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Nutrient retention capacity of rice husk biocharcoal in co-composted poultry manure

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Abstract

A waste by-product of local rice mill namely rice husk biocharcoal (RHC) was investigated for its effects in minimising nutrient losses and retaining nutrients during composting of poultry manure. Treated poultry manure was co-composted with RHC at two rates (10% and 5%) and determined for their composting nutrient content, leaching rates through laboratory column leaching test and the leached composts were viewed under SEM/EDX. RHC was quantified to minimise nitrogen loss during composting where 10% and 9% of N was retained in compost treated with RHC 10% and RHC 5% correspondingly as compared to control. Meanwhile laboratory leaching tests and SEM micrograph on RHC-compost at both rates have proven that RHC does physically trapped and chemically sorb organic and inorganic molecules such as C, N, P, K, NO_3 Ca and P and retained them against leaching losses.

Keywords: by-product, composting, biocharcoal and leaching losses

Introduction

Rice husk biocharcoal (RHC) is a waste by-product of cyclone gasification in major rice processing mills in Malaysia. Theeba et al. (2012) has reported an estimated amount of RHC by-product generated from major rice processing mill in Malaysia is about 32,000 metric tonnes. The material tends to accumulate adjacent to the gasification units due to an absence of demonstrated use for the RHC, lack of knowledge of the properties of the char, and the lack of enforcement of waste management regulations. RHC shares some of the characteristics of biochar, which has been defined as the porous carbonaceous solid produced by thermochemical conversion (usually slow pyrolysis) suitable for the safe and long-term storage of carbon (Shakley and Sohi 2010). RHC accumulation in rice processing mills is seen as a problem by most of the rice processing mill owners especially in Kelantan as the waste is disposed with some cost annually. Thus, investigation on potential utilisation of this waste especially into agronomic practice is very practical and highly fits as waste management approach to overcome the current issue.

Co-composting biomass such as poultry manure with RHC is expected to be an efficient utilisation based on many findings on the positive effects of biochars in composting (Steiner et al. 2007).

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Furthermore, in Malaysia, composting of biomass and animal waste especially poultry manure is widely being practised mainly as fertilisers for crop production. Currently, wastes generated from poultry farms increases as a result from rapid growth of chicken industry. Based on report by Department of Agriculture (2012), price per kg for composted chicken manure is RM1.40 and untreated or pure is RM0.36. Chicken manure is still preferred and widely used by farmers as organic fertilisers as it is cheaper than other locally produced commercial organic fertilisers such as Complehumus (RM2.50/kg), Wonderful Organic (RM2.00/kg) and AmmoGold (RM1.40/kg). The utilisation of the chicken farm waste mainly chicken manure as sources of nutrients for food crop production is becoming very important as it is the most cost-effective source. However, direct applications of chicken manure into the soil as fertilisers may cause environmental problems such as the foul odour and may trigger pest infestations. The main drawback of composting includes the inefficiency of the composting process due to nutrient losses through volatilisation and leaching (Eghball et al. 1997). Tiquia et al. (2000) also stated nutrient loss, specifically N, can be a major problem in composting animal manure, where half and more of the total N content of the manure being lost during composting. Composted manure generally contains at least 50% and up to 90% of the N found in fresh manure

Many studies have been carried out to investigate the performance of biochar to enhance biomass composting process and properties. According to Yoshizawa et al. (2007), biochar can be applied to composting biomass to accelerate the process. It also functioned to reduce the possible odour from organic nutrient sources during the composting process (Kleeberg et al. 2005). This may be explained by greater reproduction rate of microorganisms in the presence of biochar (Steiner et al. 2004). In summary, biochar addition to composting biomass could serve as an aeration-facilitating bulking agent, a greenhouse gas adsorbent, odour control agent, microbial population and retention enhancer, and also nutrient and water ab- and adsorber for better uptake by plant. This significantly adds to the value of biochar in organic agriculture. Biochar as a component of compost can have synergistic benefits. It can increase microbial activity and reduce nutrient losses during composting (Dias et al. 2010). In the process, the biochar becomes 'charged' with nutrients, covered with microbes, and pH-balanced, and its mobile matter content is decomposed into plant nutrients. Steiner et al. 2010 has studied co-composting pine chip biochar at 20% with poultry manure significantly reduced NH_3 emissions, N losses and H_2S emmisions. Jindo et al. (2012), found application of 2% oak tree biochar blended with poultry manure and farm waste showed significant positive effects on chemical and biochemical properties of compost. Therefore, this study was carried out to investigate the effects of our local mill waste RHC as a form of biochar in nutrient retention during the composting of poultry manure and the finished compost.

