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Effects of Raw Materials and Bulking Agents on the Thermophilic Composting Process

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Three typical biological solid wastes, namely, animal manure, garbage, and sewage sludge, were compared with regard to the composting process and the changes in microbial community structure. The effects of different bulking agents such as rice straw, vermiculite, sawdust, and waste paper were compared in manure compost. The differences in the microbial community were characterized by the quinone profile method. The highest mass reduction was found in garbage composting (56.8%), compared with manure and sludge (25% and 20.2%, respectively). A quinone content of 305.2 μmol/kg was observed in the late stage of garbage composting, although the diversity index of the quinone profile was 9.7, lower than that in manure composting. The predominant quinone species was found to be MK-7, which corresponds to Gram-positive bacteria with a low G+C content, such as *Bacillus*. The predominance of MK-7 was especially found in the garbage and sludge composting process, and the increase in quinones with partially saturated long side-chains was shown in the late composting process of manure, which corresponded to the proliferation of *Actinobacteria*. The effects of different bulking agents on the composting process was much smaller than the effects of different raw materials. High organic matter content in the raw materials resulted in a higher microbial biomass and activity, which was connected to the high mass reduction rate.

Keywords: Composting, manure, garbage, sludge, quinone profile

Composting is the process in which complex heterogeneous materials are degraded by a mixture of microorganisms [19]. Composting has been used in agriculture to produce fertilizer since antiquity in Egypt, India, and China. With the wide use of chemical fertilizer, composting has been gradually abandoned as a means of producing fertilizer. The increased interest of organic living, however, has rejuvenated composting as a technique for the disposal of organic solid wastes. In the modern composting process, the materials used have been changed to industrial wastes such as sludge and food waste. Composting techniques have also added mixing, aeration, and temperature control. The high temperature rapid composting technique has improved disposal efficiency, shortened the composting time, and become an effective measure for rapid disposal of various organic wastes.

Garbage, domestic animal manure, and municipal sludge are three common organic wastes. Domestic animal manure can be easily disposed through static pile, windrow composting, or in-vessel composting systems [18, 25, 40]. Sludge can be composted using forced aeration technology [10, 39, 46], and sometimes inoculum or bulking agents are added [23, 41]. For garbage disposal, in-vessel composting systems or small-scale composters are often used [11, 21, 24, 28]. The different raw materials contain different organic ingredients, which result in different compost properties [37]. Raw materials can sometimes be mixed to achieve better composting conditions. The different approaches should be studied for a detailed understanding of the characteristics of the raw materials, such as garbage, sludge, and manure, to establish suitable composting techniques that can be applied to various biological solid wastes.

The composting process is controlled through regulation of the microbial activity among different microorganisms such as bacteria and fungi during the composting process. It is difficult to detect the microbial community structure and its fluctuation by the traditional plate counting method, which is too time-consuming to characterize the complex microbial community in composting. Culture-independent methods have been developed for environmental microorganisms;

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these include molecular biological methods targeting 16S rRNA genes, phospholipid fatty acids (PLFA) profites, and respiratory quinone profiles. Polymerase chain reaction–denaturing gradient gel electrophoresis (PCR–DGGE) was used to characterize the microbial community structure during composting [5, 12]. However, this method does not always account for the change in microbial biomass because of the low extraction efficiency of DNA from organic-rich materials such as composts. The quinone profile has a linear relationship with microbial biomass, and the analysis of quinones is simple, highly reproducible, easy to interpret, and applicable to almost all respiratory and photosynthetic microorganisms [14]. The quinone profile method has been widely applied to detect environmental microorganisms [33]. It has also been used to characterize the dynamic microbial community during composting [6, 34–36].

Here, we compared composting processes using different raw materials under similar conditions and elucidated the effects of raw materials and bulking agents. We also aimed to determine how the microbial community changes during composting with different raw materials.

