

Application of Rice Husk as Water Treatment Agent and Soil Conditioner

Terri Zhuan Ean Lee¹, Nurul Aida Lu Mohd Irwan Lu¹, Nur Nadhirah Mohd. Razak², Mohd Effendi Wasli², Murtedza Mohamed¹, Siong Fong Sim^{1,*}

ABSTRACT

Aims: Rice husk was chemically treated as biosorbent for removal of humic substances from peat swamp runoff where the spent biosorbent was applied as soil conditioner for plant growth.

Study design: Randomized Complete Block Design.

Place and Duration of Study: Universiti Malaysia Sarawak, between September 2012 and Aug 2013.

Methodology: Rice husk was treated with sodium hydroxide and citric acid and subjected to peat swamp leachate to absorb humic substances. The humic loaded rice husk was then applied to grow *Brassica juncea* var. *rugosa* L. in six different treatments, each with five replicates, using Randomized Complete Block Design.

Results: The Fourier Transform Infrared spectra of rice husk are characterized by major absorption bands attributable to lignocellulosic compounds. Sodium hydroxide and citric acid treatment primarily removed lignin and hemicellulose increasing the binding sites thus enhancing its adsorption properties. An average of 60-70% of humic content was removed from peat swamp runoff based on the absorbance at 465 nm. The humic-loaded biosorbent was subsequently applied to *Brassica juncea rugosa* L. under six different treatments to examine its effectiveness in enhancing plant growth. These include planting media only (sand and topsoil at a ratio of 3:2), [planting media + fertilizer], [planting media + humic-modified rice husk + fertilizer], [planting media + modified rice husk + fertilizer], [planting media + raw rice husk], [planting media + raw rice husk + fertilizer]. Results showed that plants grown in humic-loaded modified rice husk and fertilizer exhibited significant improved plant growth followed by that in raw rice husk and fertilizer. Others were relatively less promising and comparable suggesting that humic fortified biomass could function as a soil conditioner to improve nutrient uptake.

Conclusion: The application of rice husk for water treatment and agriculture is an economically sustainable and environmental friendly approach.

Keywords: Chemically treated rice husk; water treatment; humic substances; adsorption; biosorbents; soil conditioner

1. INTRODUCTION

The production of paddy has increased over the past many years due to the high demands for food supply. Upon the high production of paddy, a huge amount of by-product, typically rice husk is generated. In Malaysia, approximately 562 600 tonnes of rice husk is produced annually [1]. It is a lignocellulosic biomass that is fundamentally composed of lignin, cellulose and hemicellulose with diverse functional groups such as hydroxyl, carbonyl, carboxylic, ether and etc. They have the ability to form bonding and interaction with ions presents in natural water therefore serving as potential biosorbents [2] nonetheless the biomass in its untreated state is often not readily functional. It releases organic substances giving rise to high total organic carbon thus low adsorption ability [3]. To enhance their adsorption ability, various chemical modification approaches involving alteration in the cross-linking of biomass and removal of cellulose and hemicellulose are introduced [4]. As a matter of fact, a wide range of biomass has been converted into effective biosorbent for removal of contaminants such as heavy metals and dyes from wastewater [5-9]. They have also been employed for treatment of organic pollutants with removal percentage ranging between 80 and 99.9% [10]. Obviously, application of low cost biosorbents for water purification and recycling process has been extensively studied encompassing laboratory (batch and column operations), pilot and process scale [11-12].

In this study, rice husk is chemically modified to serve as a dual function biosorbent, aiding at harvesting humic substances from organic rich water where the spent sorbent is subsequently applied to facilitate plant growth. The rationale of the study is that dissolved organic fractions, often known as humic substances, are found in considerable amount in natural water typically peat swamp runoff. The beneficial effects of humic substances in improving nutrient retention, increasing germination and stimulating root growth have been well established [13] nevertheless their presence in water causes characteristic yellowish to brownish color and unpleasant odor. Peat swamp tainted river is an important source of drinking water. In a conventional water treatment system, the humic content is coagulated using alum; the resultant sludge contains high amount of aluminium which is unsuitable for further use. With rice husk biosorbent, humic compounds can be harvested and converted into value-added product for agricultural purpose as soil conditioner. In this paper, we report the preparation and characterisation of the modified rice husk, application of the material for adsorption of humic substances and as soil conditioner for enhancing plant growth.

2. MATERIAL AND METHODS

2.1 Sample preparation

Rice husk was washed thoroughly under running tap water to remove dirt and foreign matters. The washed rice husk was oven dried at 105 °C and stored in air-tight container for further use.

2.2 Citric acid treatment

Rice husk was pre-treated with 0.5 M NaOH in water bath at 80 °C for 2 hours. They were then washed, oven dried and treated with 2.0 M citric acid in a water bath at 80 °C for 2 hours. Both treatments were conducted at a ratio of mass/volume of 1:3. The treated rice husk was washed to pH 3 and oven dried.

