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Assessing biopulping as an ecofriendly technology for paper making from rice straw using *Pleurotus sajor-caju*

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ABSTRACT

The present investigation was conducted to study and evaluate biopulping as an ecofriendly process for paper production using white rot fungi *Pleurotus sajor-caju*. A chemical analysis of the rice straw utilized in this study as the substrate revealed that it had the characteristics that make it a promising raw material for the manufacturing of pulp and paper. Rice straw subjected to fungal treatment for periods of 20, 40 and 60 days was investigated and compared to the untreated control. The findings demonstrated that the biological treatment of rice straw with *Pleurotus sajor-caju* for 60 days led to a significant reduction in pulp yield and kappa number from that of the control. Paper properties was also examined and it was found that exposure duration enhanced its tensile strength, tear index, burst index, double fold number, and brightness. The study concluded that using rice straw as a raw material and processing it in a manner that is ecologically safe can be beneficial for achieving sustainable growth.

Key words: *Biopulping, Rice straw, Pleurotus sajor-caju, paper properties*

Introduction

In the realm of industrial production, the manufacturing of pulp and paper is one of the industries with the highest demand. With a growing global population, paper demand and consumption have been rising dramatically (Kaur *et al*., 2016). It is crucial to the social, economic, and environmental growth of every nation. The preparation of the raw materials, pulping, bleaching, and paper production are the primary phases in the manufacture of pulp and paper. To obtain fibre or cellulose from fibrous material, the lignin must be separated during the pulping process. Mechanical, chemical, or a mix of these pulping techniques are used during the paper-making process to create pulp with the necessary properties. Although chemical pulping results in higher paper quality, the environmental impact is relatively significant because it generates potent liquid effluents. Due to the high concentration of chlorinated compounds in pulp and paper effluent, including chlorolignins and chlorinated hydrocarbons, along with resin acids, tannin acids, phenolic acids, lignosulphonic acids, various surfactants, plasticizers, biocides, waxes, fatty acids, heavy metals, and other complex organic and inorganic compounds, pulp and paper effluent is a significant source of environmental pollution (Pokhrel and Viraraghavan, 2004; Chandra *et al*., 2012). These substances make effluent materials more hazardous and raise the total dissolved solids, chemical oxygen demand, and biochemical oxygen demand of receiving aquatic resources, which unbalances aquatic life.

The pulp and paper sector has been severely impacted by the economy and environmental concerns, and it is under intense pressure to increase its performance in terms of pollutant release. The adoption of innovative, eco-friendly technology is under pressure due to growing environmental concerns (Dhiman *et al*., 2009). Therefore, one of the less destructive and more promising alternative to improve conventional pulping is the biopulping which have enormous potential in paper processing sectors (Yiin *et al*., 2019). According to Scott *et al*. (1998), biopulping is the process of treating wood chips and other lignocellulosic materials with lignin-degrading microorganisms such white rot fungus before pulping. It employs biological techniques as a promising substitute for alkali and chemical bleaches (Keller *et al*., 2003). Significant energy savings, an increase in paper quality, a decrease in the pulping process' negative environmental effects, and improved economic competitiveness can all be achieved with this procedure. As stated by Das and Houtman (2004), the primary environmental benefit of biopulping is a reduction in the use of massive quantities of potentially harmful chemicals in the paper-making process.

Numerous metabolic processes are carried out by a wide variety of bacterial genera, actinomycetes, and fungal species in the natural world without the production of any poisonous or dangerous byproducts (Islam *et al*., 2008). The white-rot fungi have drawn a lot of attention due to their remarkable capacity to simultaneously produce hydrolytic and oxidative extracellular enzymes to break down lignocellulose biomass and, as a result, have the best prospects for growth and application (Dhouib *et al*., 2005; Ashger *et al*., 2012). These enzymes could be produced by various white-rot fungi, though perhaps in varying amounts. Therefore, for biopulping, white-rot fungi with high lignin-degrading enzyme production and low cellulase production are preferred. Among the white rot fungi, *Pleurotus* spp. are effective lignin degraders with the capacity to successfully colonise on the substrates and breakdown a variety of lignocellulosic substrates (Patrabansh and Madan, 1997). These fungi utilise lignolytic and cellulolytic enzymes to break down the lignocellulosic wastes, which have a variety of industrial uses, including the production of food, kraft pulp, textiles, drugs, and dyes (Reddy *et al*., 2003).