MATERIALS AND METHODS

Composting System

A composting system with aeration and temperature control was used, as described previously [36]. To introduce a thermophilic composting process, the raw material was placed into 30-l stainless steel cylinders with the incubator set at 60°C. The amount of raw materials was constant, with the water content adjusted to 60–70% with different bulking agents (20% of total composting mass). Aeration was produced by an air pump with a flow rate of 1.5–2 ml/min. The temperature was monitored by a thermo recorder, and oxygen concentration in the exhaust gas was analyzed with an oxygen detector. The raw material inside the cylinder was mixed every day by hand, and samples were taken at different times during composting.

Composting Materials

Three raw materials were used for the composting experiment: cattle manure, garbage, and sludge. The fresh manure was taken from the Nagoya University Farm and was used soon after sampling. Food waste from a cafeteria was representative of garbage. The principal constituents of the food waste were vegetables (38.4%), boiled rice (18%), noodles (16.3%), fish and meat (7.9%), fried food (5%), and other (14.4%). The sludge was taken from a sewage treatment plant without anaerobic digestion. Because lime was added during the dehydration process, the sludge had a pH of 11–12. In the composting sludge, manure compost was used to adjust the pH and moisture content. Four different materials (rice straw, vermiculite, sawdust, and waste paper) were used as bulking agents to adjust the moisture content during composting. The chemical compositions of the three composting materials and four bulking agents are shown in Table 1. Among the raw materials, the carbon and the nitrogen contents were highest in the food waste. Although the carbon content was low in sludge, the C/N ratio was also low, indicating a high protein content. In the cattle manure, the C/N ratio was the highest, which was caused by high hydrocarbon content, such as cellulose, hemicellulose, and lignin. The bulking agents had a high content of C and a low N content, except for vermiculite, which is an inorganic substance.

Analytical Methods

The moisture content was determined by weight change after drying at 105°C for 24 h. The composting mass was measured by weight. The moisture content was detected by drying the compost at 105°C for 24 h and the measuring by the gravimetric method. Then, the dry mass of the composting material was calculated based on weight and moisture content value. For the analysis of C and N, the drying sample was ground and analyzed with a CHN analyzer (MT-5 CHN Corder; Yanaco Analytical Instruments, Tokyo, Japan). The pH and electric conductivity (EC) were detected with a pH and an EC meter (DKK TOA Corporation, Tokyo, Japan), respectively, after mixing the sample with water at a ratio of 1:9. Quinone profile analysis followed the method introduced by Fujie *et al.* [4] with some modifications described previously [37]. Compost samples were first extracted with a chloroform–methanol mixture [2:1 (v/v)] with sonication for 10 min. The supernatant was washed with NaCl–$CaCl_2$ (10% NaCl and 1% $CaCl_2$) and extracted with *n*-hexane. The quinones in hexane were concentrated *in vacuo* and absorbed by a Sep-Pak Plus Silica Cartridge (Waters, Tokyo, Japan). Menaquinones (MK) and ubiquinone (Q) were eluted with 2% and 10% diethylether *n*-hexane solutions, respectively. Quinones were determined by a high-performance liquid chromatograph (HPLC) with a photodiode array detector (Shimadzu, Kyoto, Japan). MK and Q are noted with a hyphen and the number of isoprenoid units and saturated double bonds with hydrogen atoms in the side chain.

Table 1. Chemical composition of composting materials and bulking agents[a].

		C (%)	N (%)	C/N	Ash (%)	Moisture (%)
Raw materials	Manure	43.3	1.60	27.1	15.6	82.0
	Sludge	26.8	2.79	9.6	36.7	61.0
	Garbage	52.3	3.79	13.8	2.7	77.0
Bulking agents	Rice straw	40.6	0.77	53	11.7	8.8
	Vermiculite	0.3	0.10	3	96.0	3.4
	Sawdust	47.3	0.08	565	0.6	16.4
	Waste paper	39.2	0.06	628	4.3	7.2

[a] Percentage on a dry weight basis.

The quinone diversity index (DQ) was calculated based on the quinone mole fractions, as described by Hu *et al*. [8]:

$$DQ = \left(\sum_{k=1}^{n} \sqrt{f_k}\right)^2 \qquad (1)$$

where f_k is the mole fraction of quinone species k, and n represents the quinone species.