2.3 Functional groups and morphological characterization

2.3.1 Fourier Transform Infrared (FTIR)

All spectra of raw and modified rice husk were obtained on a Thermo Scientific FTIR system (Thermo Nicolet Analytical Instruments, Madison, WI) in triplicates using the KBr disc method with 2 mg sample in 100 mg KBr. The spectra range between 4000 and 400 cm^{-1} at a resolution of 4 cm^{-1} . In this paper, FTIR is employed to examine the changes before and after treatment semi-quantitatively where the relative abundance of bands are compared; this strategy has been reported elsewhere [14-17].

2.3.2 Scanning electron microscope (SEM)

The morphological characteristics were observed using a Scanning Electron Microscope (Model JEOL JSM-6390LA, Japan) with an accelerating voltage of 5kV at $\times 500$ magnification. Specimens were coated with thin film of platinum prior to examination.

2.4 Adsorption of humic substances

The treated rice husk was subjected to peat swamp runoff obtained from the Asa Jaya River in Sarawak, Malaysia. The river is highly colored and is surrounded with peat swamp. The removal efficiency was determined based on the absorbance at 465 nm using a UV-Vis spectrophotometer [17]. Note that this approach focuses on the fraction of humic that introduces color to water. Fundamentally, the absorbance is proportional to the concentration of dissolved organic carbon. If the organic matter is successfully removed, a reduction in absorbance is anticipated. The percentage of absorbance reduction against the absorbance of untreated water is calculated to suggest the removal percentage. A total of 1 g of NaOH-citric acid treated rice husk was agitated at 130 rpm with 20 mL of organic rich water for 15 min and eluted through a glass column at a flow rate of 1.0 mL/min. The dosage, contact time and flow rate were optimized using the one-factor-at-a-time approach, with six replicates for each experiment. The results are summarized in Table 1. The optimization may be alternatively performed based on full factorial designs. The design inherits several advantages over the traditional one-factor-at-a-time approach. It is relatively cheaper and less time consuming. In addition, the interaction between factors can be systematically evaluated permitting more efficient optimization [18].

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Table 1. Optimization of operating conditions

Factors	Parameters	Mean Absorbance	Percentage of Removal (%)
Dosage (mL)	20	0.030 ± 0.001 ^a	60.12 %
	40	0.044 ± 0.001 ^b	41.78 %
	60	0.050 ± 0.001 ^{cd}	33.71 %
	80	0.049 ± 0.001 ^c	35.96 %
	100	0.051 ± 0.001 ^d	32.98 %
Contact Time (min)	15	0.040 ± 0.001 ^a	47.68 %
	30	0.056 ± 0.001 ^b	26.86 %
	60	0.031 ± 0.001 ^c	59.60 %
	90	0.027 ± 0.001 ^d	64.12 %
	120	0.026 ± 0.001 ^d	65.50 %
Flow Rate (mL/min)	1	0.025 ± 0.001 ^a	67.15 %
	2	0.034 ± 0.001 ^b	55.81 %
	7	0.031 ± 0.001 ^c	58.82 %
	15	0.032 ± 0.001 ^{bc}	58.04 %

* Different letters in mean absorbance of each parameter for different factors indicating significant difference at $P = 0.05$ using Tukey's test.

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2.5 Pot trials

Pot trials were performed to evaluate the effectiveness of humic-loaded biosorbent as soil conditioner in improving plant growth using Randomized Complete Block Design (RCBD). *Brassica juncea* var. *rugosa* L. were planted into six treatments as summarized in Table 2 with six replicates. The planting media was sand and topsoil with a ratio of 3:2. For treatments involving fertilizers, NPK fertilizers were applied in split application with the dosage recommended by Shekhawat et al. [19]. In addition, the amount of humic composite applied was estimated and adapted from Rajpar et al. [20]. Note that all treatments were monitored under controlled environment i.e. water, light and pest control. The plant growth parameters namely length of stem, size of leaves and number of leaves were recorded once every fortnight. At the end of the pot trial, the dry matter and root-to-shoot ratio of harvested *Brassica juncea* var. *rugosa* L. were measured to determine the physiological growth of the tested plants.

