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Efficiencies of unconventional bulking agents in composting food waste in Korea

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Abstract

Sawdust is the main bulking agent used to compost food waste in Korea but it is not an economically desirable choice because its availability entirely depends on imports. Since food waste composting provides agricultural, environmental and economic benefits, it is vital that we search for suitable replacements to sawdust from the locally available materials. In this study, we assessed the composting characteristics of food waste amended with various bulking agents including sawdust, ginkgo leaves, insect feces, and mushroom waste. Each of the bulking agents was mixed with the food waste in ratios of 3:7, respectively. Even though the initial temperatures were highest in the mixture of the food waste and insect feces whose temperature stood at 65 °C against 39, 58 and 51 °C in the sawdust, ginkgo leaves and mushroom waste mixtures, respectively on the third day of the experiment (DAT 3), it was terminated on the 21st day (DAT 21) because of excessively high water content (70.92%). The water content of the composted food waste supplemented with sawdust, mushroom waste, and ginkgo leaves stood at 51.28, 39.81, and 44.92%, respectively at the end of the experiment and therefore, the fully mature composts satisfied the water content requirement of less than 55% established by the Rural Development Agency of the ministry of Agriculture of Korea. The results of the CoMMe-101, Solvita and seed germination index indicated that the composted food waste amended with the mushroom waste and ginkgo leaves matured relatively quicker than that of the sawdust amendment. Based on the above observations, it is clear that the mushroom waste and ginkgo leaves are actually more effective bulking agents than the sawdust and as such, are recommended as suitable replacements for sawdust in food waste composting.

Keywords: Aerobic composting, Bulking agent, Food waste, Maturity

Introduction

Food waste constitutes a copious proportion of the municipal solid waste and is expected to incessantly increase against the backdrop of rapidly growing human population, urbanisation and blossoming global economy [1]. Currently, food waste generation in South Korea stands at 14,389-ton day^{-1} according to the data from the Ministry of Environment and therefore, accounting for about 26.8% of all the domestic waste generated [2]. Discarding this mammoth waste is already posing a monumental challenge for cities and municipalities because of the difficulties in finding suitable landfills presaging a huge future food waste disposal predicament. Although food waste contains sky-high concentrations of readily degradable organic substrates such as starches, sugars, proteins and lipids, its unique intrinsic characteristics including excessive moisture content [3], inadequate porosity [4], high NaCl content [5], and others prohibit a smooth composting process.

Possibilities of improving on the above mentioned inadequate properties of food waste have been widely studied with a sole goal of optimising the composting process in order to abate negative environmental impacts and produce quality soil amendments. In this regard,

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Adhikari et al. [6] assessed the suitability of different materials for use as bulking agents in composting food waste and they indicated that a good bulking agent must have an excellent water absorbing capacity, a neutral pH, a relatively high C/N ratio and ability to maintain a free air space of above 30%. Even though, the study downplayed the bulking agents of wood origin, woody residues have continually received the most research attention and are the most widely used in food waste composting [7]. For example, sawdust and coco peat are the most commonly used bulking agents in South Korea [8]. The challenge, however, is that both of them have to be imported into the country which is costly and therefore, necessitates research into potential bulking agents from locally available materials. The purpose of this study was to assess and select the various locally available potential bulking agents basing on temperature changes of the compost pile, physicochemical characteristics and speed of maturity of the composted materials.

Materials and methods

Characterizations of the composting device, food waste and bulking agents

Food waste was collected from a local food waste recycling facility and then composted. Three non woody materials including mushroom waste, insect frass and ginkgo leaves were assessed for their suitability to compost the food waste by comparing their efficiencies to sawdust. The characteristics of the food waste and bulking agents are given in Table 1. The schematic diagram of the composting device used in this experiment is shown in Fig. 1. The main components of the device consist of the composting box, temperature sensor and an air pump.

The compost box uses a Styrofoam material to prevent heat loss during the composting process. The interior size of the compost box was 270 mm (W) × 270 mm (D) × 250 mm (H) with an effective volume of about 11.6 L. An air pump (MA-200, wave point, USA) was installed outside the composting box to inject 1.7 L min^{-1} of air into the compost box. Thermometers (Tuban, Digital thermometer, China) were installed inside and outside the composting box to measure both the interior and exterior temperatures of the composting box throughout the composting period.

