Binderless Board Made from Composted Rice Straw as Substrate for Rice Seedlings

Bin Fu,[a] Enhui Sun,[b] Cheng Yong,[b] Ling Chen,[b] Zhenggui Wei,[a] Hongying Huang,[b] Bin Gao,[c] and Ping Qu [b,]*

A binderless board was produced from mechanically dissociated compost straw *via* suction filtration. The binderless board was applied to replace the topsoil that is currently used predominantly as the substrate for rice seedlings in China. The binderless board showed the highest tensile strength when the rice straw had been composted for 20 days. The bulk density, aeration, and total porosity of the binderless board showed an increasing trend with composting time, due to the increased decomposition of rice straw. The examination of the growth parameters and root morphology of the rice seedlings showed that electrical conductivity (EC), pH, and nutrient content of the binderless board made from rice straw composted for 10 days were conducive to the growth of seedlings. Polyphenols inhibited rice seedling height and shoot weight and promoted the rice seedling stem diameter and root weight. Considering the quality loss, growth index, and the strength of the binderless board, 10 days of composting is the optimal condition. These results indicate that binderless board can replace top soil and peat when used as the substrate for rice seedling.

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Keywords: Binderless board; Substrate; Rice seedling; Straw fiber; Compost

*Contact information: a: School of Environment, Nanjing Normal University, Nanjing, China; b: Institute of Agricultural Resources and Environment, Jiangsu Academy of Agricultural Sciences, Jiangsu Collaborative Innovation Center for Solid Organic Waste Resource Utilization, Key Laboratory for Agricultural Environment at the Lower Reach of the Yangtze River Plain, Ministry of Agriculture and Rural Affairs, Nanjing, China; c: Department of Agricultural and Biological Engineering, University of Florida, Homestead, FL, 33031, USA; *Corresponding author: qupinghappy@163.com*

INTRODUCTION

Rice is a main food source for almost one-third of the world’s population (Jafari *et al.* 2018). China is the largest producer and consumer of rice in the world, and approximately 20% of China’s arable lands, about 30,000,000 ha, is devoted to paddy cultivation (Li *et al.* 2016). As the population increases, the rice yield in China is expected to increase to 7,850 kg/ha by 2030, resulting in a total of 200 million kg of rice straw per year (Chen *et al.* 2011). However, rice straw is often considered as solid waste due to its limited industrial application. Therefore, it is necessary to develop new ways to utilize rice straw.

In China, about 40% of paddy cultivation need rice seedlings. At present, the main substrate used for rice seedlings is the high-quality farmland topsoil. Additionally, about 1,2960,000 m^3 top soil are needed for cultivating rice seedlings every year. This has many disadvantages, such as serious damage to topsoil and, inconvenient transportation. The more serious problem is that many places are now facing a lack of high-quality topsoil to take. Therefore, it is necessary to develop new and renewable substrates to replace the surface soil.

Straw not only stores more than half of the photosynthesis products of crops, but it also contains a large amount of nitrogen, phosphorus, potassium, and trace elements absorbed from the soil during crop growth. The rice straw possesses the potential for substrate utilization. Composting has been regarded as the best method for substrate utilization, ensuring maximum circulation of material and energy within the agricultural system (Hong *et al.* 2016; Zhong *et al.* 2018). The composting process can eliminate phytotoxicity, weed seeds, and pathogens, reduce the quantity and volume of biomass materials, and decrease the carbon-nitrogen (C/N) ratio. The organic matter can be stabilized by composting and transforming to "humus" (Zhu *et al.* 2021). Belal and El-Mahrouk showed that the compost from rice straw can partially or totally replace peat moss and vermiculite for ornamental plant nurseries (Belal and El-Mahrouk 2010; Vaughn *et al.* 2013). Many studies have shown that the organic residues from composting can be used as growth media (Ng *et al.* 2015; Barrett *et al.* 2016; Idrovo-Novillo *et al.* 2018 Jeong *et al.* 2018). However, these are discontinuous scattered substrates and need to be packed in containers for seedlings.