119 **Table 2. Treatments for pot trials**
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Treatment	Details on plant growth media for each treatment
T1	Control (Planting media only)
T2	Planting media + NPK Fertilizer
T3	Planting media + Modified rice husk (with humic)
T4	Planting media + Modified rice husk (with humic) + NPK fertilizer
T5	Planting media + Raw rice husk
T6	Planting media + Raw rice husk + NPK fertilizer

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2.6 Data analysis

124 The FTIR spectra were analyzed using the peak detection algorithm reported by Sim and
 125 Ting [15]. The algorithm produces a peak table representing a summary of the peaks
 126 identified including the locations and the corresponding peak areas according to samples.
 127 The peak table was square rooted and standardized prior to Principal Component Analysis
 128 (PCA) to determine whether untreated and treated rice husk are distinguishable. The peaks
 129 detected were further examined to identify the alteration experienced upon treatment. For
 130 plant growth parameters, mean values and standard deviations were calculated from
 131 replicate measurements and statistical analysis using one-way ANOVA and Tukey's test, at
 132 95 % confidence interval were conducted using SPSS version 21.0.

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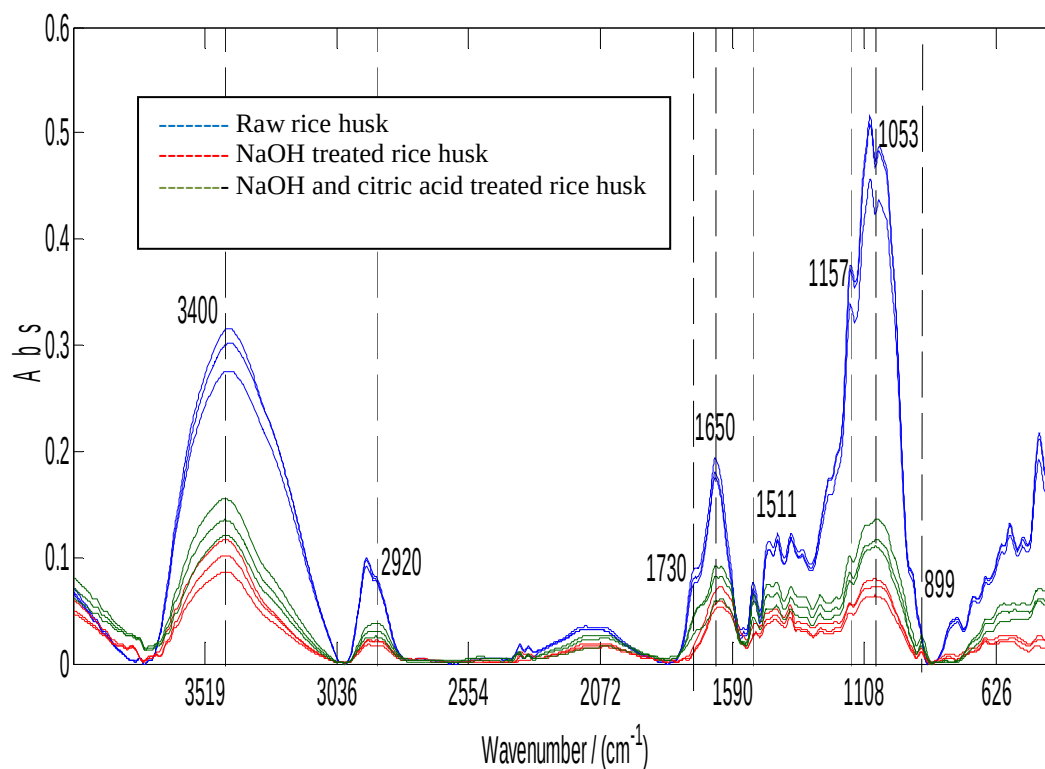
3. RESULTS AND DISCUSSION

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3.1 Characterization of rice husk biosorbents

138 Potential adsorbents usually contain porous spaces where the adsorption process is typically
 139 influenced by their surface area and polarity [21]. Raw biomasses are often not ready to
 140 function as biosorbent as their active functional groups are embedded within lignin and
 141 hemicellulose. Alkali and acid pretreatments are often incorporated to break down lignin and
 142 to hydrolyze cellulose and hemicellulose increasing the binding sites. Figure 1 illustrates the
 143 FTIR profiles of raw and treated rice husk. Fundamentally, the spectra are characterized by
 144 several major absorption bands attributable to the presence of lignocellulosic compounds at
 145 3400 cm^{-1} , $2920\text{--}2850\text{ cm}^{-1}$, $1700\text{--}1600\text{ cm}^{-1}$, 1511 cm^{-1} and 1157 cm^{-1} . The absorption
 146 band at 1157 cm^{-1} is assigned to the glycosidic linkages (C-O-C ring vibrational stretching)
 147 whilst those at $1700\text{--}1600\text{ cm}^{-1}$ and 3400 cm^{-1} are denoted to carbonyl and hydroxyl groups,
 148 respectively corroborating the findings of Adapa et al. [22]. The absorption band at 1511 cm^{-1}
 149 on the other hand is typically assigned to C=C stretching vibrations of aromatic rings of
 150 lignin. In this paper, FTIR is primarily used to examine changes experienced as a
 151 consequence of the treatment. The resultant peak table of the FTIR spectra was subjected
 152 to PCA yielding the scores plot of PC2 vs PC1 in Figure 2; as observed, untreated and
 153 treated samples are distinguishable.

