BorneoScience
The Journal of Science & Technology
Volume 42 Issue 2 : Sept 2021
Online ISSN : 2231-9085 | ISSN : 1394-4339

PAPER WASTES AS BEDDINGS IN VERMICOMPOST PRODUCTION

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Received 31st July 2021; accepted 4nd October 2021
Available online 20th December 2021

ABSTRACT. *Paper waste is one of many wastes produced by men leading to more landfill spaces to dispose of them. Improper management of wastes can become a nuisance and can become a source of pollution and environmental degradation. This research aimed to determine the effect of different paper wastes (white paper, newspaper, and brown paper) as bedding materials on the efficiency of vermicomposting and nutrient content of the vermicompost. Vermicompost substrates (cow dung, vegetable waste and waste paper) were digested using earthworms (Eudrilus eugeniae) for up to 68 days and were assessed across physical (temperature and weight loss) and chemical parameters (pH, macro- and micro-nutrients content). The vermicompost gave pH values ranging from 7.9 to 9.9 for different paper beddings. The temperature in all vermicompost piles averaged 26 to 34˚C, while weight losses were recorded at 26 to 38%. Chemical analyses of all vermicompost substrates showed no significant difference for N, P, Fe, Cu and Mg contents. In contrast, the C:N ratio, K, Na, Ca, Zn and Mn of the vermicompost products were significantly different (P<0.05). Although vermicomposting using newspaper bedding recorded the shortest period to mature with most nutrient contents suitable for application on plants, the Cu content was too high, suggesting that the amount of newspaper used as bedding should be reduced and substituted with other organic substances such as crop residues. Vermicomposting using paper wastes as beddings for earthworm (E. eugeniae) shows a good potential of producing vermicompost that can be used as a soil amendment.*

KEYWORDS: paper wastes, beddings, *Eudrilus eugeniae*, vermicompost, nutrient content

INTRODUCTION

Paper or paper-based products is one of the many types of wastes produced by human beings. Paper products, from newspaper to food packaging and office papers, are used in everyday life. The global consumption of paper has increased to 400 million tonnes per year, with an average global consumption of 55 kg per capita annually (Environmental Paper Network, 2018). The bulk amount of paper wastes has led to more landfill spaces acquired to dispose of them. Improper management of waste disposal raises public concern over potential harmful effects as such method can cause soil pollution (Wang *et al*., 2015) and land degradation (Adamcová *et al.*, 2016). Polluted soil and water supply conditions are basically not ideal for humans, animals, and crops. Accumulation of polluting materials may cause health, safety and aesthetic concerns and represent a problem requiring safe disposal (Liu *et al.*, 2012). Proper waste management can reduce or eliminate adverse impacts on the environment and human health besides supporting economic development and improving quality of life. Paper recycling is one disposing method practised worldwide (Waste Management World, 2013), but not all papers or paper-based products are recyclable.

Vermicomposting is a bio-oxidative process involving microorganisms inside the earthworm's gut that assist the biochemical degradation of organic matter (Roshan Singh and Kalamdhad, 2016). Fragmentation of substrate by earthworms increases the surface area exposed to the microorganisms, thus modifying the physical and chemical properties of the substrates (Huang and Xia, 2018). Vermicomposting is an alternative eco-friendly method that can be applied to manage and reduce paper waste, as paper is a good source of carbon and can be used as a bulking agent when mixed with other organic substances such as livestock manure, crop residues and kitchen waste to improve its nutrient content (Latifah *et al.*, 2009). Earthworms ingest, grind and digest organic wastes into vermicompost that contain relatively higher concentrations of plant nutrients, soil enzymes, humic acids and microbial population due to the earthworms and microorganisms (Khwairakpam and Bhargava, 2009). When vermicompost is added as soil amendments to soils, they boost nutrients availability to the crop, improve soil structures and enhance crop growth, and indirectly produce better crop yield (Zucco *et al*., 2015; Piya *et al*., 2018).