The composting process not only decomposes the wax on the surface of straw but it also partially dissociates the cellulose, hemicellulose, and lignin (Qu *et al.* 2017). The length to diameter ratio, and specific surface area of straw fibers resulting from controlled composting are not big enough to form the binderless board. Mechanical refining technologies are used to reduce straw particle size, dissociate the fibers, decrease cellulose crystallinity, increase specific surface area, and enhance the interfacial bonding force by cutting, shearing, and compression (Sandberg *et al.* 2020). After the mechanical refining, the binderless board is produced on a three-dimensional filter mold using vacuum. Water was removed from the board in a drying tunnel at 160 °C. Hydrogen bonds and Van der Waals forces were formed between fibers in the drying process. The binderless board must have a certain strength when it is dry for the transportation. It was not necessary to remain strong in the presence of water for the application. Besides, the aeration porosity and water-holding porosity were also important indices for growing seedlings. The binderless board with a certain strength can substitute for plastic growing trays, thus reducing pollution from petroleum-based plastics. In addition, using the straw board can result in considerable savings in cost and labor compared to traditional top soil that are in use.

To reduce damage to the farmland topsoil, binderless board from straw is proposed as the growing media for rice seedlings. The overarching objective of this study is to produce binderless board for rice seedlings by suction molding. The chemical and physical properties during the composting were investigated. The porosity, nutrient, and polyphenol content of binderless boards were evaluated. The effects of composting time on the mechanical properties of the binderless board, and on seedling growth in it were tested.

EXPERIMENTAL

Materials and Preparation

Rice straw obtained from local farms (Nanjing, China) was ground to 2 to 3 cm size. Urea (Jiangsu Linggu Chemical Co., Ltd., Jiangsu, China) was applied to adjust the C/N ratio to 25:1. The moisture content was approximately 50% during the entire process. The composting was performed in a container (3m×3m×3m) with mechanical ventilation.

The compost was manually turned over every five days. Temperature probes were placed at five different locations in the middle of the compost pile to test the composting temperature (Fig. 1), and the average temperature recorded daily. Samples were collected at 10, 20, 30, and 40 days. All samples were stored at -20 °C, for further analysis.

The binderless board was produced as follows: the compost from rice straw was defibered at the concentration of 3% for 8 min in the beater (JKCT-SJA; Suzhou Jinke Automation Equipment Co., Ltd., Suzhou, China); the pH of the solution was adjusted to 5 with H_2SO_4. After pulping, the refined pulp was transported to the pulp molding machine using pumps. The binderless board was molded into board (28 cm × 58 cm ×1.5 cm) with pulp molding dies at a suction pressure of -0.06 MPa and suction time of 1 s (JKF-9060; Suzhou Jinke Automation Equipment Co., Ltd., Suzhou, China). The binderless boards with composting times of 0, 10, 20, 30, and 40 days are referred to as T0, T10, T20, T30, and T40, respectively. The tested rice variety was Nanjing 46, and the sowing amount was 160g/block. The seedling raising site was the intelligent greenhouse of Jiangsu Academy of Agricultural Sciences (118.8755106 E 32.033657295 N).

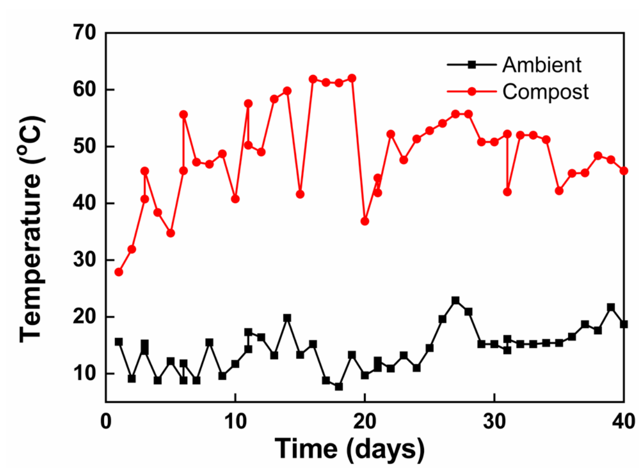

Fig. 1. Ambient temperature and compost temperature of the pile during the composting process