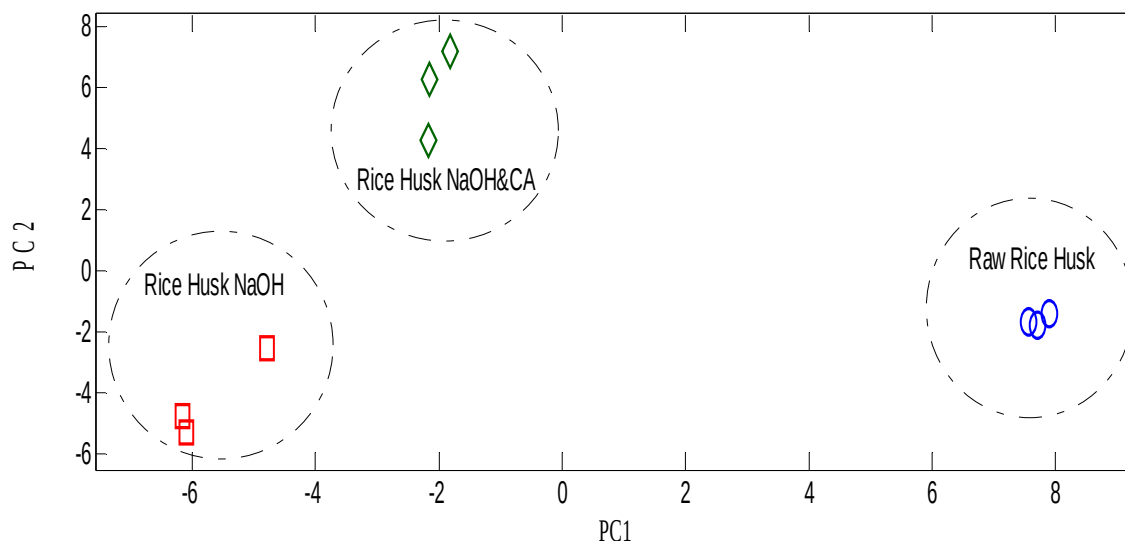
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Figure 1. The FTIR spectra of raw and modified rice husk

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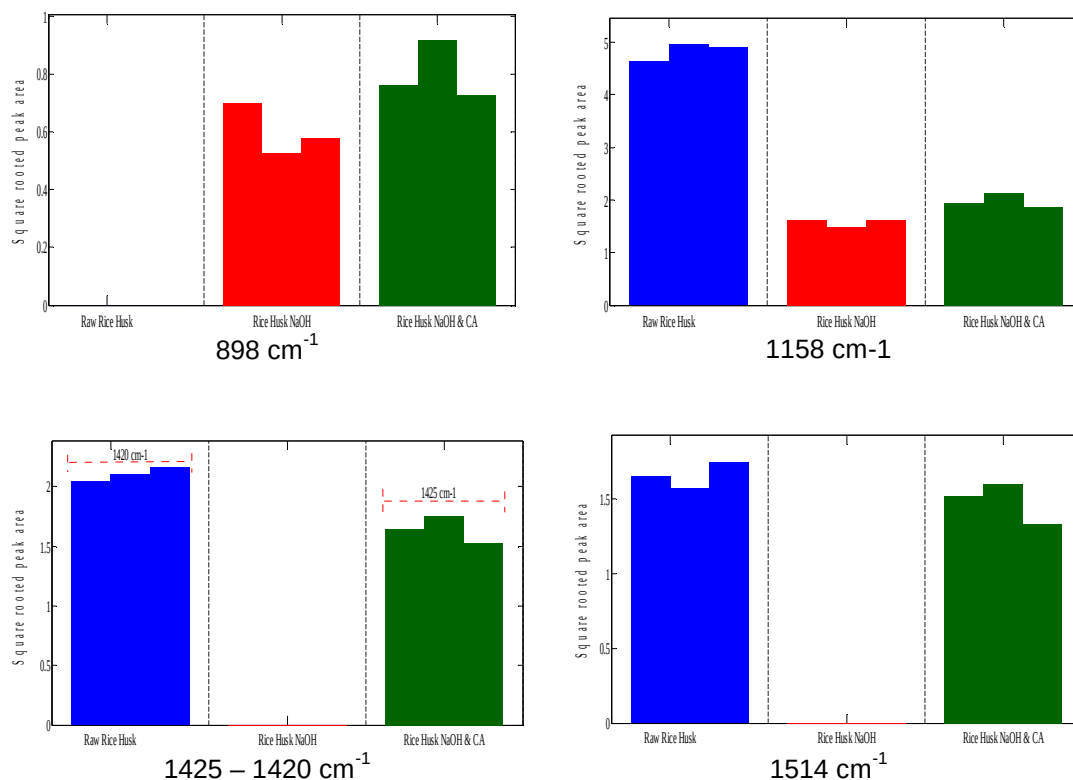
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Figure 2. The PCA scores plot of raw and modified rice husk