Agricultural residues have recently become one of the most significant alternative resources because of the rising demand for fibrous raw materials on a global scale, the global shortage of trees, and the rise in sustainability consciousness (Gharehkhani *et al*., 2017; Bhardwaj *et al*., 2019). In many areas, particularly in poor nations, agricultural wastes can be used as a productive substitute for forest resources (Fahmy *et al*., 2017). Agro-waste-based raw materials have high fibre content and are simple to pulp, making them ideal for producing high-quality paper (Jimenez *et al*., 2008). The current use of these agricultural wastes is not desirable since they are burned in open land with insufficient control, which has an impact on the health of living things and the air quality (Ravindra *et al*., 2019). But in order to better utilise these inexpensive and plentiful agricultural wastes, their cellulose components need be separated from the basic materials used to create paper (Rudi *et al*., 2016). The output of pulp and paper worldwide is currently over 400 million tonnes, and it is anticipated that this production will increase in the future (Jahan *et al*., 2016) as a result of the rapid growth in the global demand for paper. By incorporating local lignocellulosic agricultural wastes like rice straw for paper production, this demand can be met. In developing nations, especially India, rice straw is a plentiful and convenient non-wood raw material (Rodriguez *et al*., 2010). These nations produce a lot of rice straw, which causes major issues for farmers. In India, burning paddy fields is a widespread occurrence (Athira *et al*., 2019). Thus, turning this trash into a valuable raw material for making paper is an environmentally benign method of waste management (Van Thanh *et al*., 2020). Therefore, by altering the production process through biopulping and employing cellulose-rich agricultural wastes as raw material, pollutant load can be decreased. In the light of information presented above, the purpose of the current study was to investigate the environmentally friendly production of paper from rice straw. In this work chemical composition of rice straw was examined and also it elaborates the effect of fungal treatment on physical strength of paper.

Materials and Methods

Raw material

Rice straw for paper making was collected from local fields of Kashmir Valley, J&K, India and was taken to Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar for analysis. The required quantity of rice straw was cut into pieces measuring 2 to 2.5 inches. According to the standard TAPPI test method T 267 om-85, the chopped material was oven dried and powdered with the use of a dust producing machine with a 0.4 mm slot size. A sample of two g of dust was taken for proximate analysis

Proximate chemical analysis

The chemical composition of rice straw was determined with the standard TAPPI methods including ash content (T 211 om-93), alcohol benzene solubility (T 204 cm-97), 1% NaOH solubility (T 212 om-98), hot water solubility (T 207 om-99), lignin content (T 222 om-02) and holocellulose content (T 249 cm-00).

Preparation of fungal inoculum

A pure culture of white rot fungal species *Pleurotus sajor-caju* was obtained from Mushroom Research and Training Centre, SKUAST-K, Shalimar, Srinagar. On potato dextrose agar slants, stock culture was kept at 4°C with occasional transfers.

Mycelium discs from pre-cultured fungus samples were added to 200 millilitre of potato dextrose broth as an inoculant. For 10 days, the cultured broth was incubated at 27°C. To remove extra medium from the fungus biomass, the growing mycelium mat was filtered and washed with sterile water. To create a homogeneous suspension, 100 ml of sterile water was combined with mycelium extracted from the cultured samples. The rice straw was inoculated using the prepared fungal suspension, which was maintained in a refrigerator at 4°C.

Biological treatment of rice straw

The biopulping of rice straw of size 0.5- 2.0 cm was carried out in Erlenmeyer flasks. To prevent contamination by microorganisms that could stop fungus from growing, these flasks were filled with 100 grams (oven-dry weight) of rice straw and sterilised at 121°C for 15 min. Each flask was then inoculated with a uniform suspension of fungus after sterilisation. The moisture content of each flask was maintained to a level of 60%. An un-inoculated flask of sterilized rice straw was used as control. Each biotreated and control flasks were incubated at 27° C for a periods of 20, 40 and 60 days.