RESULTS AND DISCUSSION

Change in Composting Activity

After measuring changes in temperature and oxygen consumption, the composting process was divided into three stages: initial (0–3 days), middle (3–7 days), and late (7–14 days) (Fig. 1). With all raw materials and bulking agents, the initial stage showed higher temperature than the incubator and a higher oxygen consumption rate, indicating rapid proliferation of microorganisms. The middle stage was characterized by a gradual decrease in temperature and oxygen consumption; during the late period, the temperature was the same as the ambient temperature, and the oxygen consumption decreased and remained low. The change of temperature and oxygen consumption was different with different raw materials. In manure composting, the temperature and oxygen consumption increased rapidly to a peak value and then decreased soon after. In garbage and sludge composting, however, the activity was relatively high during the middle stage and continued to the late period. In manure composting with different bulking agents, the composting activity was similar except for relatively low oxygen consumption with vermiculite and high temperature using rice straw.

The composting activity can be reflected by the change of temperature in the composting materials and oxygen consumption in the exhaust gas. In the self-heated composting process of food waste, the oxygen consumption and

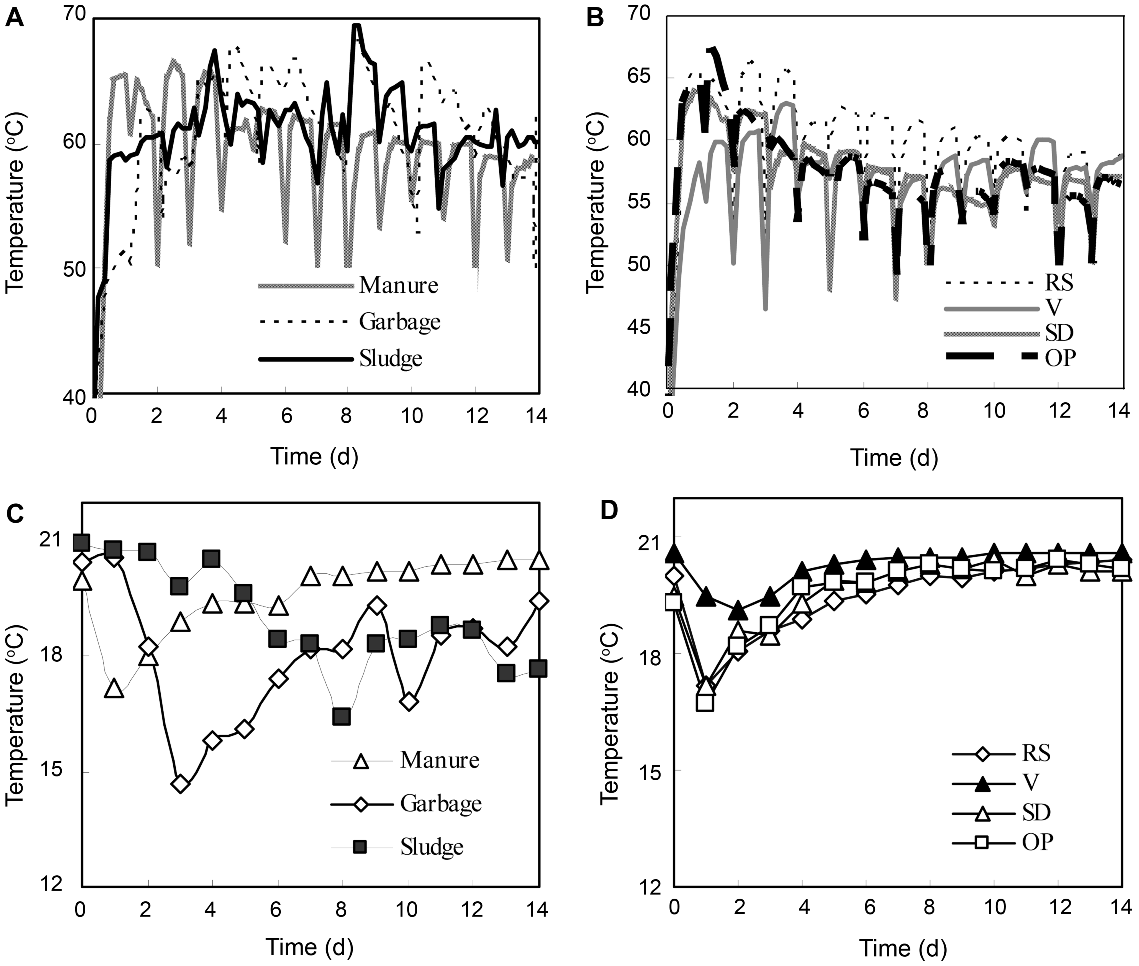

Fig. 1. Change in temperature and oxygen consumption during composting with different raw materials and bulking agents.
A. Temperature change with different raw materials; **B**. Temperature change with different bulking agents; **C**. O_2 content change with different raw materials; **D**. O_2 content change with different bulking agents. Manure was used as the raw material for the bulking agent experiment. RS: Rice straw; V: Vermiculite; SD: Sawdust; WP: Waste paper.

temperature are linearly related [1]. The differences in composting activity may be due to different amounts of degradable organic substances such as proteins, lipids, and starch. The decomposition of organics and the proliferation of microbial populations may be related and promoted mutually. The results until now suggest that the improvement of composting processes seems to depend on the properties of raw materials [3, 43]. Manure and sludge may contain less degradable substances compared with food waste. Composting processes with the same raw material but different bulking agents did not differ greatly, as the bulking agents were either inorganic or recalcitrant organic substances such as cellulose, hemicellulose, and lignin [3].

Change in Chemical Properties During Composting Process