Materials and methods

Composting process

The composting experiment was conducted at the compost building of MARDI Integrated Organic Farm. Three types of compost were developed in this experiment; T1: Compost without RHC, T2: Compost with 10% RHC and T3: Compost with 5% RHC. All the three compost types were developed in 150 kg piles (size of 3m x 1m). The main component of the compost was chicken manure (N: 2.4%, P: 1.8%) used at the volume of 95% (120 kg). As for compost in T2 and T3, RHC which was collected from local rice processing mill in Kedah, air dried and characterised for its physiochemical properties was added into the substrates during compost preparation and all the treatments were spiked with 5% concentration effective microbes EM.1® for faster degradation (Source: Pertubuhan Peladang Negeri Johor). The composting process was carried out for a period of 60 days. The composting procedure as well as determination of compost maturity was conducted according to Aini et al. (2005).

Determination of compost nutrient content

A total of 100 g compost samples from three different points in composts piles were weighed into crucibles and placed in the sampler for C, N determination using CHNOS analyser (ELEMENTAR-Vario Macro Modules 11.44 - 5201). Total P in compost samples was determined using recommended methods for plant chemical analysis (MS677: pt I to VIII: 1980, Part IV). Compost exchangeable bases (K^+, Ca^{2+} and Mg^{2+}) were determined by the replacement of exchangeable cations with ammonium acetate (1N NH4OAc) adjusted to pH 7.0 (Thomas 1982). The determination of cation exchange capacity (CEC) was done through washing of the absorbed NH_4^+ with 100 ml ethanol to remove excess NH_4^+ and consequently replaced by 100 ml 1N K_2SO_4. Total silica in compost samples was determined using recommended methods for plant chemical analysis (MS677: Pt I to VIII 1980, Part 2 II).

Laboratory column leaching test and SEM/EDX spectra of compost

Nutrient leaching is the downward movement of dissolved nutrients in the soil profile with percolating water. The rate of compound dissolution was determined using leaching tubes (Maher 1998) with the modification of the amount of leaching water and frequency of leaching events closely followed the rainfall distribution pattern in Peninsular Malaysia ~2334 mm/year (Wong et al. 2009). All tests were carried out with same soil, Serdang series (24% sand, 34% clay, 34% silt) taken from a secondary forest (approximately 20 years) with medium organic C 1.89%, total N 0.11%, K 32.56 cmol(+)/kg soil, available P 21.4 mg/kg, Ca 3.76 cmol(+)/kg soil, Mg 1.79 cmol(+)/kg soil, CEC 8.61 cmol(+)/kg and pH in range 4.65 – 5.53. Soil samples were collected before fertilisation. Leached nutrient concentrations were measured via Atomic Absorption Spectrophotometer for Nitrate (NO_3) and Inductively Couple Plasma-Optical Emission Spectrometer (ICP-OES) for Phosphorus (P) and potassium (K). The final compost of T1, T2 and T3 after leaching with water with the volume of 2000 mm (average rainfall volume Malaysia), were viewed under Scanning Electron Microscopy/Energy Dispersive X-ray (SEM/EDX), model JEOL JSM6400. The oven dried compost samples were placed on stubs and coated with 5 nm gold using a sputter coater model BAC-TEC, SCD005 for 30 min. The prepared samples were then viewed under SEM/EDX for its spectrum.

Statistical analysis

All data were subjected to statistical analysis using one-way ANOVA. Treatment means were compared using Duncan Multiple Range Test (DMRT) at $p < 0.05$ using SAS version 9.3.