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The abundance of absorption bands identified is examined and compared across samples. Figure 3 illustrates the relative abundance of several absorption bands, indicative of lignocellulosic characteristics, before and after treatment. The band at 1157 cm^{-1} and 3400 cm^{-1} are markedly reduced suggesting hydrolysis of glycosidic and OH bonds, respectively. The absorbance at 1420 cm^{-1} and 894 cm^{-1} on the other hand are often employed to suggest the crystalline and amorphous properties of the cellulose structure. A smaller ratio of A_{1420}/A_{894} after treatment infers greater distortion [23]. The characteristic band of lignin at 1511 cm^{-1} is found to reduce in its intensity after NaOH pretreatment; this may have associated to the degradation of lignin. The band however is re-introduced and shifted to 1514 cm^{-1} after citric acid treatment possibly due to the presence of lignin-carbohydrate complex material, known as pseudo-lignin, which is formed by the reaction of -residual lignin with cellulose and hemicelluloses in acidic condition [24-25]. Re-condensation of lignin and its deposition on the cellulose surface may also contribute to the reappearance of lignin band in rice husk [26]. The band at 1053 cm^{-1} and 1456 cm^{-1} , assigned to methoxyl-O-CH₃, is found abundantly in lignin and hemicellulose [27]; it is likewise diminished after treatment corroborating delignification and dissolution of hemicellulose.

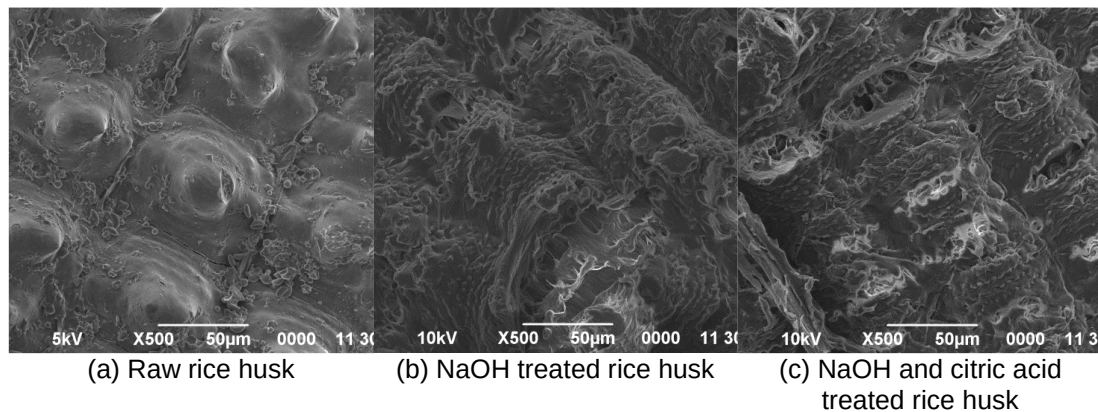


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Figure 3: The relative abundance of some absorption bands before and after treatment

The micrographs of raw rice husk and treated rice husk are shown in Figure 4. Morphologically, the raw rice husk shows well-defined rigid structure with conical-shaped protrusion on its surface. The protrusions are degraded after NaOH pretreatment where rough surface with minimal fractures is observed suggesting removal of extractives, waxes

191 and oils from the surface. Addition of citric acid to NaOH treated biomass further
192 demonstrates prominent fractured on the outer surface area exposing the inner layer
193 membranes.
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195 **Figure 4. SEM images of raw and treated rice husk**

196 3.2 Biosorbents for water treatment

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198 The treated rice husk is employed to remove dissolved organic carbon from peat swamp
199 runoff where the removal of humic substances is visually observed by color reduction in
200 water and is supported by the absorbance readings of UV-Vis. An average of 60-70% of
201 humic matter that absorbs radiation in the visible region is removed using the modified rice
202 husk. No adsorption is attained with raw biomass; the color of water on the contrary
203 becomes more yellowish (supported with increased absorbance) suggesting leaching of
204 tannin and lignin compounds. Statistical analysis shows significant difference ($P = 0.05$) in
205 the adsorption test between the untreated water, water treated with raw rice husk and water
206 treated with modified rice husk.