Changes in pH, EC, and C and N content during composting are shown in Table 2. The pH values increased to above 8 with manure and garbage, whereas the pH values were high initially with the sludge and decreased during composting. EC values decreased in the middle period of manure composting and then increased slightly. In sludge and garbage composting, EC values increased continuously. The increase in pH is accompanied by the liberation of NH_3 during composting [22, 26], whereas the increase in EC may be due to the increased inorganics from the decomposition of organic components. After composting, the ECs were related as follows: garbage>sludge>manure. High EC values may indicate phytotoxic/phytoinhibitory effects on the growth of plant as applied to soil [9]. The low EC value in manure compost suggests that it is more suitable for agricultural application. Because the pH increases to above 8, regardless of the different raw materials, it can be used as an indicator of the succession of the composting process.

The C and N contents were different initially in different raw materials and in the same raw material with different bulking agents. However, the C content was generally decreased and N content increased, which resulted in a lower C/N ratio except in the middle stage of sludge composting and in the late stage of manure–vermiculite composting. The C/N ratio in manure compost was higher than that in sludge and garbage throughout the process. The changes in C and N content and C/N ratio indicate the decomposition of organic components, which resulted in the relative preservation of N and the loss of C during the composting process. This did not change with the change in raw materials and bulking agents.

The composting mass reduction rate was similar for manure and sludge, with a value of 10.9−25% with manure and 20.2% with sludge. Higher mass reduction was found

Table 2. Change in chemical properties during composting processes with different raw materials.

Materials	Bulking agents[a]	Composting stages	C (%)	N (%)	C/N	Ash (%)	Composting mass (% of initial)	pH	EC (mS/cm)
Manure	RS	Initial	41.2	1.1	38.9	14.8	100.0	7.9	4.2
		Middle	40.0	1.2	32.5	16.2	91.4	8.8	3.7
		Late	39.8	1.5	26.6	19.4	76.3	8.6	3.7
	V	Initial	20.8	0.7	28.5	56.2	100.0	8.2	2.3
		Middle	19.6	0.8	25.0	58.8	95.6	8.4	1.6
		Late	17.9	0.8	21.8	63.1	89.1	8.2	1.5
	SD	Initial	44.6	1.0	45.2	6.2	100.0	8.2	3.3
		Middle	43.8	1.1	39.1	7.3	84.7	8.7	2.7
		Late	43.3	1.3	32.7	8.3	75.0	8.4	3.0
	WP	Initial	41.4	1.0	41.4	8.2	100.0	8.2	2.9
		Middle	40.3	1.1	38.2	8.9	92.3	8.6	2.3
		Late	39.1	1.3	31.2	10.8	76.4	8.5	2.5
Garbage	RS	Initial	45.4	2.2	20.5	8.6	100.0	7.0	5.3
		Middle	45.0	2.7	16.5	13.5	63.8	8.7	7.0
		Late	38.3	3.3	11.5	19.9	43.2	8.4	8.8
	V	Initial	27.6	2.1	13.3	34.0	100.0	8.3	3.8
		Middle	20.1	2.3	8.8	49.9	68.2	8.5	4.7
		Late	11.7	1.8	6.3	64.4	52.8	8.4	4.7
Sludge+manure compost		Initial	33.0	2.3	14.1	27.5	100.0	10.5	4.8
		Middle	30.4	1.8	16.9	30.8	89.2	8.4	5.1
		Late	28.4	2.0	13.9	34.4	79.8	8.1	5.7