Results and discussion

Compost nutrient contents

Physiochemical characteristics of RHC are shown in *Table 1* and the effects of RHC in compost will be discussed based on these characteristics. The changes in preserved total carbon (C) in composts throughout the composting period are shown in *Figure 1.* Total C was preserved significantly higher in

T2 (28.4%) and T3 (28%) than T1 (26.6%). Recalcitrant carbon (17%) derived from the added RHC may explain the higher C value in T2 and T3. Meanwhile changes composts C/N ratio as shown in *Figure 2*, illustrated that there is no significant differences between the treatments. However it's noticeable that the C/N ratio of T2 and T3 still remained higher than T1 throughout the composting process even when the CO2 respiration was highest in these treatments (T2 and T3). This explains that the RHC C remained relatively inert during the composting process and able to provide enhanced durability when applied as soil amendment with an important implication for C sequestration. The nitrogen preserved in compost is shown in *Figure 3*. It was found that the N in compost was significantly preserved in T3 and T2 mainly during the thermophilic phase as compared to T1, which indicated that the use of RHC has a positive effect in reducing N losses during the composting process. Steiner et al. (2010) reported the similar event, where the addition of biochar (10 – 20%) in compost significantly reduced the losses of N about 7.7 – 23.2 %. Similar observations have been made by Hua et al. (2009) who reported that incorporation of bamboo char (BC) during sludge composting reduced nitrogen losses during the process. The positive effect was related to the BC specific surface (330 m^2/g) and bulk density (0.75 g/cm) indicating substantial ammonia adsorption capability of BC. His statement concurred with this study, whereby RHC had higher specific surface area of 401 m^2/g and lower bulk density of 0.17 g/cm^3. A study by Thies and Rilling (2009) explained biochar undergoing surface oxidation increased during composting enhancing its capacity to chemisorb nutrients. In this study, N content generally showed an increase pattern from 0 to 50 days in all compost piles. Mineral contents such as P, K, Ca, Mg and Si of matured compost at day 50 were shown in *Table 2*. Si content of compost in T2 and T3 were significantly higher compared to T1 mainly contributed by the high amorphous silica content (78.8%) in RHC. However, silica effects on composting were not focused in this study. Magnesium content in T2 and T3 was also significantly higher than in T1. Meanwhile nutrients P, K, Ca were not significantly different between treatments.

Table 1. Physicochemical characteristics of RHC in this study

Characteristics	Values
pH	8.9 ± 1.1
Bulk density (g/cm^3)	0.17 ± 0.3
Moisture content %	7.1 ± 0.3
CEC (cmol/kg soil)	17.0 ± 1.3
Total carbon (%)	16.0 ± 0.5
Total N (%)	0.1 ± 1.2
Ash (Armophous Silica) (%)	78.8 ± 0.8
Atomic ratio H/C	0.534
Atomic ratio O/C	0.173
Methylene blue adsorption capacity (mg/g)	38.5
BET surface area ($m^2 g^{-1}$)	401.1 ± 0.76
Pore volumeat P/P_0 0.95 ($cm^3 g^{-1}$)	0.322
BET average pore diameter (nm)	2.7 (mesopores)
SEM pore diameter (µm)	10 (macropores)
Water Holding Capacity % (pF 2 – pF 4)	101 – 89.1

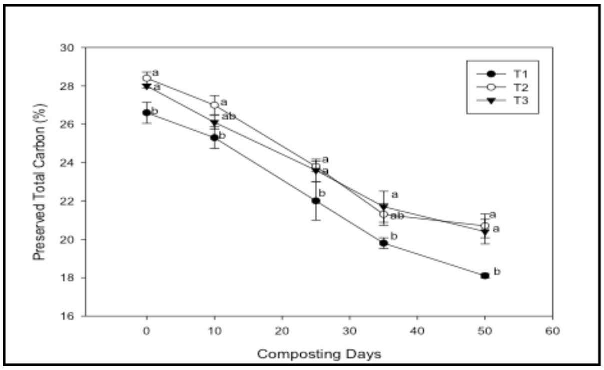


Figure 1. Total Carbon preserved in composts throughout composting process. Means with different letters are significantly different by DMRT at $p < 0.05$