207 3.3 Biosorbents for soil amendment

208 Table 3 shows the growth performance of *Brassica juncea* var. *rugosa* L. grown under six
209 different treatments. Statistical analysis indicates that there are significant differences in
210 plants grown in T1 (planting material only) and T4 (planting material + Modified rice husk +
211 humic + NPK fertilizer) throughout the experiment for leaf area, number of leaves and length
212 at 95 % confidence interval ($P = 0.05$). The growth performance of T1 (planting material
213 only), T2 (planting material + fertilizer), T3 (planting material + humic loaded modified rice
214 husk) and T5 (topsoil + raw rice husk) however are not significantly different at each
215 observation period. The results shows that under poor sandy soil, no improved plant growth
216 is evidenced even with fertilizer; this may imply that the available nutrients are unable to be
217 taken up efficiently. The plants grown in modified rice husk with humic substances and
218 added fertilizer grew better than plants grown in untreated rice husk, with and without
219 fertilizer. This appears to suggest that humic substances may have served as a carrier to
220 enhance the uptake of nutrients hence promoting its growth in poor sandy soil.

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Table 3. Growth parameters of *Brassica juncea* var. *rugosa* L. measured through 8 weeks

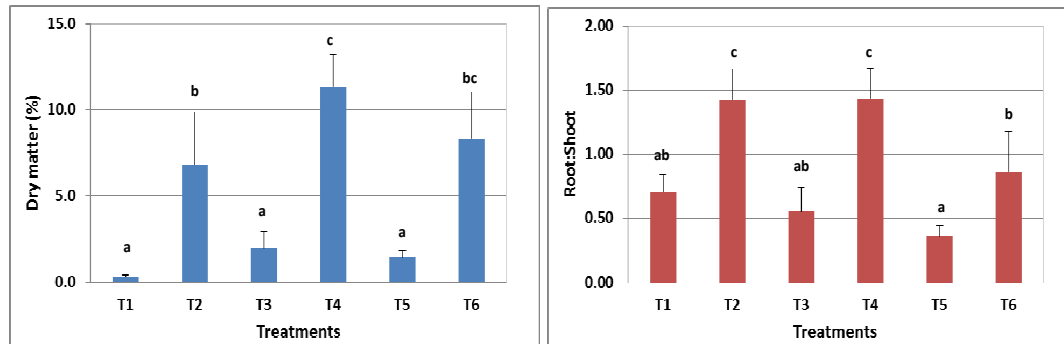
Growth Parameters	Treatment	Observations			
		Week 2	Week 4	Week 6	Week 8
Length of leaves (cm)	T1	0.50 ± 0.06 ^a	1.50 ± 0.82 ^a	2.33 ± 0.61 ^a	3.00 ± 0.42 ^a
	T2	0.50 ± 0.06 ^a	3.60 ± 0.51 ^b	5.48 ± 0.90 ^b	5.68 ± 0.98 ^b
	T3	0.55 ± 0.14 ^a	1.62 ± 0.62 ^a	2.93 ± 0.56 ^a	2.95 ± 0.54 ^a
	T4	1.12 ± 0.22 ^b	6.82 ± 0.63 ^c	8.37 ± 1.07 ^c	8.63 ± 1.18 ^c
	T5	0.55 ± 0.24 ^a	1.18 ± 0.48 ^a	1.18 ± 0.48 ^a	1.98 ± 1.04 ^a
	T6	1.42 ± 0.21 ^b	4.93 ± 0.37 ^d	4.93 ± 0.37 ^b	6.20 ± 0.80 ^b
Leaf Area (cm ³)	T1	0.92 ± 0.08 ^a	2.07 ± 0.39 ^a	2.35 ± 0.31 ^a	2.72 ± 0.60 ^a
	T2	1.07 ± 0.39 ^{ab}	2.85 ± 0.58 ^a	4.17 ± 1.55 ^a	4.60 ± 2.01 ^{ab}
	T3	1.17 ± 0.45 ^{ab}	1.60 ± 0.28 ^a	1.78 ± 0.33 ^a	1.78 ± 0.33 ^a
	T4	1.55 ± 0.29 ^{bc}	8.87 ± 1.63 ^b	9.38 ± 2.39 ^b	13.02 ± 2.71 ^c
	T5	0.87 ± 0.19 ^a	2.35 ± 0.61 ^a	2.47 ± 0.53 ^a	2.47 ± 0.53 ^a
	T6	1.70 ± 0.14 ^c	6.90 ± 2.04 ^b	7.25 ± 2.57 ^b	7.67 ± 2.79 ^b
Number of Leaves	T1	2.00 ± 0.00 ^a	3.17 ± 0.98 ^a	3.17 ± 0.75 ^a	3.33 ± 0.52 ^a
	T2	2.00 ± 0.00 ^a	4.50 ± 1.52 ^{abc}	4.17 ± 0.98 ^{abc}	5.17 ± 1.47 ^{ab}
	T3	2.00 ± 0.00 ^a	4.00 ± 0.00 ^{abc}	3.83 ± 0.41 ^{ab}	3.83 ± 0.41 ^a
	T4	2.33 ± 0.52 ^b	5.50 ± 0.55 ^c	5.17 ± 0.41 ^{bc}	7.83 ± 1.83 ^c
	T5	2.00 ± 0.00 ^a	3.33 ± 1.03 ^{ab}	3.67 ± 0.52 ^a	4.33 ± 0.82 ^{ab}
	T6	2.33 ± 0.52 ^a	4.83 ± 0.75 ^{bc}	5.33 ± 1.21 ^c	5.83 ± 0.41 ^b

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* Different letters in each treatment for growth parameters at each observation period indicating significant difference at $P = 0.05$ using Tukey's test.