Eudrilus eugeniae, commonly known as the `African Night Crawler', is an epigeic earthworm of the family Eudrilidae. Epigeic earthworms are known for their voracious feeding habit, better ability to accept different organic waste materials and high fertility (Rini *et al*., 2020). Out of the 4,400 species of earthworms, *E. eugeniae* is commonly used in vermicomposting in most countries (Sehar *et al*., 2016). It is a hermaphrodite as it possesses both male and female reproductive systems. The earthworm has a uniform purple grey colour and its length is approximately 10 cm to 12 cm. As described by Reinecke *et al*. (1992), *E. eugeniae* has a life duration of around 60 days and can reach a maturity stage at approximately 40 days. It will start to produce cocoons at 46 days with a rate of 1.3 cocoons per worm per day.

A favourable living environment for the compost worms, including beddings, food sources, moisture, aeration, and protection from extreme temperatures, must be provided to ensure an efficient vermicomposting process (Munroe, 2014). The selection of bedding materials is key to successful vermicomposting due to its ability to hold moisture and provide aeration (Manaig, 2016). Bedding materials maintain the correct level and consistency of moisture, provide adequate aeration for oxygen supply, and protect the worms from extreme temperatures (Munroe, 2014). Earthworms can be highly productive (and reproductive) when conditions are favourable and good bedding materials are essential in meeting those needs (Jemal and Abebe, 2020). Therefore, the selection of substrate materials is a key to efficient vermicomposting process (Latifah *et al*., 2009). This study was conducted with the hypothesis that different bulking materials or beddings, namely different paper materials, influence the efficiency of vermicomposting and the quality of vermicompost produced.

MATERIALS AND METHODS

Materials

Cow dung was collected from a dairy farm at Universiti Putra Malaysia Bintulu Sarawak Campus (UPMKB) and was dried under the sun for a week. Three types of papers namely white paper, newspaper and brown paper envelopes were collected from offices in UPMKB. All non-compostable materials like plastic tapes, glues and staples were removed from the paper wastes which were then shredded into small pieces using a shredder machine and soaked in water for 24 hours separately. Vegetable market wastes were collected from the Bintulu Wet Market. Vegetable wastes were cleaned and chopped into smaller pieces using knives. Earthworm (*E. eugeniae*) was obtained from a supplier in Sarikei, Sarawak. Upon arrival, the worms were kept in plastic drawers filled with pre-decomposed cow manure, vegetable wastes and shredded paper.

Vermicomposting

The experiment was conducted at Share Farm 1 of UPMKB. All materials and experiments were setup under a 20 x 20 m^2 shaded area. A total of 15 plastic drawers with a dimension of 0.31 m (H) x 0.61 m (W) x 0.92 m (L) were used as composting bin. Eight holes (with a diameter of 1 cm each) were drilled on every drawer to provide aeration and drainage. Drawers were stacked up to save space with some gap between the drawers to provide aeration and release of heat. A complete random design (CRD) with three treatments and five replications were adopted. Each treatment consisted of a different combination of paper waste, cow dung, vegetable waste and earthworms as listed in Table 1.

Table 1. Composition of substrates in the compost mix

Materials	Amount
Paper wastes (white paper, brown paper or newspaper)	200 g
Cow dung	200 g
Vegetable waste	200 g
Earthworms	200 g
Water	100 mL

Pre-decomposition process of wastes was carried out for 12 days. All mixtures were heaped together and then inserted into the vermicomposting drawers. The mixture was mixed thoroughly for proper aeration and decomposition. After 12 days, earthworms were released on the top of the pre-decomposed mixture. Throughout the study, the mixture was sprayed with water after three to four days depending on the moisture of the mixture. The experiment was conducted for 65 days or until the vermicompost has completely matured. Harvesting was carried out after all materials in the compost pile were completely decomposed. A good quality vermicompost has a typical smell but not a bad smell while the colour is usually black. The vermicompost was air-dried after harvesting and the physico-chemical analyses were conducted after that.

Physicochemical analysis

Vermicompost products were analysed for pH, total organic carbon, macronutrients (N, P, K), micronutrients (Ca, Mg, Na, Zn, Fe, Cu and Mn), weight loss and degradation rate. The pH value was determined using the H_2O method where 10 g of dried compost was added with 100 mL distilled water, shaken at 180 rpm for 15 minutes and left for 24 hours before the pH was determined using a calibrated pH meter. The total organic carbon was determined using the dry combustion method (Schumacher, 2002). An oven-dried sample was placed in a furnace and initially turned to ash at 300˚C for an hour and at 550˚C for another 8 hours. The nitrogen content of the compost was analysed using the Kjeldahl method (Nathan and Sun, 2006) and available P was analysed using the Bray 1 method (Bray and Kurtz, 1945). Meanwhile, the determination for other nutrients in the vermicompost was analysed using the single dry ashing method (Nathan and Sun, 2006) and determined using the Atomic Absorption Spectrometer (AAS).