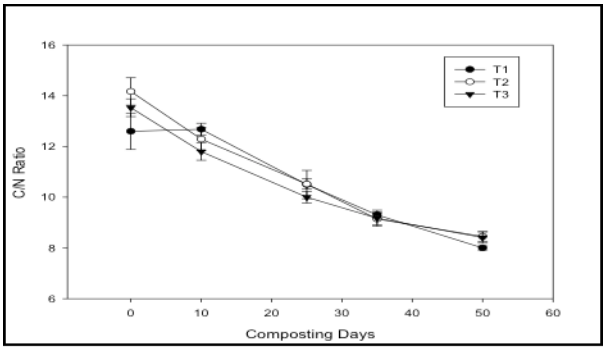


Figure 2. Changes C/N ratio of composts throughout *composting process.*

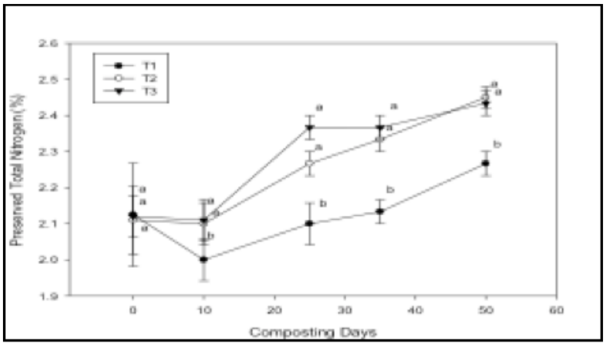


Figure 3. Total Nitrogen preserved in composts throughout composting process. Means with different *letters are significantly different by DMRT at* $p < 0.05$

Table 2. Other nutrient contents in final compost at 50 days. Means with different letters are significantly different by DMRT at $p < 0.05$

Treatments	%				mg/kg
	P	K	Ca	Mg	Si
T1	$1.46^{a} \pm 0.35$	$2.00^{a} \pm 0.15$	$8.0^{a} \pm 0.61$	$0.90^{b} \pm 0.23$	$65^{b} \pm 4.1$
T2	$1.52^{a} \pm 0.15$	$2.13^{a} \pm 0.21$	$8.3^{a} \pm 0.35$	$1.0^{ab} \pm 0.43$	$145^{a} \pm 10$
T3	$1.43^{a} \pm 0.25$	$2.18^{a} \pm 0.15$	$8.5^{a} \pm 1.04$	$1.2^{a} \pm 0.26$	$140^{a} \pm 5.1$

P = Total Phosphorus, K = Potassium, Ca = Calcium, Mg = Magnesium and Si = Silica

Nutrient-RHC interaction in compost

Nutrient-RHC interactions in compost were evaluated through laboratory column leaching test and SEM micrograph. Results of total nutrient leaching rates in compost for NO_3, P and K are shown in *Table 3*. *Figures 4* to *6* shows the percentage of cumulative leaching values for each nutrient element representing the trends in nutrient leached out from compost at different rainfall volume. As for NO_3 the leaching values were significantly higher in T1 as compared to T2 and T3. It was estimated that the NO_3 leaching rate of compost in T2 was reduced at 21% and T3 at 15.8% from the control (T1). Total P leaching was reduced 4.6% in T2 and 6% in T3 respectively. Total K leaching was reduced at 14.9% for T2 and 13.4% for T3. T2 had the lowest leaching values and trend throughout the experiment. A study by Melgar et al. (1992) showed a linear relation existed between depths of movement of nitrate and cumulative rainfall. Rainfall patterns have often been studied for the variability in leaching patterns at a single site. Sogbedji et al. (2001) stated that biochar may therefore act as the most effective material in reducing leaching losses in regions of high rainfall. It was also investigated that biochar porosity and surface area contributed to nutrient adsorption. Lebo et al. (2003) found that biochar with low oxidation to be hydrophobic and sorbs hydrophobic molecules such as N, P and S to its particles. Kwon and Pignatello (2005) stated that since molecules of various sizes and chemicals characteristics could sorb onto biochar particles, adsorption is likely to happen in which inorganic molecules attached to minerals or organic matter will sorb directly or precipitates on biochar surfaces. This finding is supported by RHC MB adsorption capacity of 38.5 mg/g in this study.

The SEM micrograph of water leached compost in T2 and T3 showed an example of nutrient elements such as N, P, K, Ca and Mg trapped in between the pore structures and at the surface (*Figure 7* and *Figure 8*). RHC in this study are found to physically retain the organic substances in their pore structure even after leaching of water. Some nutrient particles were observed to adhere on the surfaces on RHC under the spectrum of SEM. The presence of micro and macro pores in RHC (2.7 nm to 10 μm) proved the interactions between nutrient particles and RHC surfaces. This condition was not detected in T1 because it was not amended with RHC. Nguyen et al. (2004) and Yu et al. (2006) explained that biochar had fine pores that allowed trapping of different compounds physically within pores. Kaiser and Guggenberger (2000) stated that biochar adsorbs organic C that is rich in functional group (carboxylic and phenolic functionalities). The authors further explained that this process was made possible by the presence of oxidised functional groups on the surface of biochar particles.