Experimental set up

Composting followed adjusting water content of the food waste to the optimum required range of 50–65% and adding bulking agents at a rate of 30% (w/w). For quick temperature rise at the outset of composting, 90 g of quicklime was added to each compost pile. In addition, 90 g of livestock manure compost and 30 g of effective microorganisms were added for the purpose of inoculating composting materials with aerobic microbes. Also added were 35 g of sugar dissolved in 35 ml of distilled water for supply of nutrients to the effective microorganisms. The composting process lasted for a total of 56 days. The interior and exterior temperatures of the composting units were recorded at 6 p.m. every day since the start of the composting process. The composting materials were turned on a weekly basis with compost samples collected after every turning session and taken to the laboratory for analysis. Compost analysis followed strict adherence to the compost test methods espoused by the rural development agency [9].

Compost quality analysis

Water content was determined as a difference between the weights of a wet compost sample and the sample oven-dried at 105 °C for 24 h. The pH was measured by a pH meter (Thermo, ORION versastar pro, USA) after extracting 3 g of a dry compost sample with 30 ml of distilled water and shaking for 30 min followed by standing for 1 h. NaCl content was measured using a salinity meter (PAL-SALT, ATAGO, Japan). T-C and T-N were measured with an elemental analyzer (Thermo, Flash EA 1112sesries, USA).

Compost maturity tests

Compost maturity was determined using three different methods namely; CoMMe-101, Solvita, and Germination index. For CoMMe-101(E&A Teck, CoMMe-101, Korea), compost from which the foreign matter had been

Table 1 Characteristics of the food waste and bulking agents

Classification	PH (1:10)	EC (dS m^{-1})	NaCl (%)	Water content (%)	T-N (%)	T-C (%)	C/N ratio
Food waste	7.69 ± 0.11	52.70 ± 1.47	2.07 ± 0.06	75.38 ± 0.40	3.63 ± 1.41	63.68 ± 0.45	17.54
Sawdust	5.18 ± 0.03	3.96 ± 0.48	0.10 ± 0.00	41.29 ± 1.06	1.95 ± 2.05	63.69 ± 10.05	32.73
Mushroom waste	4.39 ± 0.03	17.52 ± 0.82	0.57 ± 0.06	15.41 ± 0.19	1.61 ± 0.70	64.16 ± 5.22	39.88
Insect feces	6.20 ± 0.02	8.18 ± 1.52	0.27 ± 0.06	64.24 ± 2.78	2.15 ± 2.31	62.61 ± 2.79	29.06
Ginkgo leaves	3.95 ± 0.02	11.85 ± 2.52	0.47 ± 0.06	8.81 ± 0.93	0.95 ± 0.10	66.45 ± 2.94	69.84