Characterization of biopulping

Each biotreated and control flasks were taken out after 20, 40 and 60 days of incubation. After every incubation phase, each biotreated and untreated (control) rice straw was pulped mechanically. The pulp made from biotreated and untreated (control) rice straw was analysed for pulp properties using the standard TAPPI procedures, characterising the pulp in terms of pulp yield and kappa number. Standard sheets of 60 gsm were produced from each pulp in a laboratory sheet making machine and were conditioned for 24 hours at 27°C and 65% relative humidity in accordance with standard TAPPI test method T402 sp-98. In addition to conditioning, the physical strength of paper was assessed using standard TAPPI testing methods at intervals of 20, 40, and 60 days. Tensile strength, tear index, burst index, double fold number was measured by TAPPI methods T 494 om-01, T 414 om-98, T 403 om-97, T 423 cm-98 respectively and brightness by ISO 2470-1.

Results and Discussion

Chemical analysis of rice straw

The chemical characteristics of the rice straw were presented in Table 1 and include ash content, alcohol benzene solubility, 1% NaOH solubility, hot water solubility, lignin content and holocellulose content. The ash is primarily composed of various metal salts, including carbonates, silicates, oxalates, potassium phosphates, magnesium, calcium, iron, manganese as well as silicon (Shakhes *et al*., 2011). In the present study ash content of rice straw was higher (12.10 ± 0.126 %) than other agricultural resi-

Table 1. Chemical characterization of rice straw

Parameters	Results
Ash content (%)	12.10 ± 0.126
Alcohol benzene solubility (%)	4.71 ± 0.346
1% NaOH solubility (%)	48.72 ± 0.595
Hot water solubility (%)	12.75 ± 0.061
Lignin (%)	16.83 ± 0.287
Holocellulose (%)	60.94 ± 0.557

dues like wheat straw (9.58%) (Malik *et al.,* 2020), sunflower stalks (7.9%) (Lopez *et al*., 2005) and cotton stalks (2.17%) (Jimenez *et al*., 2006). According to Shakhes *et al*. (2011), the nonwood plant wastes that are solubilized in alcohol-benzene contain waxes, lipids, resins, photosterols, non-volatile hydrocarbons, low molecular weight carbohydrates, salts, and other water soluble materials. The alcohol–benzene extractables of rice straw was found low (4.71 ± 0.346%) and the low ethanol-benzene extractables of rice straw point to the presence of these chemicals in very small amounts in the raw material. Perusal of data in Table 1 revealed that 1% NaOH solubility recorded in rice straw was 48.72 ± 0.595%. Rice straw is predicted to have a medium-low pulp yield due to its high concentration of 1% NaOH soluble. This content is higher than that of wheat straw (38.99%) (Malik *et al*., 2020) and cotton stalks (20.34%) (Jimenez *et al*., 2006). Hot-soluble substances in the raw materials include starch and proteins, which could consume pulping reagents. The solubility of rice straw in hot water was lower (12.75 ± 0.061%) compared to that of other species such as *Crambe tataria* (21.82%) (Tutus and Eroglu, 2004), *Typha domingensis* (24.70%) (Khider *et al*., 2012) and mustard branches (21.0 %) (Jahan *et al*., 2014). Lignin is an unwanted component of raw materials that is eliminated during the pulping process. Higher lignin necessitates more energy and chemicals. Lignocellulosics with lower lignin content can be delignified under milder pulping conditions to achieve a desired kappa value. In comparison to *Populus deltoides* (21.80%) (Akhtar, 2000), cotton stalks (22.50%) (Ali *et al*., 2011) and oil palm frond (20.1%) (Omar *et al*., 2018) rice straw was shown to have a lower lignin concentration (16.83 ± 0.287%). Results obtained in Table 1 revealed that rice straw contained (60.94 ± 0.557%) of holocellulose. Since high holocellulose concentration is linked to the distinctive strength characteristics of paper, it is regarded as a desirable quality for pulp processing. The holocellulose percentage of rice straw was found to be lower than that of other nonwood species, including cotton stalks (72.86%) (Jimenez *et al*., 2006), *Datura stramonium* stalks (66.55%) (Ganie *et al*., 2017) and wheat straw (70.11%) (Malik *et al*., 2020).

Effect of *Pleurotus sajor-caju* on pulp properties of rice straw

Data presented in Table 2 revealed that pulp yield and kappa number of rice straw after treatment with *Pleurotus sajor-caju* for 60 days were significantly lower than those of the control. During the experiment, the pulp yield decreased from about 64.52% to 58.25%. The kappa number used to represent the amount of lignin still present in fibres reduced from approximately 32.68 to 19.03 over the incubation period. This decline in pulp yield and kappa number could be due to the ability of *Pleurotus sajor-caju* to produce lignolytic and cellulolytic enzymes which causes degradation of lignin as well as cell walls. Badr El-Din *et al.* (2013) found that pretreatment of rice straw with *Pleurotus ostreatus* for 25 days resulted in a decrease in pulp yield and kappa number by 5.8 and 34.6% respectively from that of the control. Similar outcomes were also noted by Singh *et al*. (2013) during the 4-week growth of *Trametes versicolor* on an oil palm trunk and reported that the pulp yield and kappa number decreased from 40 to 33% and 23.4 to 15.2 respectively.