Analytical Methods

The nitrogen, phosphorus, and potassium content of the binderless board were tested using the Kjeldahl method (Kjeldahl 1883), Kitson and Mellon method (Kitson and Mellon 1944), and flame photometry (FP6450 Flame Photometer; Shanghai Xinyi Instrument Co., Ltd., Shanghai, China). Mechanical properties of the straw-based board were established by a tensile testing machine (HY-0580; Shanghai Hengyi Precision Instrument, Shanghai, China). The aeration porosity, water-holding porosity, and total porosity of the binderless board are represented by Eq. 1, 2, and 3,

$$\text{Aeration porosity (\%)} = [(W_1 - W_2) / V] \times 100 \quad (1)$$

$$\text{Water-holding porosity (\%)} = [(W_2 - W_3) / V] \times 100 \quad (2)$$

$$\text{Total porosity (\%)} = \text{Aeration porosity (\%)} + \text{Water-holding porosity (\%)} \quad (3)$$

where W_1, W_2, and W_3 are the weights (g) of the binderless board after immersing in water for 24 h, draining away the water, and air-drying at room temperature, respectively. Over a growth period of 21 days, the growth parameters were recorded, including weight of fresh roots, seedling height, root length, stem diameter, leaf area, and dry weight.

Seedling index was calculated according to Eq. 4 (Kuo *et al*. 2019):

Seedling index = (Stem diameter / Seedling height + Dry weight of root/dry weight of shoot) × (Dry weight of root + Dry weight of shoot) (4)

Statistical Analysis

Statistical analysis was performed on the data using one-way analysis of variance (ANOVA), with composting time as one factor, using the SPSS software (Version 17.0, IBM, Chicago, IL, USA). The variations in the mean obtained for the three treatment methods were compared by calculating the least significant difference (LSD), equal to mean ± standard deviation (SD), for the three replicates.

RESULTS AND DISCUSSION

Process of Binderless Board Production

During composting, the rice straw was stabilized and became beneficial for the growth of the seedlings (Wei *et al.* 2019). In addition, the hydrogen bond and cell wall structure in the composted straw broke down easily in the hydrapulper due to shear forces, and the pulp was converted into smaller particles of cellulose fiber. After passing through the pulping system, the pulp was transferred to the adsorption molding machine. The binderless board was shaped by suction filtration and pressing (Fig. 2). Water was then removed from the board in the drying tunnel. The paddy seeds can now be germinated in the binderless board.

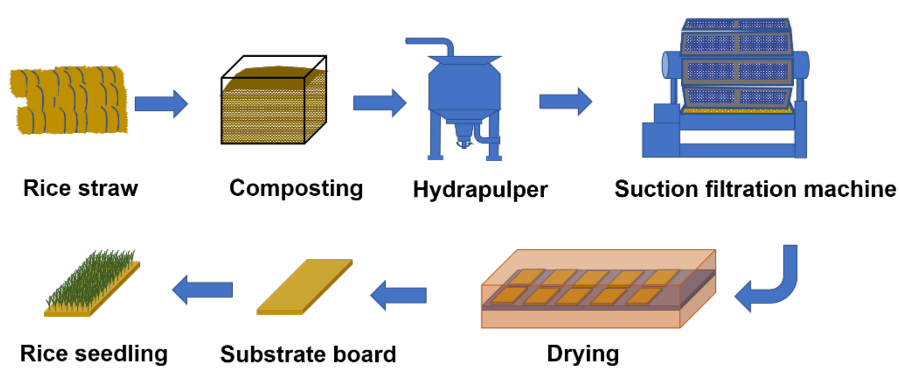

Fig. 2. Schematic illustration of binderless board production

Tensile Strength of Binderless Board

The tensile strength of the binderless board first increased and then decreased with the composting time (Fig. 5). The tensile strength of the binderless board depends on various factors, such as bonding degree of the fiber network (fiber-fiber contact area and joint strength), fiber length, strength, and orientation (Hollertz *et al.* 2017). During the forming process, the straw fibers can bond with one another and form a network when dried. The waxy layer on the surface of the straw is not decomposed in the early days of composting, and they cannot form well-knit networks. A longer composting time resulted in more components being broken down and more fine fibers formed due to the action of the beater. Rice straw after 20 days of composting had the highest tensile strength. The shorter and weaker fibers were formed after 30 and 40 days of composting; the fiber bonding ability and mechanical interlocking of fibers were weaker, which results in reduced tensile strength. It has been reported that tensile strength of paper mainly depended on the bonding ability of fibers (Taipale *et al.* 2010; Li *et al.* 2017; Yang *et al.* 2017). The main reason may be that the binding function groups, such as –OH and –COOH, are decomposed and prevents the formation of fiber network structures, leading to the decrease in bonding capacity among the straw fibers.