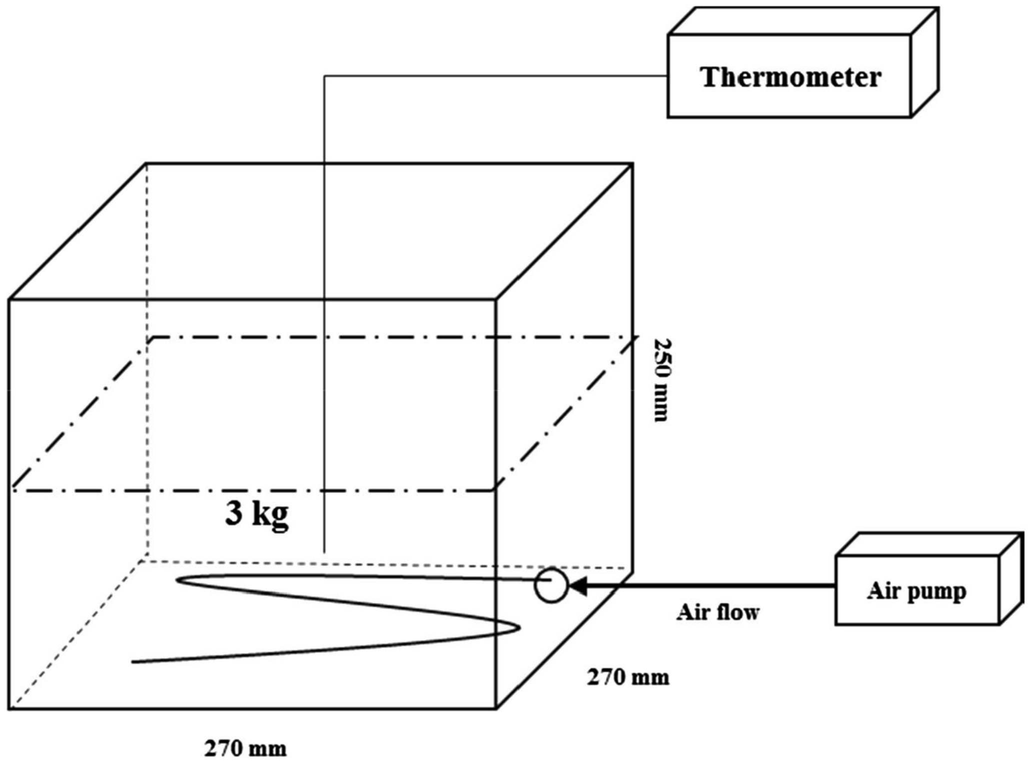

Fig. 1 Food waste composting apparatus

removed was filled in the container whose lid was tightly sealed and the contents left to stand at room temperature for 30 min. Compost maturity was then measured with a maturity tester (CoMMe-101) and a value of 80% or more was adjudged as representing a mature compost. The Solvita method (Solvita & Woods End Laboratories, Solvita, USA) followed filling the Solvita container with compost from which the foreign matter had been removed tapping the container in order to properly settle the added materials. Compost maturity was assessed by inserting both NH_3 and CO_2 probes into the sample followed by tight closing of the lid of the solvita jar and standing the set up for 4 h. The colour changes were quantified with a Solvita DC reader (Solvita & Woods End Laboratories, Solvita dc reader, USA), and compared to a standard color chart with a color grade of 4 or higher considered to represent a completely mature compost.

The germination index method was executed by extracting 1 g of fresh compost with 50 ml of distilled water in a hot water bath maintained at 80 °C for 2 h and then later filtered. 5 ml of the filtrate were added to a petri dish fitted with a filter paper while the control had its petri dish filled with 5 ml of distilled water. 30 grains of the Seohomu seeds purchased from Nongwoobio, Korea, were added to each petri dish. The growth temperature was maintained at 25–28 °C and the incubation lasted for a total of 5 days. The seed germination index (GI) was quantified by determining the germination rate (GR) and relative length of radicles (RE) as shown in Eqs. (1)–(3) with the compost registering a GI value of over 70 considered mature.

$$\mathrm{GR} = (\mathrm{GRt}/\mathrm{GRc}) \times 100 \tag{1}$$

$$\mathrm{RE} = (\mathrm{RLt}/\mathrm{RLc}) \times 100 \tag{2}$$

$$\mathrm{GI} = \mathrm{GR} \times \mathrm{RE}/100 \tag{3}$$

where GRt is the germination rate of seeds in the compost growth media, GRc is the germination rate in the control growth media (distilled water), RLt is the average length of radicles of the seedlings in the compost growth

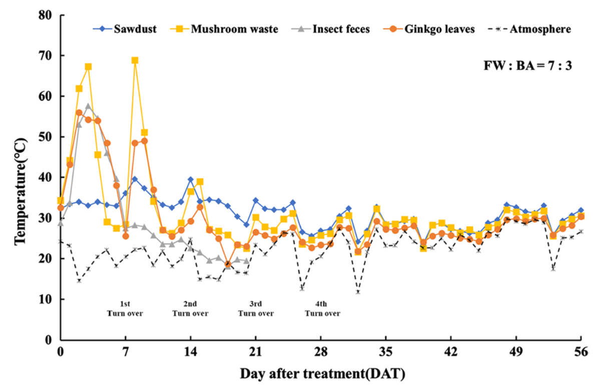

Fig. 2 Variations in temperatures during food waste composting. FW: Food waste; BA: Bulking agent

media and RLc is the average length of seedling radicles in the control experiment.

Results and discussion

Temperature

The composting process is divided into three stages i.e. the mesophilic phase followed by a thermophilic phase and then a long cooling and maturing stage. In the initial stages of composting, mesophilic microorganisms degrade relatively low-molecular substances which raises the temperature of the compost pile thus, giving way to the thermophilic phase. During the thermophilic stage, harmful microorganisms and weed seeds are killed by the extremely high temperatures thus sanitizing the compost product [10]. With reference to the current study, all the treatments attained their thermophilic stages between the third and tenth days of the composting experiment as shown in Fig. 2.