Table 2. Pulp yield and kappa number of control and treated rice straw

Incubation period (days)	Pulp yield (%)		Kappa number	
	Control	Treated	Control	Treated
20	64.62	60.76	32.75	23.27
40	64.54	57.48	32.68	18.36
60	64.41	56.52	32.62	15.46
Mean	64.52	58.25	32.68	19.03

Effect of *Pleurotus sajor-caju* on paper properties of rice straw

Data displayed in Table 3 showed the paper properties of rice straw that was treated with *Pleurotus sajor-caju* for 60 days. Results of the present study revealed that paper made from biotreated pulp showed the higher strength properties than controlled paper which might be probably due the better delignification of pulp by white rot fungus *Pleurotus sajor-caju*. Tensile strength significantly increased during the incubation periods (from 22.69 to 27.47 Nm/g). Similarly, tear index (2.18 – 3.55 mN.m^2/g), burst index (0.947 – 1.827 Kpa.m^2/g), double fold number (13 – 22) and brightness (30.73 – 37.36%) was also increased during the experiment. Yaghoubi *et al*. (2008) discovered that the biological treatment of rice, wheat and barley straws with '*Ceriporiopsis subvermispora* increased tensile index of hand sheets by 51%, 62% and 36.7% respectively

Table 3. Paper properties of rice straw with and without *Pleurotus sajor-caju* treatment

Treatments	Incubation periods (days)			
	20	40	60	Mean
	Tensile strength (Nm/g)			
Control	22.64	22.69	22.73	**22.69**
Pleurotus sajor-caju	25.53	27.64	29.23	**27.47**
	Tear index (mN.m^2/g)			
Control	2.14	2.18	2.21	**2.18**
Pleurotus sajor-caju	3.06	3.56	4.02	**3.55**
	Burst index (Kpa.m^2/g)			
Control	0.93	0.95	0.96	**0.95**
Pleurotus sajor-caju	1.56	1.81	2.11	**1.83**
	Double fold number			
Control	12	13	14	**13**
Pleurotus sajor-caju	17	22	26	**22**
	Brightness (%)			
Control	30.67	30.72	30.79	**30.73**
Pleurotus sajor-caju	34.84	37.56	39.67	**37.36**

and burst factor by 33%, 36% and 45% respectively as compared to the control straws. Similarly, Singh *et al*. (2013) also reported that the tensile strength, burst index and tear index of paper sheet produced from *Trametes versicolor* treated oil palm trunk increased with the exposure time.

Conclusion

This study demonstrated the enormous potential of biological processing for converting rice straw into pulp and paper. The proximate chemical study of rice straw revealed that it has the characteristics needed to make paper, and its transformation into pulp and paper might be advantageous for farmers, businesses, and the environment. When rice straw was treated with *Pleurotus sajor-caju* as compared to the control, significant changes in the loss of pulp yield and kappa number were observed. The tensile strength, tear index, burst index, double fold number and brightness of paper produced from treatment combination of rice straw and *Pleurotus sajor-caju* were increased as compared to the control straw. The findings of this study demonstrated that biological treatment of rice straw can generate paper of good quality and also decreases the utilization of pulping chemicals. Hence, biopulping can be viewed as an environmentally favourable method of producing paper.

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Conflict of interest

There are no competing interests.

References

Akhtar, R. S. 2000. Studies on pulping and bleaching of *Poplar deltoides.* Ph.D Thesis, University of Roorkee, India.

Ali, M., Byrd, M. and Jameel, H. 2011. Soda-AQ pulping of cotton stalks. pp. 18-22. In: *Proceedings of Technical Association of Pulp and Paper Industries Pulping Conference*, September, 8-11, Seattle, USA.

Ashger, M., Iqbal, H. M. N. and Asad, M. J. 2012. Kinetic characterization of purified laccase produced from *Trametes versicolor* IBL-04 in solid state bio processing of corn cobs. *BioResources*. 7: 1171-1188.