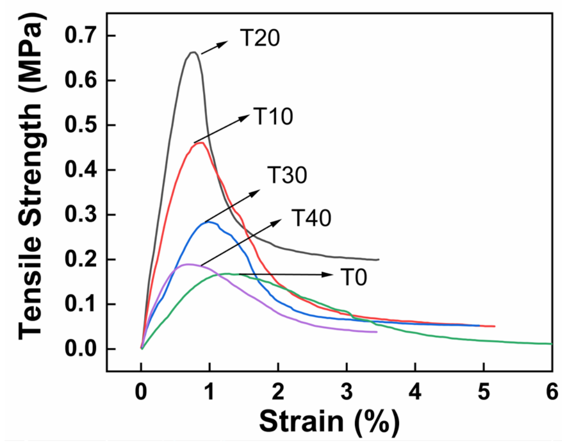

Fig. 3. Tensile strength of binderless board

Physical Properties of Binderless Board

Media porosity is a significant factor affecting plant growth (Meyer and Cunliffe. 2004). The straw composting for 0, 10, 20, 30, and 40 days, resulted in aeration porosities of 6.02%, 7.44%, 8.98%, 19.54%, and 21.06%, and water holding porosities of 43.02%, 46.34%, 53.54%, 67.35%, and 66.19%, respectively (Table 1). The aeration porosity and total porosity showed an increasing trend with composting time. The reason may be the decomposed cellulose, lignin, and hemicellulose in rice straw produced a large amount of micropores.

Table 1. Physical Properties of Binderless Board

	Bulk Density (g/cm^3)	Aeration Porosity (%)	Water Holding Porosity (%)	Total Porosity (%)	EC (ms/cm)	pH
T0	0.12 ± 0.01	6.02 ± 0.12	43.02 ± 0.23	49.04 ± 0.32	1.28 ± 0.16	5.23 ± 0.17
T10	0.13 ± 0.02	7.44 ± 0.11	38.9 ± 0.21	46.34 ± 0.31	1.32 ± 0.25	5.39 ± 0.15
T20	0.14 ± 0.01	8.98 ± 0.09	44.56 ± 0.18	53.54 ± 0.32	1.36 ± 0.31	5.54 ± 0.09
T30	0.16 ± 0.03	19.54 ± 0.05	47.81 ± 0.17	67.35 ± 0.29	1.29 ± 0.19	5.38 ± 0.11
T40	0.18 ± 0.02	21.06 ± 0.08	45.13 ± 0.20	66.19 ± 0.24	1.65 ± 0.21	5.54 ± 0.02

The physical parameters, such as bulk density, aeration porosity, and total porosity, are important parameters to be considered in the preparation of growing media (Moldes *et al.* 2007). Bulk density increased with the composting time due to the decomposition of rice straw by microorganisms. The same phenomenon was observed for porosity with more micropores formed during the composting process. As can be seen in Fig. 4, the straw surface becomes uneven and loose with the decomposition of its components. These results are beneficial for the growth of seedlings. However, the EC and pH increased with composting time. The higher EC and pH are not conducive to seed germination and growth. It is well known that the suitable pH for most crops is in the range of 5 to 7 because all essential nutrients are available to the plant and harmful microbial activity are inhibited at these pH values (Zhang *et al.* 2012). The indictor of desirability and quality of the substrate is the EC (Mininni *et al.* 2013). Higher EC levels have the potential to provide the nutrients for the growth of seedlings (Medina *et al.* 2009; Tittarelli *et al.* 2009; Carmona *et al.* 2012).

Nutrient and Polyphenol Content of Binderless Board

The nitrogen, phosphorus, and potassium content of the substrate block increased with the composting process due to the mass loss caused by straw decomposition (Table 2). Polyphenols are known to have phytotoxic and antimicrobial effects. Polyphenols and antioxidant phytochemicals exist in plant material; high levels of polyphenols hinder seed germination (Northup *et al.* 1998). Polyphenol content of composted straw for 0, 10, 20, 30, 40 days are 8.09, 15.51, 7.13, 5.94, and 4.27 mg/g, respectively. Polyphenol content increased and then decreased during the composting process due to the degradation and polymerization of phenolic substances (Bustamante *et al.* 2008).