Statistical Analyses

Data were analysed statistically using a one-way ANOVA using Statistical Analysis Software (SAS) Ver. 9.2. The significant difference between the mean values for each measured parameter was compared using the Duncan Multiple Range Test (DMRT) at $P<0.05$.

RESULTS

Analyses related to the physical and chemical properties of different types of vermicompost were conducted to identify their distinct qualities. Four parameters were compared to determine the quality of vermicompost mixtures namely temperature, pH value, weight loss and nutrient contents.

Temperature of Vermicompost

Changes in temperature occurred during vermicomposting. From day 1 to day 10, the average temperature was 31.26˚C for white paper mixture, 31.03˚C for brown paper mixture and 30.96˚C for newspaper mixture. A gradual decrease in temperature was observed from day 11 until day 18 with temperature declining to 26.2˚C for white paper mixture, 26.4˚C for brown paper mixture and 26.2˚C for newspaper mixture. Thereafter, the temperature fluctuated within the range of 27.4˚C to 30.2˚C for white paper mixture, 28˚C to 30.4˚C for brown paper mixture and 27.8˚C to 31˚C for newspaper mixture. In the last 20 days before harvesting, the temperature for each vermicompost mixture was maintained within the range of 29.8 to 30.4˚C. No significant difference in temperature was observed for all vermicompost mixtures.

pH Value of Vermicompost

The pH value during the early stage of composting recorded a value of pH7.9 for white paper mixture, pH7.6 for brown paper mixture and pH7.8 for newspaper mixture. Meanwhile, at the final stage of vermicomposting, pH for all vermicompost has increased. After harvesting, differences between treatments were highly significant with the white and brown paper beddings showing higher pH value than the newspaper bedding. Both white paper and brown paper mixtures recorded a pH value of 9.9 and 9.5, respectively. However, pH value for newspaper bedding recorded a slight increase to pH7.9.

Weight of Vermicompost

The initial weight for all vermicompost was 600g and this was reduced with the vermicomposting period. Significant difference was observed between the white paper bedding and the newspaper bedding. Newspaper bedding recorded a weight loss of 38% followed by the brown paper bedding and the white paper bedding with 32% and 27% weight loss, respectively.

Physico-chemical Parameters of Vermicompost

Table 2 shows the physico-chemical parameters measured. The time duration required to complete vermicomposting were different according to beddings. Newspaper bedding took approximately 50 days to mature, followed by brown paper with 57 days and white paper with 60 days. As for nutrient contents, all three types of vermicompost showed variations where both white paper and newspaper beddings were significantly different from brown paper mixture. The C:N ratio for white paper and newspaper beddings was 22:1 and 19:1, respectively, while brown paper mixture recorded a ratio of 12:1.

Table 2. Physico-chemical parameters of vermicompost using different paper types

Elements	Treatments (Paper Type)		
	White paper	Brown paper	Newspaper

Time duration to reach maturity (days)	60	57	50
C:N ratio	22.1^{a}	12.42^{b}	18.71^{a}
N (%)	2.15^{a}	3.44^{a}	2.59^{a}
P (mg/g)	0.0041^{a}	0.0048^{a}	0.0063^{a}
K (mg/g)	29.39^{b}	40.12^{a}	46.76^{a}
Ca (mg/g)	57.66^{a}	20.21^{c}	30.57^{b}
Mg (mg/g)	8.95^{a}	8.19^{a}	9.68^{a}
Na (mg/g)	4.65^{b}	4.83^{ab}	5.78^{a}
Fe (mg/g)	0.98^{a}	1.14^{a}	1.18^{a}
Cu (mg/g)	0.79^{a}	0.764^{a}	0.82^{a}
Zn (mg/g)	0.47^{a}	0.24^{b}	0.25^{b}
Mn (mg/g)	0.82^{ab}	0.73^{b}	0.93^{a}