Mushroom waste treatment attained the highest thermophilic temperature of 68.9 °C while the sawdust treatment registered the lowest thermophilic temperature which peaked at only 39.6 °C. The rapid rise in temperature at the outset of the composting experiment may be due to the exothermic reaction of quicklime. Temperatures of the composting materials remained high until the 3rd turning on the 21st day of the experiment (DAT 21), but continued decreasing afterwards and reached the atmospheric temperature levels at the 4th turning on the 28th day of the experiment (DAT 28). The average temperature of the entire composting process was highest in the mushroom waste treatment at 35.6 °C, followed by ginkgo leaves treatment (34.2 °C), sawdust treatment (31.8 °C) and insect feces treatment (31.8 °C). The higher average temperatures recorded in the food waste mixtures containing mushroom waste (2.3 °C higher than the other treatments), might have been due to the active decomposition of organic matter in the food waste by the mammoth of microorganisms present in mushrooms as was indicated by Choi et al. [10] and Ann et al. [11].

Water content

Water content in the composting piles directly affects the growth of microorganisms beneficial in the composting process. When the water content is lower than 40%, the activity of microorganisms is lowered, so composting is slower while the composting materials rot if the water content is too high. It is thus necessary to adjust the water content of the composting pile to levels suitable for the growth conditions of microorganisms. According to Jeon and Hur [12] the optimum range of water content required for composting is between 50 and 65%. An additional requirement is that mature compost must have moisture content of less than 55% stipulated by the rural development agency of the ministry of Agriculture in order to qualify for usage in South Korea. In the current study, the water content of all the treatments except mushroom waste were within the optimum range at the beginning of the experiment. However, the water content in the mixtures containing insect feces increased to 73.1%, about 10% higher than the optimum range and decayed as a result leading to its termination on the second turning (DAT 14) as shown in Fig. 3. The water content in the rest of the treatments decreased to 44.1% in mushroom waste containing mixtures and 38.1% in ginkgo leaves containing mixtures at the end of the composting process thus satisfying the compost quality standard set by RDA as indicated in Fig. 3.

pH

Optimal pH requirement for the growth of microorganisms needed in the composting process reported from previous studies varies from 5.5 to 9.5 [13–15].

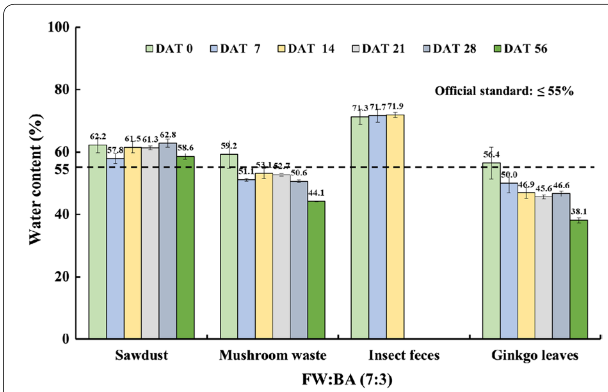

Fig. 3 Changes in water content during food waste composting. FW: Food waste; BA: Bulking agent

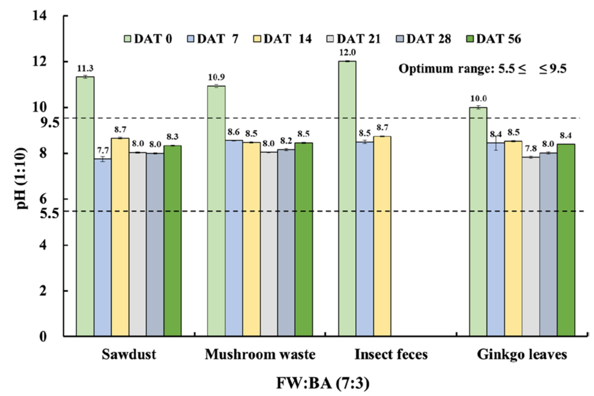

Fig. 4 Changes in pH during food waste composting. FW: Food waste; BA: Bulking agent

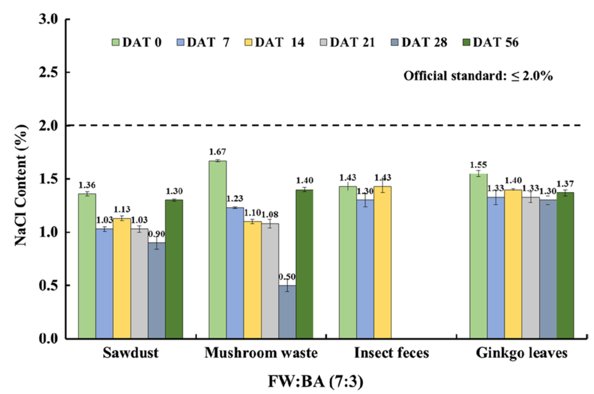

Fig. 5 Variations in NaCl contents during food waste composting. FW: Food waste; BA: Bulking agent