Table 2. The Nutrient Content of Substrate Block

Sample	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Available Nitrogen (g/kg)	Available Phosphorus (g/kg)	Available Potassium (g/kg)
T0	9.54 ± 0.11	1.18 ± 0.53	7.41 ± 1.13	0.83 ± 0.05	0.389 ± 0.98	2.87 ± 1.98
T10	10.01 ± 0.09	1.35 ± 0.34	11.45 ± 0.76	1.29 ± 0.13	0.67 ± 0.12	5.87 ± 1.18
T20	10.79 ± 0.13	1.47 ± 0.25	17.99 ± 0.45	1.45 ± 0.28	0.85 ± 0.15	12.62 ± 0.98
T30	12.22 ± 0.11	1.53 ± 0.32	22.56 ± 0.51	1.62 ± 0.17	0.91 ± 0.13	13.26 ± 1.53
T40	12.82 ± 0.21	1.95 ± 0.21	25.27 ± 0.43	2.25 ± 0.15	1.17 ± 0.09	14.27 ± 1.78

Growth Parameters of Rice Seedling

The seedlings grown in substrate made with straw composted for 10 days showed the best seedling index. The seedling index is a composite index that integrates many single indexes and is more comprehensive in evaluating seedling. So, it is generally used as the basic quantitative index of seedling evaluation. In this case, T10 proved to be a suitable substrate for germinating rice seedlings. The results for rice offer proof that it is possible to use compost from rice straw for seedling production in nurseries. Nutrient and water absorbing organs such as roots can affect grain yield and quality (Pan *et al.* 2016). The water and nutrient uptake are remarkably influenced by the morphological characteristics of the root system. The root morphological characteristics can also be affected by the root growth environment (Panu *et al.* 2016). The root length, surface area, average diameter, volume, tips, and forks of rice seedlings are listed in Table 3. The roots grow better in composted straw than in fresh straw; the root growth is influenced by the nitrogen content in the growing media (Liu *et al.* 2018). The results from this study show that composting time within a range of 10 to 40 days had no obvious effect on the root growth of rice seedlings. Seedling growth parameters are listed in Table 4. The seedling growth index of rice seedlings improved with the increase of polyphenols content in the binder-less board with composting time from 10 to 40 days. The polyphenols content and the seedling growth index showed significant positive correlations with coefficients of correlation (R^2) above 0.9, indicating that the polyphenols were conducive to improve the index of rice seedlings (Fig. 6). Namely, the polyphenols inhibited rice seedling height and shoot weight, and promoted the rice seedling stem diameter and root weight.

Table 3. Root Morphological Traits of Rice Seedlings

Sample	Length (cm)	Surface Area (cm^2)	Average Diameter (mm)	Root Volume (cm^3)	Tips	Forks
T0	164.63	11.55	0.22	0.066	2339	1134
T10	165.18	11.69	0.23	0.067	2600	1022
T20	168.60	12.11	0.23	0.069	2625	1011
T30	166.94	11.76	0.23	0.067	2624	1157
T40	169.75	12.28	0.23	0.071	2619	1009

Table 4. Growth Parameters of Rice Seedlings

Samples	Seedling Height (mm)	Stem Diameter (mm)	Fresh Weight (g)		Dry Weight (g)		Seedling Index
			Root	Shoot	Root	Shoot	
T0	175.24 ± 1.21	2.64 ± 0.25	0.17 ± 0.01	0.23 ± 0.01	0.017 ± 0.002	0.029 ± 0.001	0.028
T10	179.24 ± 2.12	2.84 ± 0.35	0.21 ± 0.02	0.29 ± 0.02	0.023 ± 0.001	0.031 ± 0.002	0.052
T20	180.3 ± 1.56	3.29 ± 0.15	0.28 ± 0.01	0.33 ± 0.01	0.027 ± 0.003	0.033 ± 0.002	0.041
T30	285.77 ± 1.69	2.82 ± 0.18	0.19 ± 0.03	0.33 ± 0.02	0.021 ± 0.002	0.032 ± 0.003	0.036
T40	279.92 ± 1.54	2.85 ± 0.12	0.16 ± 0.01	0.27 ± 0.01	0.017 ± 0.004	0.029 ± 0.002	0.028