Note: Means within a row with different superscripts are significantly different ($P<0.05$)

No significant difference was detected for N, P, Fe, Cu and Mg contents among treatments. No significant difference was also observed between the K content in the vermicompost of brown paper and newspaper beddings but both treatments were found to be significantly higher ($P<0.05$) than the K content of vermicompost with the white paper bedding which was 29.39 mg/g. Meanwhile, differences in the Ca content among all vermicompost were highly significant ($P<0.05$) where vermicompost with the white paper bedding recorded the highest Ca content (57.66 mg/g), followed by the newspaper (30.57 mg/g) and brown paper (20.21 mg/g) beddings. Significant difference ($P<0.05$) was also detected between the Na content of vermicompost with newspaper (5.78 mg/g) and white paper (4.65 mg/g) beddings. Vermicompost with the white paper bedding also recorded significantly higher Zn content (0.47 mg/g) and was found to be significantly different ($P<0.05$) from the brown paper and newspaper beddings. As for Mn content, only vermicompost with the newspaper bedding (0.93 mg/g) was found to be significantly different than the brown paper bedding (0.73 mg/g).

DISCUSSION

Vermicomposting Temperature

Temperature is an important factor in vermicomposting (Bernal *et al.*, 2008). *Eudrilus eugeniae* used in this study is sensitive to extreme temperature, hence temperatures must be maintained between 13˚C to 30˚C (Latifah *et al.*, 2009) by frequently spraying the compost with water. Fluctuation in temperature among the three different vermicompost beddings were between 28˚C to 31.5˚C. Similar temperature range was also reported by Twana and Fauziah (2012), Basheer and Agrawal (2013) and Wani *et al.* (2013). High temperature reaching an average of 31˚C was recorded during day 2 for all vermicompost. Such conditions may be due to the release of heat from the raw materials especially the cow manure (Eghball, 2002). Nagavallemma *et al.* (2005) reported that more heat was generated during the early phase of composting that can exceed 50˚C. However, in the present study, the temperature did not exceed 32˚C as all raw materials were dried before being mixed and heaped together. Moreover, substrates were kept under moist conditions and watered every three to four days to provide good and moist beddings for earthworms.

It was found that the best time to release earthworms into the pre-decomposed organic mixtures was between day 12 and day 15 when the temperature was about 27 to 30˚C. Similar temperature range was also reported by Fornes *et al.* (2012) and Nattudurai *et al.* (2014). However, it must be noted that this suggestion should not be generalized as different compost mixtures will generate different degree of heat at a different time frame. The temperature was slightly higher during the final stage of vermicomposting which could be related to the drying out process of the vermicompost.

Vermicomposting normally takes place at an ambient temperature and requires high humidity to avoid earthworms from being killed. This contradicted the normal composting requirement where high temperature is needed for material sanitation (Singh *et al.*, 2011). Sudden temperature change such as above 35˚C and below 5˚C could kill earthworms (Dominguez *et al.*, 2001). In the present study, vermicomposting boxes were placed under shaded area to avoid direct sunlight that can cause inconsistency in temperature and kill the earthworms as the temperature can get too warm fast (Twana and Fauziah, 2012). Drilled holes on the boxes also help in providing aeration and controlling the temperature in the vermicompost piles, thus providing favourable conditions for the earthworms.

pH Value of Vermicompost

Neutral and partial alkaline pH values are indicators of a stable and mature vermicompost. The optimum pH value for a good quality vermicompost is between pH6 and pH8 as this range can support good microbial activity and provide favourable growth condition for earthworms (Bernal *et al.* 2008). The pH value will normally decrease by time and the alteration of pH happens because of chemical reactions which occur during organic matter fragmentation (Latifah *et al.* 2009).

The pH value for all vermicompost was significantly different during the final stage of vermicomposting. High pH values were recorded for vermicompost with white paper and brown paper beddings due to the decomposition of nitrogenous substrates, resulting in the production of NH_3 (Twana and Fauziah 2012). This result contradicted findings by other researchers (Chen *et al.*, 2013; Rumpel *et al.*, 2013; Kumar *et al*., 2021) where values were recorded below pH8.5. White paper and brown paper contain up to 46% of ash (Ochoa de Alda, 2008) consisting of calcium carbonate ($CaCO_3$), clay and titanium oxide (TiO_2) used as fillers in the production of paper. High amount of these elements may have contributed to the high pH value at the end of the vermicomposting process (Altemeier *et al.,* 2004).