[a] RS: Rice straw; V: Vermiculite; SD: Sawdust; WP: Waste paper.

Three stages: “initial” correspond to 0 day, “middle” to 7 days, and “late” to 14 days.

in garbage composting with a value of 47.2%–56.8%, indicating higher composting activity. The different raw materials affected the mass reduction rate because of the differences in the composition of raw materials and the composting activity in the process. The addition of rice straw, sawdust, and waste paper showed similar mass reduction rates in manure composting, whereas a lower value of mass reduction was found in the manure composting process with vermiculite as the bulking agent. It was confirmed by other researchers that the supplementary addition of vermiculite to the composting mixture did not significantly improve the weight loss rate and the decomposition rate of food wastes [27]. Compared with the effect of raw materials, the mass reduction rate was less affected by different bulking agents. Similar results were found by Seo *et al.* [27] in composting food wastes.

Change of Microbial Properties During Composting Process

Fig. 2 shows the quinone content and DQ value in composting of different raw materials. The quinone content was the highest in the middle period of manure composting, whereas the quinone content increased and showed the highest value in the late period in garbage and sludge composting. The maximum quinone content in garbage composting was 305.2 μmol/kg, which was higher than that for sludge and manure. This indicates that the microbial biomass was higher in garbage composting than in manure and sludge composting. DQ values for the manure and garbage composting processes increased gradually from the initial stage to the late period, but the DQ value reduced in the sludge composting in the middle stage and then increased slightly. The DQ value was the highest in manure composting (18–22) compared with garbage (9.7) and sludge (9.2), suggesting a more diverse microbial community. Bulking agents did not affect the change of quinone content and DQ value.

Table 3 shows changes in the mole fraction of different quinones with different raw materials. More quinone species were developed in manure and sludge compared with garbage at the initial stage of composting. A predominance of Q-9, MK-6, and MK-7 was found in manure, and different menaquinones existed in sludge at this period. No quinones were detected at the onset of garbage composting. The results indicate that the initial microbial community was different among the three different composting materials. During composting, ubiquinones decreased, and different menaquinones increased; MK-7 showed the most rapid increase and became predominant in the middle and late periods. The mole fraction of MK-7 ranged from 16% to 35% in the middle period of manure composting but was 60%–80% in garbage and sludge composting. The fraction of MK-7 decreased in the late period of composting, whereas other partially saturated and long-chain menaquinones such as MK-9(H4), MK-8(H6), NK-9(H8), MK-10(H4), and MK-10(H6) increased during the same time, especially in manure composting. The MK/Q ratio increased and was higher in sludge and garbage composting. The MK-8 fraction increased at the middle-late period of manure composting with sawdust as bulking agent, and in the garbage and sludge composting process. The results reflect the different microbial community structures with different raw materials.