Therefore, the pH of the composting materials was set in the range of 5.5 to 9.5 following suggestions presented in the aforementioned previous studies. As shown in Fig. 4, the pH of the mixtures of the food waste and bulking agents rose sharply to 11.3 in sawdust, 10.9 in mushroom waste, 12.0 in insect feces and 10.0 in ginkgo leaves possibly due to quick lime added to stimulate temperature rise. The pH values, however, decreased rapidly after the seventh day of the experiment (DAT 7) and reached the lowest values of 8.3 in sawdust, 8.5 in mushroom waste, and 8.4 in ginkgo leaves at the end of the experiment as shown in Fig. 4. This was in line with a proposition set by Kang et al. [16] that during composting, the pH tends to increase in the first 2 to 3 weeks as ammonia gas is produced from the decomposition of nitrogen but decrease later due to the decomposition of organic acid to organic matter.

NaCl content

The high NaCl content of the food waste poses challenges because excess NaCl in the soil, inhibits the absorption of other ions, affects crop metabolism due to water stress, and reduces rates of photosynthesis [17]. It's against this background that the rural development agency established a limit of 2.0% NaCl content for the mature compost. That means that all the treatments in the current study satisfied that guideline since the NaCl content decreased from 2.07% in the uncomposted food waste to 1.40%, 1.37% and 1.30% in the mushroom, ginkgo leaves and sawdust containing food waste mixtures, respectively as shown in Fig. 5.

Compost maturity

Ammonia is the main compound released from the actively composting pile [18] while no ammonia is released from mature compost. Application of immature compost to soil elicits adverse effects on the seeds due to the exothermic reaction that occurs when the organic matter is decomposed in the soil [18]. For this reason, application of mature compost for agricultural production is a necessity. Changes in maturity during composting are shown in Table 2, and as clearly indicated, the germination index (GI) on the 14th day of the experiment (DAT 14) in all treatments was over 70, except for the sawdust containing mixture. All treatments had GI values of 127 or more on the final day of the experiment (DAT 56) with ginkgo leaves containing mixture registering the highest value of 141, followed by the mushroom waste containing mixture at 138 while sawdust came in the last spot with a value of 127. With reference to CoMMe-101, the mixture containing ginkgo leaves completed the curing stage on DAT 14 of the composting process while the rest of the treatments matured on the 42nd day (DAT 42). On the other hand, all treatments recorded a color value of over 4 on DAT 14 and all the treatments had completely mature compost on DAT 42 except the saw dust mixture. Overall, food waste amended with the ginkgo leaves matured most rapidly, followed by the mushroom waste amendment while the sawdust amendment recorded the slowest speed of composting. The fastest rate at which the food waste amended with ginkgo leaves matured might have been due to the relatively high porosity of the deciduous leaves when

Table 2 Variations in food waste compost maturity as affected by the different bulking agents

Sample	Compost maturity indices														
	Germination Index (%)[a]					CoMMe-101[b]					Solvita[c]				
	DAT 14	DAT 21	DAT 28	DAT 42	DAT 56	DAT 14	DAT 21	DAT 28	DAT 42	DAT 56	DAT 14	DAT 21	DAT 28	DAT 42	DAT 56
Saw dust	67	76	81	110	127	Curing	Curing	Curing	Cured	Cured	2	3	3	5	6
Mushroom waste	94	113	116	128	138	Curing	Curing	Curing	Cured	Cured	6	6	7	7	7
Insect feces	85	NA	NA	NA	NA	Curing	NA	NA	NA	NA	6	NA	NA	NA	NA
Ginkgo leaves	89	110	114	130	141	Cured	Cured	Cured	Cured	Cured	5	5	6	7	7

NA Not analysed

[a] *G.I.* Germination index

[b] *DAT* Day after treatment

[c] Compost maturity levels, G.I. > 70%, CoMMe-101 maturity level > cured, Solvita > 4

compared to other bulking agents which resultantly hastened the decomposition of organic materials.

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Authors' contributions
All authors contributed to the study conception and design. DL and J-HL collected data, conducted the laboratory and statistical analyses and wrote the manuscript, C-HL helped in data collection whenever we needed extra manpower as well as procuring the required materials and in some aspects of data analysis. S-JP and T-KO supervised the experiment and offered technical guidance throughout the entire research period. All authors read and approved the final manuscript.

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Availability of data and materials
The data sets supporting the conclusions made are included in this article.

Competing interests
All authors declare that they have no competing interests.

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