Athira, G., Bahurudeen, A. and Appari, S. 2019. Sustainable alternatives to carbon intensive paddy field burning in India: a framework for cleaner production in agriculture, energy, and construction industries. *Journal of Cleaner Production*. 236: 117598.

Badr El- Din, S. M., Kheiralla, Z. H., Abdel Malek, S. M. and Abdel Aziz, D. H. 2013. Selection of fungal isolates for biopulping of rice straw. *BioResources.* 8(4): 4969-4980.

Bhardwaj, N. K., Kaur, D., Chaudhry, S., Sharma, M. and Arya, S. 2019. Approaches for converting sugarcane trash, a promising agro residue into pulp and paper using soda pulping and elemental chlorine-free bleaching. *Journal of Cleaner Production*. 217: 225–233.

Chandra, R., Singh, R. and Yadav, S. 2012. Effect of bacterial inoculum ratio in mixed culture for decolorization and detoxification of pulp paper mill effluent. *Journal of Chemical Technology & Biotechnology*. 87(3): 436–444.

Das, T. K. and Houtman, C. 2004. Evaluating chemical, mechanical and biopulping processes and their sustainability characterization using life-cycle assessment. *American Institute of Chemical Engineers*. 23: 347-357.

Dhiman, S. S., Garg, G., Mahajan, R., Garg, N. and Sharma, J. 2009. 'Single lay out' and 'mixed lay out' enzymatic processes for bio-bleaching of kraft pulp. *Bioresource Technology*. 100: 4736-4741.

Dhouib, A., Hamza, M., Zouari, H., Mechichi, T., H'midi, R., Labat, M., Martinez, M. J. and Sayadi, S. 2005. Autochthonous fungal strains with high ligninolytic activities from Tunisian biotopes. *African Journal of Biotechnology*. 4: 431-436.

Fahmy, Y., Fahmy, T. Y., Mobarak, F., El-Sakhawy, M. and Fadl, M. 2017. Agricultural residues (wastes) for manufacture of paper, board, and miscellaneous products: background overview and future prospects. *International Journal of Chem Tech Research*. 2(10): 424–448.

Ganie, S. A., Ara, S., Agarwal, S., Mehmood, M. A. and Bhat, R. A. 2017. Exploration and feasibility of non-wood herbaceous weed as a raw material for the production of alkaline sulphite cellulosic pulp for paper making. *Asian Journal of Science and Technology*. 8(11): 6545-6549.

Gharehkhani, S., Yarmand, H., Goodarzi, M. S., Shirazi, S. F. S., Zubir, M. N. M., Amiri, A., Solangi, K., Ibrahim, R., Kazi, S. N. and Wongwises, S. 2017. Experimental investigation on rheological, momentum and heat transfer characteristics of flowing fiber crop suspensions. *International Communications in Heat and Mass Transfer*. 80: 60–69.

Islam, M. N., Karim, M. R. and Malinen, R. O. 2008. Beneficial effects of fungal treatment before pulping and bleaching of *Acacia mangium* and *Eucalyptus camaldulensis*. *Turkish Journal of Agriculture and Forestry*. 32: 331-338.

Jahan, M. S., Rumee, J. N., Rahman, M. M. and Quaiyyum, A. 2014. Formic acid/acetic acid/water pulping of agricultural wastes. *Cellulose Chemistry and Technology*. 48(1): 111-118.

Jahan, M. S., Uddin, M. N. and Akhtaruzzaman, A. F. M. 2016. An approach for the use of agricultural by-products through a biorefinery in Bangladesh. *Forestry Chronical*. 92(4): 447–452.

Jimenez, L., Angulo, V., Ramos, E., de la Torre, M. J. and Ferrer, J. L. 2006. Comparison of various pulping processes for producing pulp from vine shoots. *Industrial Crops and Products*. 23: 122–130.

Jimenez, L., Rodriguez, A., Perez, A., Moral, A. and Serrano, L. 2008. Alternative raw materials and pulping process using clean technologies. *Industrial Crops and Products*. 28(1): 11-16.

Kaur, D., Bhardwaj, N. K. and Lohchab, R. K. 2016. Prospects of rice straw as a raw material for paper making. *Waste Management*. 60: 127-139.