The characteristics of RHC such as MB adsorption capacity of 38.5 mg/g of RHC in this study further explains that it had the ability of adsorbing organic molecules from the nutrient substrates into its particles. Dunisch et al. (2007) found larger mass of N, P and K sorbed to wood biochar/ash after these materials were dipped in commercial inorganic fertiliser solution as compared to fresh wood. He also reported smaller sized biochar particles generally sorbed more nutrients than larger one, suggesting effects of surface area. Tseng and Tseng (2006) stated higher porosity of biochar with higher pore numbers contributed to nutrient adsorption by trapping nutrient-containing water in the soil matrix. Thus, as in this study RHC particle size of <1mm and surface area of 401 m^2/g with abundant of micro and macro pores suggested that RHC had the ability to sorb the nutrient solution and trap the nutrient particles into its pores and surface. T2 showed to have the least leaching rates, followed by T3 and T1. This also explained the direct correlation of higher concentration of RHC amended in T2 had lower nutrient leaching values due to higher micro and macro pores present in the developed compost. The data of laboratory column nutrient leaching test and SEM micrograph proved that RHC physically trap and sorb organic and inorganic molecules such as C, N, P and K and retained them against leaching losses. The proposed mechanisms involved in this process can be summarised as:

i) biochar had the potential characteristics in slowing down leaching may be due to increase in the water holding capacity by biochar which was also reported by Tryon (1948)

ii) biochar's negative surface charge directly retains positively charged nutrient which was also found by Liang et al. (2006)

iii) fresh biochar sorbs nutrients in hydrophobic organic matter as also reported by Lebo et al. (2003)

Table 3. Mean ± standard error of total percentage of nutrient elements leached from compost. Means with different subscripts letter are significantly different by LSD test at $p < 0.05$

Treatments	%NO_3	%P	%K
1	$81.4^a \pm 2.01$	$48.6^a \pm 3.04$	$65.0^a \pm 6.2$
2	$60.4^b \pm 2.97$	$44.0^a \pm 6.17$	$50.1^a \pm 6.47$
3	$65.6^b \pm 7.17$	$42.6^a \pm 3.29$	$51.6^a \pm 5$

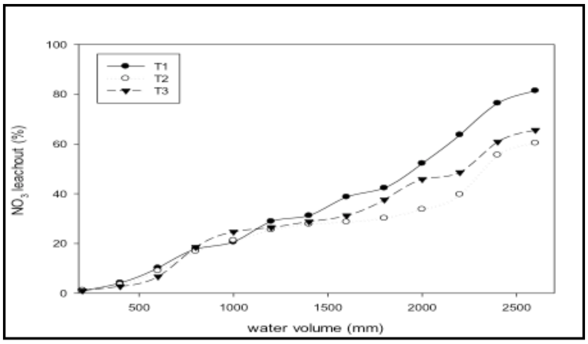


Figure 4. Cumulative leaching value (%) of NO_3 under estimated average rainfall volume in Peninsular Malaysia

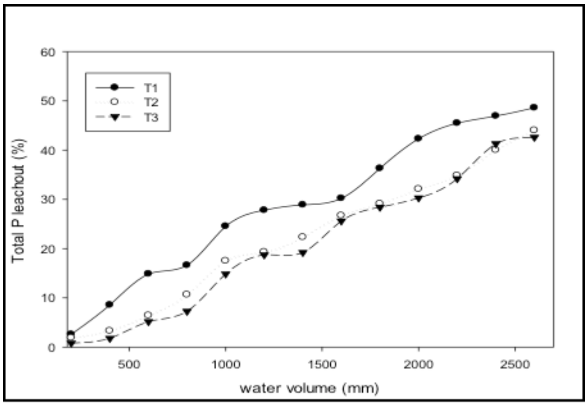


Figure 5. Cumulative leaching value (%) of P under estimated average rainfall volume in Peninsular Malaysia