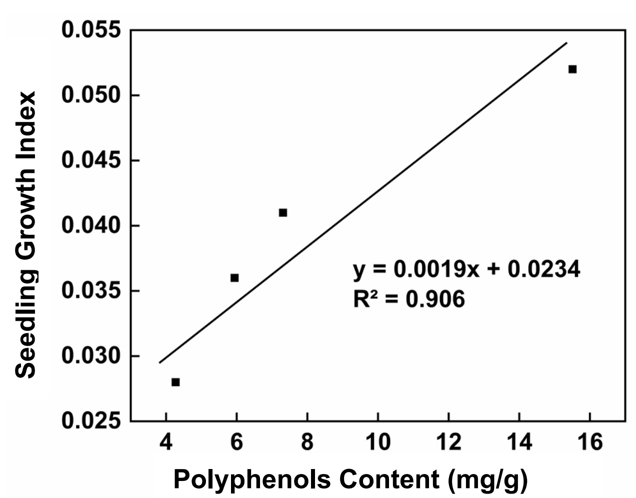

Fig. 4. The correlation plot of polyphenols content *vs.* seedling growth index

Cost Analysis and Application Prospects

The weight losses at 10, 20, 30, and 40 days were 16.8%, 25.7%, 35.1%, and 44.2%, respectively. The mass loss increased linearly with composting time. Because excessive mass loss will increase the production cost of the straw block matrix, the suitable composting time for rice straw was judged to be 10 days. The production cost of the binderless board calculated based on the annual production of 15 million pieces is 0.01 dollar/block. The size of the binderless board is 28 cm × 58 cm ×1.5 cm, which matches with the existing rice transplanter (Fig. 5). Therefore, binderless board produced from rice straw can replace the nonrenewable top soil and peat when used as the substrate for rice seedling.

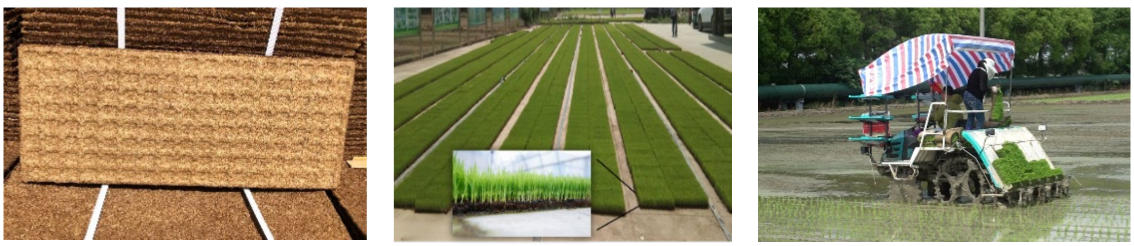

Fig. 5. Picture of the substrate board, rice seedling, mechanical transplanting

CONCLUSIONS

1. Rice straw was subjected to composting, mechanical dissociation, and suction filter molding to produce binderless board as a substitute for using topsoil. With the decomposition of lignin and hemicellulose, cellulose was increasingly exposed, and smaller microfibrils were formed. All samples possessed a crystalline structure, which allowed them to retain the strength to form a fibrous network.
2. After 20 days of composting, the rice straw had the highest tensile strength due to the well-knit network among the fibers. High physical parameters, such as bulk density, aeration porosity, and total porosity are conducive to seed germination and growth.
3. The seedlings grown in substrate produced with straw composted for 10 days exhibited the best growth parameters. Polyphenols inhibited rice seedling height and shoot weight and promoted the rice seedling stem diameter and root weight.
4. Mass loss, growth index, and binderless board strength, all the three criteria are important. Compost for 10 days can kill pathogenic bacteria and weed seeds. And the tensile strength can be improved. Considering mass loss and growth index, the composting time for 10days is the optimal condition. It is highly recommended that binderless board is a suitable topsoil substitute for rice seedlings.

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REFERENCES CITED

Barrett, G. E., Alexander, P. D., Robinson, J. S., and Bragg, N. C. (2016). "Achieving environmentally sustainable growing media for soilless plant cultivation systems – A review," *Scientia Horticulture* 212, 220-234. DOI: 10.1016/j.scienta.2016.09.030

Belal, E. B., and El-Mahrouk, M. E. (2010). "Solid-state fermentation of rice straw residues for its use as growing medium in ornamental nurseries," *Acta Astronaut.* 67(9-10), 1081-1089. DOI: 10.1016/j.actaastro.2010.06.030

Bustamante, M. A., Paredes, C., Marhuenda-Egea, F. C., Pérez-Espinosa, A., Bernal, M. P., and Moral, R. (2008). "Co-composting of distillery wastes with animal manures: Carbon and nitrogen transformations in the evaluation of compost stability," *Chemosphere* 72(4), 551-557. DOI: 10.1016/j.chemosphere.2008.03.030