Vermicompost with newspaper bedding recorded a pH value of 7.9 due to the lower ash content in newspaper which range from 0 to 10%. Similar values were also recorded by other researchers (Twana and Fauziah, 2012; Basheer and Agrawal, 2013; Hanc and Chadimova. 2014; Yang *et al.* 2014). The near-neutral pH was due to the secretion of $\boldsymbol{NH_4^+}$ that temporarily reduced the pool of H^+ ions in organic compounds (Brady and Weil, 2002). Decrease in pH may be due to the mineralization of N into $\boldsymbol{NO_2^-}$ or $\boldsymbol{NO_3^-}$ and $\boldsymbol{PO_4^{3-}}$ and the bioconversion of the organic materials into intermediate species of organic acids such as humic acid and fulvic acids (Ndegwa and Thompson, 2001; Latifah *et al.*, 2009). Furthermore, newspaper can retain moisture well as it is made up of cellulose fibres sheathed in lignin (Ward *et al.* 2014). The use of newspaper as a bedding may have caused the retention of the vermicompost pH as a moisture content ranging from 50% to 70% can indirectly avoid N-loss and prevent increase of pH (Altemeier *et al.* 2004).

Time Duration and Weight Losses in the Vermicompost

The percentage of weight loss was above 26% for all vermicompost. Even though the amount of vegetable waste and cow manure were similar, weight loss and time duration to complete the vermicomposting process were different for different beddings. Paper types can influence microbial and earthworm activities (Latifah *et al.* 2009). This current research confirms the results of other vermicomposting research (Basheer and Agrawal, 2013; Hanc and Chadimova, 2014) where weight loss was recorded at 18% to 40% within 50 to 70 days.

The present study indicated that vermicompost mass with newspaper bedding was largely reduced in the shortest time compared to white paper and brown paper beddings. Each paper has different properties that can influence its decomposition rate. For newspaper, its capacity to absorb and hold moisture ranged from 7.5 to 9.5% and this is higher than white paper (4 to 4.5%) and brown paper (5 to 6.5%) (Sutcu and Akkurt, 2009). The ability of paper to retain moisture depends on the amount of cellulose and hemicelluloses (Guo *et al.*, 2014). Newspaper contains 40 to 45% cellulose and 23 to 35% hemicelluloses (Serrano *et al.*, 2014), while both white paper and brown paper contain about 30 to 45% of cellulose and 20 to 35% of hemicelluloses (Ward *et al.*, 2014). Newspaper hence can be easily fragmented by earthworms as they are able to chew moist paper and transform it into small pieces rapidly compared to dried ones (Sathe, 2004). The weight of paper can also influence the duration of decomposition (Altemeier *et al.*, 2004). Thinner paper enables rapid degradation as it can be easily consumed by earthworms (Latifah *et al.*, 2009). Besides that, newspaper porosity which is as much as 70% also enables the mass to be reduced rapidly (Okada *et al.*, 2003).

Cow manure also contributed to the decomposition process by becoming the catalyst for microbes and earthworms, enabling them to consume the organic materials (Chen *et al.*, 2013). Twana and Fauziah (2012) found that cow manure helps in promoting the release of CO_2 through the mineralization process of organic matter and the release of moisture through evaporation. Meanwhile, the presence of earthworms also helps in enhancing the biological process, leading to higher weight loss (Mehta *et al.*, 2013). Other than that, high percentage of decomposition could also be due to the worm's physical activities such as burrowing and mixing that increase the surface area of materials to microorganisms, hence creating favourable conditions for microbial activities (Fornes *et al*., 2012).

