solid content and high viscosity. By incorporating with willow catkins and kapok fibers, a low-cost GL/WC and GL/KF composite paper can be prepared. *(2)* In papermaking, the proportion of *ginkgo* leaf is preferably between 70% and 90%. The higher the content of *ginkgo* leaf, the better the UV resistance. The higher the content of willow catkins or kapok fibers, the better water resistance and softness of the composite papers. The UPF value reaches 1928 when the proportion of *ginkgo* leaf is 90%. The water contact angle reaches 144.2°, and the composite paper is the softest when the proportion of willow catkins is 30%. *(3)* The prepared GL/WC and GL/KF composite papers both show similar fluorescence and higher UV resistance. However, the strength and softness of the former are higher than those of GL/KF composite paper with the same proportion.

ACKNOWLEDGEMENTS

This work is supported by Postgraduate Research & Practice Innovation Program of Jiangsu Province (KYCX24_2576).

REFERENCES

1. Asyraf, M.R.M., Syamsir, A., Ishak, M.R., Sapuan, S.M., Nurazzi, N.M., Norrrahim, M.N.F., Ilyas, R.A., Khan, T., Rashid, M.Z.A., 2023: Mechanical properties of hybrid lignocellulosic fiber-reinforced biopolymer green composites: A review. Fibers and Polymers 24(2): 337-353.
2. Chen, Y.M., Fu, C.X., Wu Z.Y., Xu, H.M., Liu, H.M., Harald, S., Lin, J.X., 2021: Ginkgo biloba. Trends in Genetics 37(5): 488-489.
3. Fan, Z.T., Li, Z., Qi, W., Zhao, S. T., Zhou, B., Liu, S.Y., Tian, Y. M., 2023: Preparation of in - situ modified diatomite and its application in papermaking. Colloids & Surfaces A: Physicochemical & Engineering Aspects 657: 130582.
4. François, C., Huang, X.Y., James, T.L., Cassandra, L.Q., 2019: Validation of a 16th century traditional Chinese medicine use of ginkgo biloba as a topical antimicrobial. Frontiers in Microbiology 10: 775.
5. GB/T 18318.2-2009: Textiles. Determination of bending behaviour. Part 2: Heart loop method.
6. GB/T 18830-2009: Textiles. Evaluation for solar ultraviolet radiation protective properties.
7. GB/T 12914-2018: Paper and board. Determination of tensile properties. Constant rate of elongation method.
8. Guo, J., Wu, Y.Q., Wang, G.B., Wang T.L., Cao F.L., 2020: Integrated analysis of the transcriptome and metabolome in young and mature leaves of Ginkgo biloba L. Industrial Crops & Products 143: 111906-111906.

9. Hou, X.L., Fang F.F., Guo, X.L., Jakpa, W.Z., Ma, B.M., 2017: Potential of sorghum husk extracts as a natural functional dye for wool fabrics. ACS Sustainable Chemistry and Engineering 5(6): 4589-4597.
10. Hu, L., Wang, F., Xu, G., Xu, B., 2017: Unique microstructure of kapok fibers in longitudinal microscopic images. Textile Research Journal 87(18): 2255-2262.
11. Hu, P.T., Liu, D.H., Cao, Z.G., Wei, H., Zhu, F.J., Ma, W.L., Zhang, Z.F., Liu, L.Y., Feng, J.L., Li, Y.F., Li, Y.F., Li, Y.F., 2023: Effectively removing gaseous polycyclic aromatic hydrocarbons (PAHs) by willow catkins: Do you still dislike the catkins floating? Journal of Hazardous Materials 455: 131639.
12. Li, J.H., Jing, L., Wang S.F., Yao, J.B., Wang, F.F., 2023: Advances on analysis methods of ginkgo biloba leaf extract. Journal of Liquid Chromatography & Related Technologies 46(6-10): 138-152.
13. Li, Y.C., Wang, H.C., Wang, F.M., Xue, K., Cui, L.N., Shen, H., Xu, G.B., 2023: Hollow reversible kapok fibrous membranes with amphiphilicity, natural antibacterial properties, and biodegradability. Industrial Crops & Products 204: 117401.
14. Li, Y.J., Wang, G.L., Wei, T., Fan, Z.J., Yan, P., 2016: Nitrogen and sulfur co-doped porous carbon nanosheets derived from willow catkin for supercapacitors. Nano Energy 19: 165-175.
15. Lin, H.Y., Li, W.H., Lin, C.F., Wu, H.R., Zhao, Y.P., 2022: International biological flora: Ginkgo biloba. Journal of Ecology 110(4): 951-982.
16. Maninder, M., Vasudha, B., Sudha, R., Nitya, S., Vinod, K., Vaishali, A., Monika, G., 2023: Deep eutectic solvents (DESs) and natural deep eutectic solvents (NADESs): Designer solvents for green extraction of anthocyanin. Sustainable Chemistry and Pharmacy 34: 101168.
17. Nissim, W.G., Palm, E., Pandolfi, C., Mancuso, S., 2021: Willow and poplar for the phyto-treatment of landfill leachate in Mediterranean climate. Journal of Environmental Management 277: 111454.
18. Pan, X.L., Liu, Y.L., Ma, Z.H., Qin, Y., Lu, X.H., Feng, X., Shao, Q., Zhu, Y.D., 2024: Molecular insight into the mechanism of lignin dissolution in acid choline chloride-based deep eutectic solvents. Journal of Molecular Liquids 406: 125123.
19. Patrycja, B., Iwona, A., Katarzyna, F., 2023: The potential of Ginkgo biloba as a source of biologically active compounds - a review of the recent literature and patents. Molecules 28(10): 2195.
20. Sangalang, R.H., 2021: Kapok fiber-structure, characteristics and applications: (A review). Oriental Journal of Chemistry 37(3): 513-523.
21. Verenkar, N.G.S., Krishnan, S., 2020: Evaluation of natural dyes Curcuma longa and Nyctanthes arbor-tristis with different mordants on plant tissues under fluorescence microscopy. Microscopy Research and Technique 84(5): 902-911.
22. Wan, X., Gu, G., Lei, M., Zeng, W.B., 2020: Bioaccessibility of metals/metalloids in willow catkins collected in urban parks of Beijing and their health risks to human beings. Science of the Total Environment 717: 137240.
23. Wang, F.F., Ye, S.H., Ding, Y., Ma, Z.Y., Zhao, Q.K., Zang, M., Li, Y., 2022: Research on structure and antioxidant activity of polysaccharides from Ginkgo biloba leaves. Journal of