The corresponding microorganisms for thermophilic composting have been analyzed by many researchers. It was indicated that thermophilic *Bacillus* and some *Actinobacteria* such as *Thermobifida fusca* are the predominant microbial species [2, 17, 20, 26]. For example, Strom [32] found that 80% of the isolated bacteria in a food waste

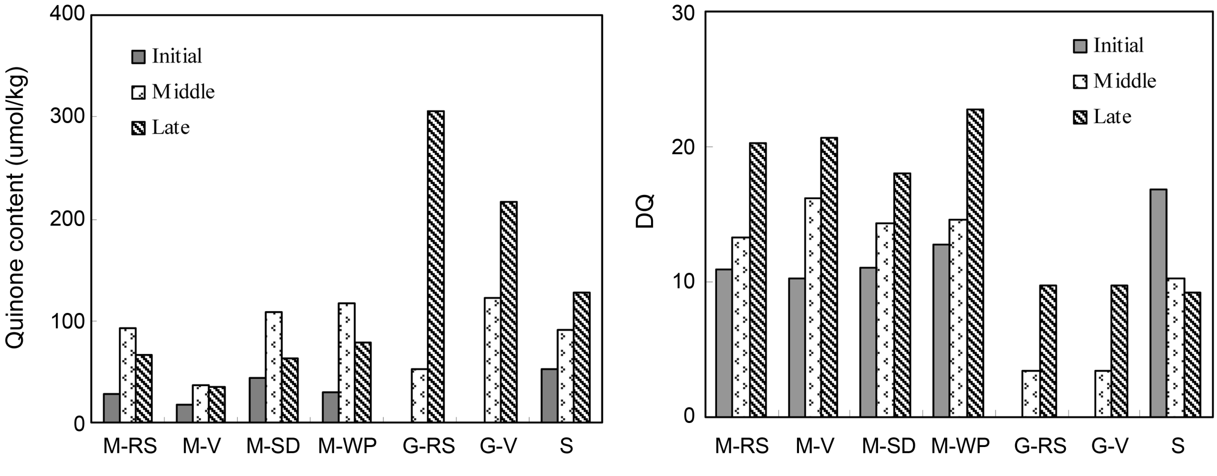

Fig. 2. Changes of quinone content and DQ during composting process with different raw materials.

M-RS: Manure-Rice straw; M-V: Manure-Vermiculite; M-SD: Manure-Sawdust; M-WP: Waste paper; G-RS: Garbage-Rice straw; G-V: Garbage-Vermiculite; S: Sludge. The values are the average of two determinations (two separate experiments) with maximum difference less than 26% for total quinone content and 6% for DQ. Three stages: "initial" corresponds to 0 day, "middle" to 7 days, and "late" to 14 days.

Table 3. Changes in quinone mole fraction during composting of different biological solid wastes.