Figure 5 illustrates the dry matter and root-to-shoot ratio of *Brassica juncea* var. *rugosa* L.; plants grown in modified rice husk with humic substances and fertilizer illustrate the highest dry matter percentage that is statistically different from those planted in T2 and T6 (under conditions with fertilizer alone and fertilizer and raw rice husk, respectively). This is in agreement to the findings of Rao et al. [28] that dry matter yield increases with application of humic acid. Other studies further demonstrate that humic substances have the ability to

enhance plant growth with less fertilizer; the beneficial effects of combining humic acid and fertilizer was evidenced with improved growth and yield of green mustard [29]. Plants grown in raw rice husk and fertilizer also exhibit encouraging growth though not as good as that with humic composite and fertilizer; the positive performance may be associated to the nature of lignocellulosic biomass as a potent soil stabilizer. After eight weeks, it is evidenced that plants grown in humic and fertilizer are better than that grown in fertilizer alone (T2 and T6). This suggests that the humic loaded biomass may be used as soil conditioner to facilitate nutrients retention nevertheless the beneficial effects in promoting plant growth would require further long-term experimentation and testing on various types of plant species.



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249 **Figure 5. Dry matter and root-shoot ratio of *Brassica juncea* var. *rugosa* L. under**
 250 **different treatment**

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254 4. CONCLUSION

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256 The application of rice husk for water treatment and agriculture is an economically
 257 sustainable and environmental friendly approach. Rice husk was chemically treated,
 258 experiencing removal of lignin and hemicellulose hence enhancing the adsorption ability of
 259 the material. It was used to remove humic substances from water tainted by peat swamp
 260 runoff where the spent sorbent was recycled as soil conditioner. Results show that *Brassica*
 261 *juncea* var. *rugosa* L. grown under rice husk fortified with humic compounds and fertilizer is
 262 encouraging.

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265 REFERENCES

266

- 267 [1] Kartini K., Mahmud BH, Hamidah MS. Improvement on mechanical properties of rice
 268 husk ash concrete with superplasticizer. The International Conference of
 269 Construction and Building Material. 2008; 20: 221-230.
- 270 [2] Reddy DHK, Seshaiyah K, Reddy AVR, Lee SM. Optimization of Cd (II), Cu (II) and
 271 Ni (II) biosorption by chemically modified *Moringa oleifera* leaves powder. Carbohydr
 272 Polym. 2012; 88: 1077-1086.
- 273 [3] Nakajima A, Sakaguchi T. Recovery and removal of uranium by using plant wastes.
 274 Biomass. 1990; 21(1): 55-63.
- 275 [4] Wan Ngah WS, Hanafiah MAKM. Removal of heavy metal ions from wastewater by
 276 chemically modified plant wastes as adsorbents: A review. Bioresource Technol.
 277 2008; 99(10): 3935-3948.