Carmona, E., Moreno, M. T., Avilés, M., and Ordovás, J. (2012). "Use of grape marc compost as substrate for vegetable seedlings," *Scientia Horticulture* 137, 69-74. DOI: 10.1016/j.scienta.2012.01.023

Chen, M., Shelton, A., and Ye, G. Y. (2011). "Insect-resistant genetically modified rice in China: From research to commercialization," *Annu. Rev. Entomol.* 56, 81-101. DOI: 10.1146/annurev-ento-120709-144810

Hollertz, R., Durán, V. L., Larsson, P. A., and Wagberg, L. (2017). "Chemically modified cellulose micro- and nanofibrils as paper-strength additives," *Cellulose* 24(9), 3883-3899. DOI: 10.1007/s10570-017-1387-6

Hong, J., Ren, L., Hong, J., and Xu, C. (2016). "Environmental impact assessment of corn straw utilization in China," *J. Clean. Prod.* 112, 1700-1708. DOI: 10.1016/j.jclepro.2015.02.081

Idrovo-Novillo, J., Gavilanes-Terán, I., Angeles Bustamante, M., and Paredes, C. (2018). "Composting as a method to recycle renewable plant resources back to the ornamental plant industry: Agronomic and economic assessment of composts," *Process Saf. Environ. Prot.* 116, 388-395. DOI: 10.1016/j.psep.2018.03.012

Jafari, H., Kalantari, D., and Azadbakht, M. (2018). "Energy consumption and qualitative evaluation of a continuous band microwave dryer for rice paddy drying," *Energy* 142, 647-654. DOI: 10.1016/j.energy.2017.10.065

Jeong, S. T., Kim, G. W., Hwang, H. Y., Kim, P. J., and Kim, S. Y. (2018). "Beneficial effect of compost utilization on reducing greenhouse gas emissions in a rice cultivation system through the overall management chain," *Sci. Total Environ.* 613-614, 115-122. DOI: 10.1016/j.scitotenv.2017.09.001

Kuo, W. R., Yeh, N. C., Fujimoto, N., and Lin, H. C. (2019). "Physicochemical properties and fertility index of culture media containing distillery residue biochar and their applications to plug seedling," *J. Fac. Agric. Kyushu. Univ.* 64(1), 127-135. DOI: 10.5109/2232296

Kitson, R. E., and Mellon, M. G. (1944). "Colorimetric determination of phosphorus as molybdivanadophosphoric acid," *J. Ind. Eng. Chem. Anal.* 16(6), 379-383. DOI: 10.1021/i560130a017

Kjeldahl, C. (1883). "A new method for the determination of nitrogen in organic matter," *Z. Anal. Chem.* 22, article no. 366.

Li, H., Yang, J., Li, P., Lan, T., and Peng, L. (2017). "A facile method for preparation superhydrophobic paper with enhanced physical strength and moisture-proofing property," *Carbohydr. Polym.* 160, 9-17. DOI: 10.1016/j.carbpol.2016.12.018

Li, Y., Hallerman, E. M., Liu, Q., Wu, K., and Peng, Y. (2016). "The development and status of *Bt* rice in China," *Plant Biotechnol. J.* 14(3), 839-848. DOI: 10.1111/pbi.12464

Liu, K., He, A., Ye, C., Liu, S., and Zhang, Y. (2018). "Root morphological traits and spatial distribution under different nitrogen treatments and their relationship with grain yield in super hybrid rice," *Sci. Rep.-UK.* 8(1), article no. 131. DOI: 10.1038/s41598-017-18576-4

Medina, E., Paredes, C., Perez-Murcia, M. D., Bustamante, M. A., and Moral, R. (2009). "Spent mushroom substrates as component of growing media for germination and growth of horticultural plants," *Bioresource Technol.* 100(18), 4227-4232. DOI: 10.1016/j.biortech.2009.03.055

Meyer, M. H., and Cunliffe, B. A. (2004). "Effects of media porosity and container size on overwintering and growth of ornamental grasses," *HortScience* 39(2), 248-250. DOI: 10.21273/hortsci.39.2.248