	Manure+RS			Manure+V			Manure+SD			Manure+WP			Garbage+RS			Garbage+V			Sludge+compost		
	Begin	Middle	End	Begin	Middle	End	Begin	Middle	End	Begin	Middle	End	Begin	Middle	End	Begin	Middle	End	Begin	Middle	End
Q-8	0.02	0.04	0.04	0	0.11	0.10	0.06	0.06	0.09	0.07	0.03	0.04	0	0	0	0	0	0	0.08	0	0
Q-9	0.36	0.21	0.05	0.12	0.21	0.05	0.26	0.13	0.01	0.15	0.10	0.04	0	0	0	0	0	0	0.02	0.01	0
Q-10	0.08	0.07	0.02	0.05	0.12	0.05	0.16	0.08	0.02	0.07	0.06	0.03	0	0	0	0	0	0	0.02	0	0
Q-10(H2)	0.04	0.03	0.01	0	0.02	0.01	0	0.01	0	0.03	0.01	0.01	0	0	0	0	0	0	0.01	0	0
MK-6	0.08	0.11	0.04	0.13	0.03	0.02	0.09	0.11	0.04	0.14	0.15	0.04	0	0.06	0.04	0	0.05	0.03	0.04	0.02	0.02
MK-7	0.07	0.35	0.19	0.16	0.13	0.07	0.08	0.31	0.14	0.10	0.35	0.11	0	0.81	0.61	0	0.68	0.61	0.10	0.60	0.54
MK-7(H2)	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
MK-7(H4)	0	0	0.07	0	0	0.09	0	0	0.03	0	0	0.03	0	0.05	0	0	0	0	0	0	0
MK-8	0.04	0.05	0.06	0.06	0.04	0.04	0.03	0.07	0.27	0.04	0.05	0.03	0	0.08	0.15	0	0.21	0.15	0.12	0.17	0.17
MK-8(H2)	0.00	0	0.03	0	0	0	0	0	0.05	0	0	0.04	0	0	0	0	0	0	0.09	0.02	0.01
MK-8(H4)	0.02	0.01	0	0.03	0.01	0	0.02	0.01	0	0.03	0.06	0.01	0	0	0	0	0	0	0.19	0.04	0.02
MK-8(H6)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MK-9	0.06	0.02	0.04	0.05	0.02	0.04	0.03	0.02	0.04	0.03	0.02	0.04	0	0	0.02	0	0.06	0.02	0.02	0.01	0.02
MK-9(H2)	0	0	0.03	0	0.01	0.03	0	0.05	0.05	0	0.04	0.05	0	0	0	0	0	0	0.07	0.02	0.01
MK-9(H4)	0	0	0.07	0	0.01	0.03	0.01	0.01	0.03	0.02	0.01	0.04	0	0	0	0	0	0	0.06	0.01	0.02
MK-9(H6)	0	0.01	0.13	0	0.05	0.11	0	0	0.06	0	0.01	0.10	0	0	0	0	0	0	0.03	0.01	0.01
MK-9(H8)	0	0.01	0.08	0	0.05	0.09	0	0	0.03	0	0	0.03	0	0	0	0	0	0	0.10	0.02	0.02
MK-10	0.03	0.01	0	0.05	0.01	0.01	0.05	0.02	0.02	0.05	0.01	0.03	0	0	0	0	0	0	0.01	0	0.01
MK-10(H2)	0	0	0	0	0	0.01	0	0.01	0.01	0	0.01	0.03	0	0	0	0	0	0	0	0	0
MK-10(H4)	0	0	0.02	0	0	0.02	0	0.02	0.01	0	0.01	0.04	0	0	0.04	0	0	0.04	0.01	0.02	0.05
MK-10(H6)	0	0.01	0.04	0	0.01	0.05	0	0.01	0.02	0	0.01	0.13	0	0	0.05	0	0	0.05	0.01	0.02	0.04
MK-10(H8)	0	0.01	0.04	0	0.01	0.06	0	0	0.01	0	0.01	0.04	0	0	0	0	0	0.05	0.01	0.01	0.02
MK-11	0.11	0.02	0.01	0.17	0.06	0.04	0.10	0.03	0.01	0.12	0.02	0.04	0	0	0	0	0	0	0.02	0	0
MK-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0.01	0.01
MK-others	0.11	0.03	0.03	0.17	0.08	0.07	0.12	0.05	0.02	0.15	0.04	0.05	0	0	0.03	0	0	0.03	0.02	0.01	0.02
MK/Q	1.02	1.85	7.05	4.93	1.15	3.69	1.11	2.51	6.65	2.09	3.96	7.60	-	-	-	-	-	-	6.71	77.48	265.1

RS: Rice straw; V: Vermiculite; SD: Sawdust; WP: Waste paper.
Three stages: “initial” corresponds to 0 day, “middle” to 7 days, and “late” to 14 days.
The values are the average of two experiments, with maximum difference less than 54%.