Molecular Structure 1252: 132185.
24. Winges, F., Muhammad, T., Shi, X.R., Wang, X.J., Ahmed, W., Kim, I., Wei, K., 2024: Deep eutectic solvent dyeing of cellulose acetate nanofibers with disperse dyes: Kinetics, Isotherm, and Thermodynamic Studies. Fibers and Polymers 25(4): 1325-1337.
25. Wu, J., Zhang, X.X., Zhao, Z., Wu, J.B., Wang, J.Z., Wang, J.Y., 2020: Hierarchical carbon microtubes from willow catkins for Li-S batteries. Materials Letters 261: 127079.
26. Wu, Y., Wu, X.Y., Shi, T.L., Chen, H., Kun, H., Sun, M., Zhang, J.L., 2019: The microstructure and mechanical properties of poplar catkin fibers evaluated by atomic force microscope (AFM) and nanoindentation. Forests 10: 938.
27. Xia, Q.Q., Chen, C.J., Yao, Y.G., Li, J.G., He, S.M., Zhou, Y.B., Li, T., Pan, X.J., Hu, L.B., 2021: A strong, biodegradable and recyclable lignocellulosic Bioplastic. Nature Sustainability 4: 627-635.
28. Zhang, H., Zhang, Y.Y., Wang, X.Y., Wang, W., Wu, Z., Sun, Y., Wang, Z. Q., 2024: Chestnut shell dyes extracted by deep eutectic solvent in green dyeing of silk fibers for enhanced washable, antibacterial and UV protection properties. Industrial Crops & Products 213: 118449.
29. Zheng, Y., Wang, J., Wang, A., 2021: Recent advances in the potential applications of hollow kapok fiber-based functional materials. Cellulose. 28: 5269.
30. Zhou, J. M., Wu, S.B., Liu, Y., 2024: Structural changes of poplar lignin during the ternary deep eutectic solvent (DES) treatment and synergetic alkali-DES treatment. Industrial Crops & Products 208: 117782.
31. Zhou, Q., Rather, L.J., Mir, S.S., Ali, A., Q. Haque, M.R., Li, Q., 2022: Bio colourants from the waste leaves of Ginkgo biloba L. tree: Wool dyeing and antimicrobial functionalization against some antibiotic-resistant bacterial strains. Sustainable Chemistry and Pharmacy 25: 100585.

ZIXING MA*, MENG ZHOU*, YANGYI WANG, QIYUE WANG, HELAN XU,
XIULIANG HOU**
JIANGNAN UNIVERSITY
SCHOOL OF TEXTILE SCIENCE & ENGINEERING
1800 LIHU ROAD, WUXI
CHINA
*The authors contributed equally to this article and are considered co-first authors.
**Corresponding author: houxl@jiangnan.edu.cn