Keller, F. A., Hamilton, J. E. and Nguyen, Q. A. 2003. Microbial pretreatment of biomass potential for reducing severity of thermo-chemical biomass pretreatment. *Applied Biochemistry and Biotechnology*. 105: 27–41.

Khider, T. O., Omer, S. H. and Elzaki, O. T. 2012. Soda and soda-anthraquinone pulping of *Albizia lebbeck* from Sudan Suranaree. *Journal of Science and Technology*. 18(3): 1-5.

Lopez, F., Eugenio, M. E., Diaz, M. J., Nacimiento, J. A., Garcia, M. M. and Jimenez, L. 2005. Soda pulping of sunflower stalks. Influence of process variables on the resulting pulp. *Journal of Industrial and Engineering Chemistry*. 11(3): 387–394.

Malik, S., Rana, S., Joshi, G., Gupta, P. K. and Sharma, A. 2020. Valorization of wheat straw for the paper industry: Pre-extraction of reducing sugars and its effect on pulping and papermaking properties. *ACS Omega*. 5: 30704-30715.

Omar, N. N., Abdullah, N., Mustafa, I. S. and Sulaiman, F. 2018. Characterisation of oil palm frond for bio-oil production. *ASM Science Journal*. 11(1): 9-22.

Patrabansh, S. and Madan, M. 1997. Studies on cultivation, biological efficiency and chemical analysis of *Pleurotus sajor-caju* (fr.) Singer on different bio-wastes. *Acta Biotechnologica*. 17 (2): 107–122.

Pokhrel, D. and Viraraghavan, T. 2004. Treatment of pulp and paper mill wastewater: a review. *Science of Total Environment*. 333: 37–58.

Ravindra, K., Singh, T. and Mor, S. 2019. Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. *Journal of Cleaner Production*. 208: 261-273.

Reddy, G. V., Babu, P. R., Komaraiah, P., Roy, K. R. M. and Kothari, I. L. 2003. Utilization of banana waste for the production of lignolytic and cellulolytic enzymes by solid substrate fermentation using two *Pleurotus* species (*P. ostreatus* and *P. sajorcaju*). *Process Biochemistry*. 38: 1457–1462.

Rodriguez, A., Sanchez, R., Requejo, A. and Ferrer, A. 2010. Feasibility of rice straw as a raw material for the production of soda cellulose pulp. *Journal of Cleaner Production*. 18(10): 1084–1091.

Rudi, H., Resalati, H., Eshkiki, R. B. and Kermanian, H. 2016. Sunflower stalk neutral sulfite semi-chemical pulp: an alternative fiber source for production of fluting paper. *Journal of Cleaner Production*. 127: 562-566.

Scott, G. M., Akhtar, M., Lentz, M. J., Horn, E., Swaney, R.

E. and Krik, T. K. 1998. An overview of biopulping research: Discovery and engineering. *Journal of Korea TAPPI*. 30(4): 18-27.

Shakhes, J., Marandi, M. A. B., Zeinaly, F., Saraian, A. and Saghafi, T. 2011. Tobacco residuals as promising lignocellulosic materials for pulp and paper industry. *Bio Resources*. 6: 4481-4493.

Singh, P., Sulaiman, O., Hashim, R., Peng, L. C. and Singh, R. P. 2013. Evaluating biopulping as an alternative application on oil palm trunk using the white-rot fungus *Trametes versicolor*. *International Biodeterioration & Biodegradation*. 82: 96-103.

Tutus, A. and Eroglu, H. 2004. An alternative solution to the silica problem in wheat straw pulping. *Appita Journal Australia*. 57: 214-217.

Van Thanh, T., Thao, N. T. P., Hieu, T. T., Braunegg, S., Schnitzer, H., Braunegg, G., Van Tung,T. and Le, S. 2020. An integrated eco-system for pollution prevention and greening the production chain of small-scale rice-paper production–A case study from Vietnam. *Journal of Cleaner Production*. 245: 118785.

Yaghoubi, K., Pazouki, M. and Shojaosadati, S. A. 2008. Variable optimizationfor biopulping of agricultural residues by *Ceriporiopsis subvermispora*. *Bioresource Technology*. 99: 4321-4328.

Yiin, C. L., Ho, S., Yusup, S., Quitain, A. T., Chan, Y. H., Loy, A. C. M. and Gwee, Y. L. 2019. Recovery of cellulose fibers from oil palm empty fruit bunch for pulp and paper using green delignification approach. *Bioresource Technology*. 290: 12179.