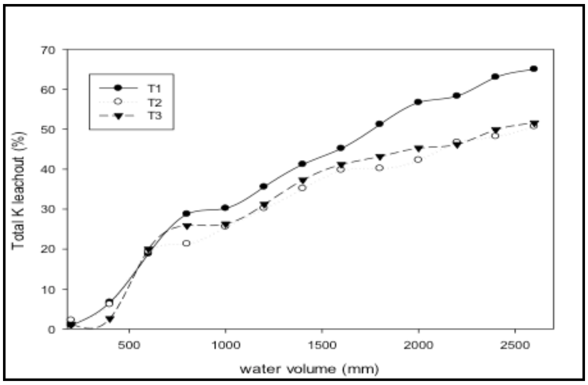
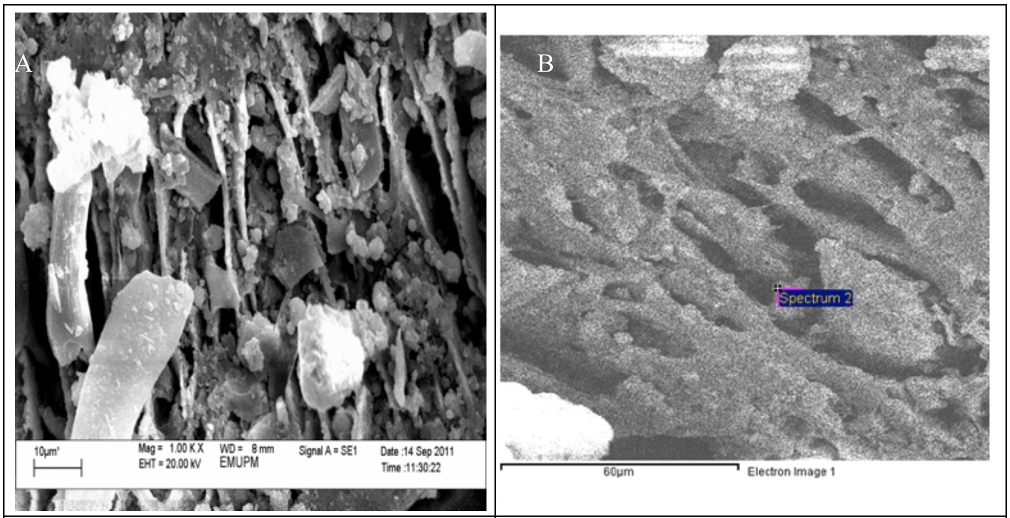
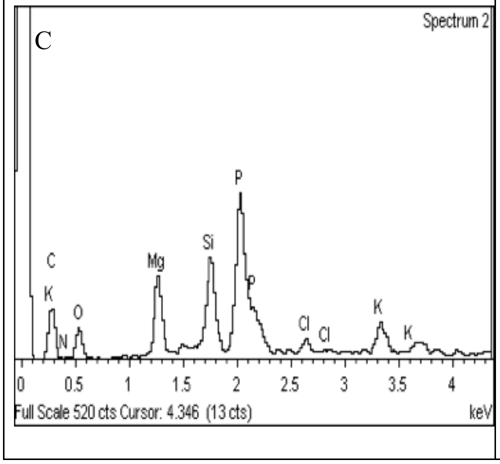


Figure 6. Cumulative leaching value (%) of K under estimated average rainfall volume in Peninsular Malaysia