- 278 [5] Chuah TG, Jumasiah A, Azni I, Katayon S, Choong TSY. Rice husk as a potentially
279 low-cost biosorbent for heavy metal and dye removal: An overview. *Desalination*.
280 2005; 175(3): 305-316.
- 281 [6] Kayal N, Sinhia PK, Kundu D. Application of chemically modified rice husk for the
282 removal of heavy metals from aqueous solution. *J Environ Sci Eng*. 2010; 52(1): 15-
283 18.
- 284 [7] Nhapi I, Banadda N, Murenzi R, Sekomo CB, Wali UG. Removal of heavy metals
285 from industrial wastewater using rice husks. *TOENVIEJ*. 2011; 4: 170-180.
- 286 [8] Sobhanardakani S, Parvizimosaed H, Olyaie E. Heavy metals removal from
287 wastewaters using organic solid waste-rice husk. *Environ Sci Pollut R*. 2013; 20(8):
288 5265-5271.
- 289 [9] Ali I. The quest for carbon active adsorbent substitutes: Inexpensive adsorbents for
290 toxic metal ions removal from wastewater. *Sep Purif Rev* 2010; 39(3-4): 95-171.
- 291 [10] Ali I, Asim M, Khan T. Low cost adsorbents for the removal of organic pollutants
292 from wastewater. *J Environ Manage* 2012; 113: 170-183.
- 293 [11] Ali I. Water treatment at adsorption columns: Evaluation at ground level. *Sep Purif*
294 *Rev* 2014; 43(3): 175-205.
- 295 [12] Ali I. Advances in water treatment by adsorption technology. *Nature London* 2006; 1:
296 2661-2667.
- 297 [13] Ali AH, Shafeek MR, Asmaa MR, El-Desuki M. Effect of various levels of organic
298 fertilizer and humic acid on the growth and roots quality of turnip plants (*Brassica*
299 *rapa*). *Curr Sci Inter*. 2014; 3(1): 7-14.
- 300 [14] Sim SF, Mohamed M, Mohd Irwan Lu NAL, Sarman NSP, Samsudin SNS.
301 Computer-assisted analysis of Fourier Transform Infrared (FTIR) spectra for
302 characterization of various treated and untreated agriculture biomass.
303 *BioResources*. 2012; 7(4): 5367-5380.
- 304 [15] Sim SF, Ting W. An automated approach for analysis of Fourier Transform Infrared
305 (FTIR) spectra of edible oils. *Talanta*. 2012; 88: 537-543.
- 306 [16] Sim SF, Mohd Irwan Lu NAL, Lee ZET, Mohamed M. Removal of Dissolved Organic
307 Carbon from Peat Swamp Runoff Using Assorted Tropical Agriculture Biomass.
308 *Pertanika J Sci Technol*. 2014a; *In Press*.
- 309 [17] Sim SF, Lee TZE, Mohd Irwan Lu NAL, Mohamed M. Modified coconut copra
310 residue as a low-cost biosorbent for adsorption of humic substances from peat
311 swamp runoff. *BioResources*; 2014b; 9(1): 952-968.
- 312 [18] Czitrom V. One factor at a time versus designed experiment. *Am Stat*; 1999;
313 53(2):126-131.
- 314 [19] Shekhawat K, Rathore SS, Premi OP, Kandpal BK, Chauhan JS. Advances in
315 Agronomic Management of Indian Mustard (*Brassica juncea* (L.) Czernj. Cosson):
316 An Overview. *Int J Agron*. 2012; Article ID 408284:14 pages.
317 <http://dx.doi.org/10.1155/2012/408284>.
- 318 [20] Rajpar I, Bhatti MB, Zia-ul-hassan Shah AN, Tunio SD. Humic acid improves growth,
319 yield and oil content of *Brassica campestris* L. *Pak J Agric*. 2011; 27: 125-13.
- 320 [21] Mtui GYS. Recent advances in pretreatment of lignocellulosic wastes and production
321 of value added products. *Afr J Biotechnol*. 2009; 8(8): 1398-1415.
- 322 [22] Adapa PK, Schonenau LG, Canam T, Dumonceaux T. Quantitative analysis of
323 lignocellulosic components of non-treated and steam exploded barley, canola, oat
324 and wheat straw using Fourier Transform Infrared Spectroscopy. *J Agric Sci*
325 *Technol*. 2011; B 1: 177-188.
- 326 [23] Fan M, Dai D, Huang B. Fourier Transform Infrared Spectroscopy for natural fibres.
327 In: Salih SM, editor. *Fourier Transform-Materials Analysis: In-Tech*; 2012.
- 328 [24] Li JB, Henriksson G, Gellerstedt G. Lignin depolymerisation /repolymerization and
329 its critical role for delignification of aspen wood by steam explosion. *Bioresource*
330 *Technol*. 2007; 98(16): 3061-3068.

- 331 [25] Hu F, Jung S, Ragauskas A. Pseudo-lignin formation and its impact on enzymatic
332 hydrolysis. *Bioresource Technol.* 2012; 117: 7-12.
- 333 [26] Ibrahim MM, El-Zawawy WK, Abdel-Fattah YR, Soliman NA. Comparison of alkaline
334 pulping with steam explosion for glucose production from rice straw. *Carbohydr*
335 *Polym.* 2012; 83(2): 720-726
- 336 [27] Yang H, Yan R, Chen H, Lee DH, Zheng C. Characteristics of hemicellulose,
337 cellulose and lignin pyrolysis. *Fuel.* 2007; 86(12-13): 1781-1788.
- 338 [28] Rao VM, Govindasamy R, Chanderasekaran S. Effect of humic acid on Indian
339 mustard (*Brassica juncea*), var. SH-9. *Curr Sci.* 2006; 6: 173-176.
- 340 [29] Petrus AC, Ahmed OH, Muhamad AMN, Nasir HM, Jiwan M. Effect of K-N-humates
341 on dry matter production and nutrient use efficiency of maize in Sarawak, Malaysia.
342 *The Scientific World Journal.* 2012; 10: 1282-1292.
- 343
- 344