Nutrient Analysis

In the present study, all vermicompost possessed considerably high levels of macronutrients (N, P, K, Ca and Mg). High N, P, K and Mg values were consistent with findings by other researchers (Frederickson *et al.*, 2007; Twana and Fauziah, 2012). The high values were due to the properties of organic matter and no loss of leachate from the closed vermicomposting system (Wani *et al.*, 2013; Hanc and Chadimova, 2014). In addition, the high value recorded for N, P, K, Ca and Mg was probably due to the addition of cow manure and excreta produced by the earthworms. Cow manure contains high amount of available P, $\boldsymbol{NH_4^+}$ and $\boldsymbol{NO_3^-}$ (Lazcano *et al.*, 2008) while earthworms' excreta are rich in $\boldsymbol{NO_3^-}$, and is usually available in the form of N, P, K, Ca and Mg (Campos *et al.*, 2014). Meanwhile, the concentration of Ca for all vermicompost was considerably too high when compared to earlier reports (Martin-Gil *et al.*, 2007; Khan and Ishaq, 2011). Leafy green vegetable waste especially spinach, contains high Ca, contributing to high concentration of Ca in all vermicompost (Ward *et al.*, 2014).

The C:N ratios ranged from 12:1 to 22:1 for all vermicompost and these values were consistent with earlier findings (Singh *et al.*, 2011; Doan *et al.*, 2014) where C:N values were recorded ratios of 10.5:1 to 30:1. The C:N values could have been influenced by the microbial respiration and mineralization of labile organic compounds responsible in reducing the weight of the organic compounds (Hanc and Chadimova, 2014). When organic compounds are consumed by microorganisms, two-thirds of the carbon will be released as CO_2 (Khan and Ishaq, 2011). The degree of vermicompost maturation can also influence the C:N ratio as more nitrogen will be released to the environment due to ammonia volatilization that occurs from time to time (Gutiérrez-Miceli *et al.*, 2007).

The concentrations of micronutrient in the vermicompost products were higher than those reported by Padmavathiamma *et al.* (2008). Comparison of micronutrient contents between treatments indicated newspaper beddings contained higher concentration of Fe, Mn and Na. This could be related to the use of newspaper, which is more favourable to the earthworms and microorganisms, thus making nutrients availability highest in the vermicompost product.

Heavy metal concentrations (Cu and Zn) were high in the vermicompost products. Heavy metals can be found in all anthropogenic sources (Liu *et al.*, 2012) such as paper ink, chemical filler and pigments that are readily available in paper wastes (Serrano *et al.*, 2014). Although Cu and Zn elements are essential for plant growth, high concentrations can suppress and have negative impacts on plant growth (Barrena *et al.*, 2014). In the present study, Cu concentrations for all vermicompost products were considered too high ranging from 0.76 to 0.82 mg/g compared to other findings (Frederickson *et al.*, 2007; Liu *et al.*, 2012). Based on this data, it is advisable to reduce the amount of paper used as bedding in order to decrease the concentration of Cu.

Meanwhile, vermicompost products made using brown paper and newspaper as beddings recorded less Zn concentration than white paper. This could be related to the adsorption of Zn by *E. eugeniae* (Liu *et al.*, 2012). Gutiérrez-Miceli *et al.* (2007) noted that the feedstock composition might cause high Zn concentration in vermicompost. The Zn concentration recorded in this study was higher from previous reports (Frederickson *et al.*, 2007; Tejada *et al.*, 2009; Fornes *et al.*, 2012). However, the Zn concentrations for all vermicompost were still within the acceptable limits for application to plants.

CONCLUSION

Analysis on the vermicompost indicated that the physical and chemical properties of different paper types can influence the maturity period and nutrient contents of the product besides the role of earthworms and other microbial activities. Factors namely temperature, moisture, aeration, pH and particle size also influenced the quality of vermicompost mixtures. Vermicomposting using *E. eugeniae* showed newspaper to be the best bedding based on total weight loss of substrates, pH and nutrient contents, followed by white paper and brown paper beddings. Newspaper bedding recorded a near-neutral pH value of 7.9 with 38% weight reduction in 50 days and contained sufficient essential nutrients required by plants. However, the Cu content was high and could cause negative effects on soil fertility and plant growth. Reduction in the amount of paper used as bedding is suggested to reduce Cu concentration in the vermicompost. Thus, paper wastes especially newspaper can be used as beddings to produce vermicompost that can be applied to soil as a soil amendment.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Putra Malaysia Bintulu Sarawak Campus for the permission to use the faculty’s facilities in conducting this research. Our sincere thanks to all staff of UPMKB especially to the officers and staff of the University Agricultural Park and Soil Science Laboratory for their assistance throughout the whole study period.

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