Mininni, C., Bustamante, M., Medina, E., Montesano, F., Paredes, C., Pérez-Espinosa, A., Moral, R., and Santamaria, P. (2013). "Evaluation of posidonia seaweed-based compost as a substrate for melon and tomato seedling production," *J. Hortic. Sci. Biotechnol.* 88(3), 345-351. DOI: 10.1080/14620316.2013.11512975

Moldes, A., Cendon, Y., and Barral, M. T. (2007). "Evaluation of municipal solid waste compost as a plant growing media component, by applying mixture design," *Bioresource Technol.* 98(16), 3069-3075. DOI: 10.1016/j.biortech.2006.10.021

Ng, L. C., Sariah, M., Radziah, O., Zainal Abidin, M. A., and Sariam, O. (2015). "Development of microbial-fortified rice straw compost to improve plant growth, productivity, soil health, and rice blast disease management of aerobic rice," *Compost. Sci. Util.* 24(2), 86-97. DOI: 10.1080/1065657X.2015.1076750

Northup, R. R., Dahlgren, R. A., and McColl, J. G. (1998). "Polyphenols as regulators of plant-litter-soil interactions in northern California's pygmy forest: A positive feedback?" *Biogeochemistry* 42, 189-220. DOI: 10.1023/A:1005991908504

Pan, S., Liu, H., Mo, Z., Patterson, B., Duan, M., Tian, H., Hu, S., and Tang, X. (2016). "Effects of nitrogen and shading on root morphologies, nutrient accumulation, and photosynthetic parameters in different rice genotypes," *Sci Rep.* 6, article no. 32148. DOI: 10.1038/srep32148

Qu, P., Huang, H., Zhao, Y., and Wu, G. (2017). "Physicochemical changes in rice straw after composting and its effect on rice-straw-based composites," *J. Appl. Polym. Sci.* 134(22), article ID 44878. DOI: 10.1002/app.44878

Sandberg, C., Hill, J., and Jackson, M. (2020). "On the development of the refiner mechanical pulping process-a review," *Nord. Pulp. Pap. Res. J.* 35(1), 1-17. DOI: 10.1515/npprj-2019-0083

Taipale, T., Österberg, M., Nykänen, A., Ruokolainen, J., and Laine, J. (2010). "Effect of microfibrillated cellulose and fines on the drainage of kraft pulp suspension and paper strength," *Cellulose* 17(5), 1005-1020. DOI: 10.1007/s10570-010-9431-9

Tittarelli, F., Rea, E., Verrastro, V., Pascual, J., Canali, S., Ceglie, F., Trinchera, A., and Rivera, C. (2009). "Compost-based nursery substrates: Effect of peat substitution on organic melon seedlings," *Compost Sci. Util.* 17(4), 220-228. DOI: 10.1080/1065657X.2009.10702427

Vaughn, S. F., Kenar, J. A., Thompson, A. R., and Peterson, S. C. (2013). "Comparison of biochars derived from wood pellets and pelletized wheat straw as replacements for peat in potting substrates," *Ind. Crop. Prod.* 51, 437-443. DOI: 10.1016/j.indcrop.2013.10.010

Wei, Y. Q., Wu, D., Wei, D., Zhao, Y., Wu, J. Q., Xie, X. Y., Zhang, R. J., and Wei, Z. M. (2019). "Improved lignocellulose-degrading performance during straw composting from diverse sources with actinomycetes inoculation by regulating the key enzyme activities," *Bioresour. Technol*. 271, 66-74. DOI: 10.1016/j.biortech.2018.09.081

Zhang, R. H., Duan, Z. Q., and Li, Z. G. (2012). "Use of spent mushroom substrate as growing media for tomato and cucumber seedlings," *Pedosphere* 22(3), 333-342. DOI: 10.1016/S1002-0160(12)60020-4

Zhong, Z., Bian, F., and Zhang, X. (2018). "Testing composted bamboo residues with and without added effective microorganisms as a renewable alternative to peat in horticultural production," *Ind. Crop. Prod.* 112, 602-607. DOI: 10.1016/j.indcrop.2017.12.043

Zhu, N., Zhu, Y. Y., Liang, D., Li, B. Q., Jin, H. M., and Dong, Y. W. (2021). "Enhanced turnover of phenolic precursors by *Gloeophyllum trabeum* pretreatment promotes humic substance formation during co-composting of pig manure and wheat straw," *J. Clean. Prod.* 315, article ID 128211. DOI: 10.1016/j.jclepro.2021.128211

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