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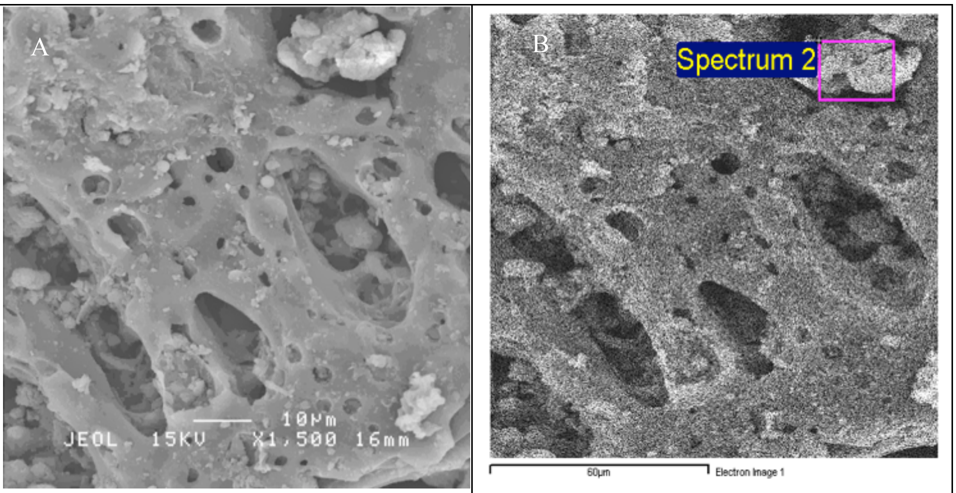
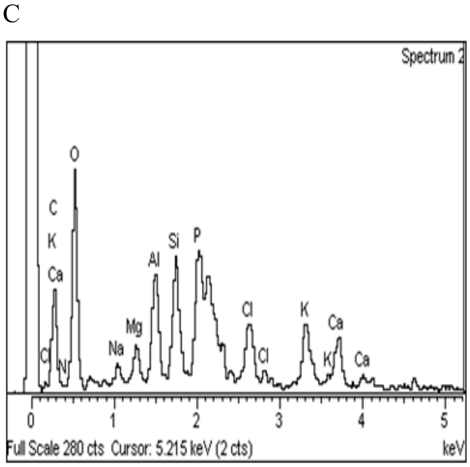
Element	Weight%	Atomic%
C	49.79	62.78
N	5.58	6.03
O	19.16	18.13
Mg	5.11	3.18
Si	5.16	2.78
P	11.35	5.55
Cl	1.22	0.52
K	2.65	1.02
Total	100.00	

Fig 7. Elements analysed using SEM-EDX spectrum for RHC-compost T2
A: Nutrient substances trapped in between the RHC pore structure and attracted to RHC surface
B: Image of SEM/EDX analysis on trapped particle (spectrum 2) inside RHC pores
C and D: Various Elements analysed for Spectrum 4





Element	Weight%	Atomic%
C	46.10	39.98
N	1.83	1.36
O	15.72	46.31
Na	2.00	0.91
Mg	2.08	0.89
Al	5.90	2.28
Si	6.34	2.35
P	7.04	2.37
Cl	4.43	1.30
K	4.35	1.16
Ca	4.21	1.09
Total	100	

Figure 8. Elements analysed using SEM-EDX spectrum for RHC-compost T3
A: Nutrient substances trapped in between the RHC pore structure and attracted to RHC surface
B: Image of SEM/EDX analysis on trapped particle (spectrum 3) inside RHC pores
C and D: Various Elements analysed for Spectrum 3

Conclusion

RHC was able to minimise nitrogen losses during composting where 9% and 10% of N was retained in compost treated with RHC 5% and RHC 10% correspondingly, as compared to untreated compost. Meanwhile laboratory leaching tests and SEM micrograph on RHC compost has proven that RHC does physically trapped and chemically sorb organic and inorganic molecules such as C, N, P, K, and P and retained them against leaching losses. Future research on incorporating RHC into mineral fertilisers is recommended. The incorporation can be done through compounding the components together or as coating material on compounded fertilisers such as urea and NPK granules. Depending on the production techniques and mechanisms such as activation of pores physically and chemically, RHC may be able to retain the minerals through adsorption into its pores and attraction onto its surface to give slow release effects of fertilisers once applied into soil.

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Abstrak

Bahan buangan kilang pemprosesan padi yang dikenali arang-bio sekam padi (RHC) telah dikaji kesan pemegangan nutrien dan pengurangan kadar larut lesap dalam kompos tinja ayam. Kadar RHC 10% dan 5% dicampur ke dalam tinja ayam untuk proses pengkomposan. Kompos yang telah matang dikaji tahap larut lesap menggunakan kaedah di dalam makmal dan imej SEM/EDX. Kedua-dua kadar kompos RHC 10% dan 5% berupaya mengurangkan kehilangan nitrogen semasa aktiviti pengkomposan berjalan berbanding dengan kawalan. Kajian tahap larut lesap makmal dan imej SEM menunjukkan partikel nutrient C, N, P, K, NO_3, Ca dan Mg telah terperangkap secara kimia-fizikal di dalam liang-liang meso dan makro RHC dan mengurangkan kadar larut lesap nutrien ke persekitaran melalui penyerap molekul organik dan inorganik oleh permukaan arang bio.