compost belonged to *Bacillus* spp. *Bacillus* contains MK-7 as its dominant quinone species. This suggests that the increase and predominance of MK-7 during composting may be caused by the proliferation of *Bacillus*. This is why the MK-7 content was higher in garbage compost compared with manure and sludge composts. The same result was found in a thermophilic contact oxidation process [16]. However, the predominance of MK-7 was not found in food waste compost at a lower ambient temperature [7]. The increase in MK-8 was also found in composting process under a lower temperature in our previous study, which may suggest the proliferation of mesophilic microbial groups corresponding to Gram-positive bacteria with low G+C contents, *Proteobacteria* and *Actinobacteria* [38]. This indicates that temperature and raw material affect the microbial community and its fluctuation during composting. Ubiquinones correspond to *Proteobacteria*, Q-9 corresponds to fungi, and Q-10(H2) exists only in fungi [15]. Ubiquinone fractions decreased during the composting, indicating that *Proteobacteria* and fungi do not correspond to thermophilic composting. The increase of Q-9 in the manure compost with the addition of vermiculite was likely due to the low organic content from addition of an inorganic component, which may be suitable for *Proteobacteria* or fungi. The increase of partially saturated and long-chain menaquinones during the late period of composting indicates the proliferation of *Actinobacteria*. The higher fraction of *Actinobacteria* in manure compost during the late period was likely caused by the lower content of degradable organics and higher cellulose content. Shin and Jeong [29] found that cellulase activities increased during the thermophilic stage and reached a maximum during the cooling stage of composting with appropriate C/N ratios. The proliferation of *Actinobacteria* during the late period may be related to the decomposition of cellulose [31, 42, 45]. The shift of bacteria community to *Bacillales* and *Actinomycetales* in the composting process was also proved by the molecular method of 16S rRNA DGGE analysis [44].

Component analysis of the quinone profile further indicated the change of microbial community structure and its variation with different raw materials (Fig. 3). Although the microbial communities were plotted at different areas initially and at the end of composting with different raw materials, a similar trend, decrease in the PC1 score, was observed in all the cases in the late stages (Fig. 3). The similar trend resulted from the increase in menaquinones with partially saturated long side-chains during composting. The microbial community in garbage compost showed a different trend during the middle period, which resulted from the increase of MK-7. Compared with the effect of raw materials, the effect of bulking agents on the microbial community was much smaller. This suggests that different raw materials are the main factors affecting the microbial community structure.

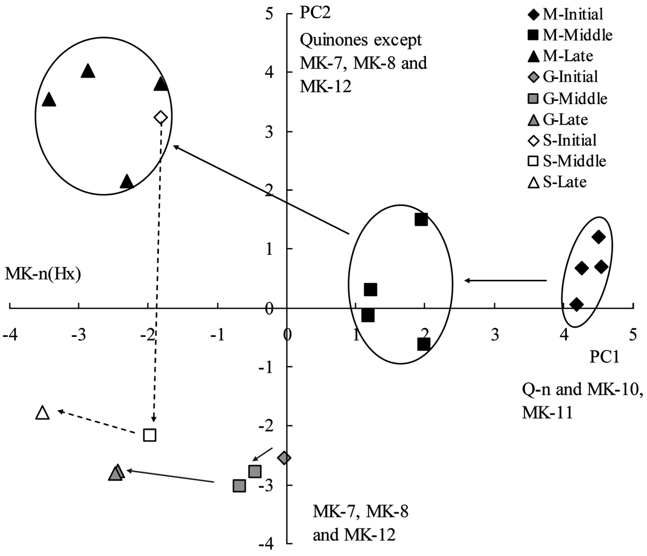

Fig. 3. Principal component analysis of the quinone profile obtained during composting processes with different raw materials. PC1 and PC2: first and second principal component in the analysis. M-Initial, M-Middle, M-Late: Manure composting, showing initial, middle, and late stages; G-Initial, G-Middle, G-Late: Garbage composting, showing initial, middle, and late stages; S-Initial, S-Middle, S-Late: Sludge composting, showing initial, middle, and late stages. Three stages: "initial" corresponds to 0 day, "middle" to 7 days, and "late" to 14 days.

Relation Between Mass Reduction and Microbial Properties

As quinone content relates to the microbial biomass, this reflects the relationship between the microbial biomass and the decomposition of waste. As shown in Fig. 4, a linear relationship was found for the quinone content with composting mass reduction and cumulative oxygen consumption (COC) in compost with different raw materials; however, no significant relationship was observed in DQ with composting mass reduction and COC. These suggest that the microbial biomass rather than the diversity of the microbial community determines composting activity. Thus, the quinone content can represent activity during composting.

Both microbial properties and physicochemical properties differ among the thermophilic composting processes with different raw materials. The raw materials may be a fundamental factor compared with bulking agents, which have less impact on the composting activity. Conditions controlling the composting process should be determined based on the raw materials, by regulating aeration, moisture content, and temperature differently.

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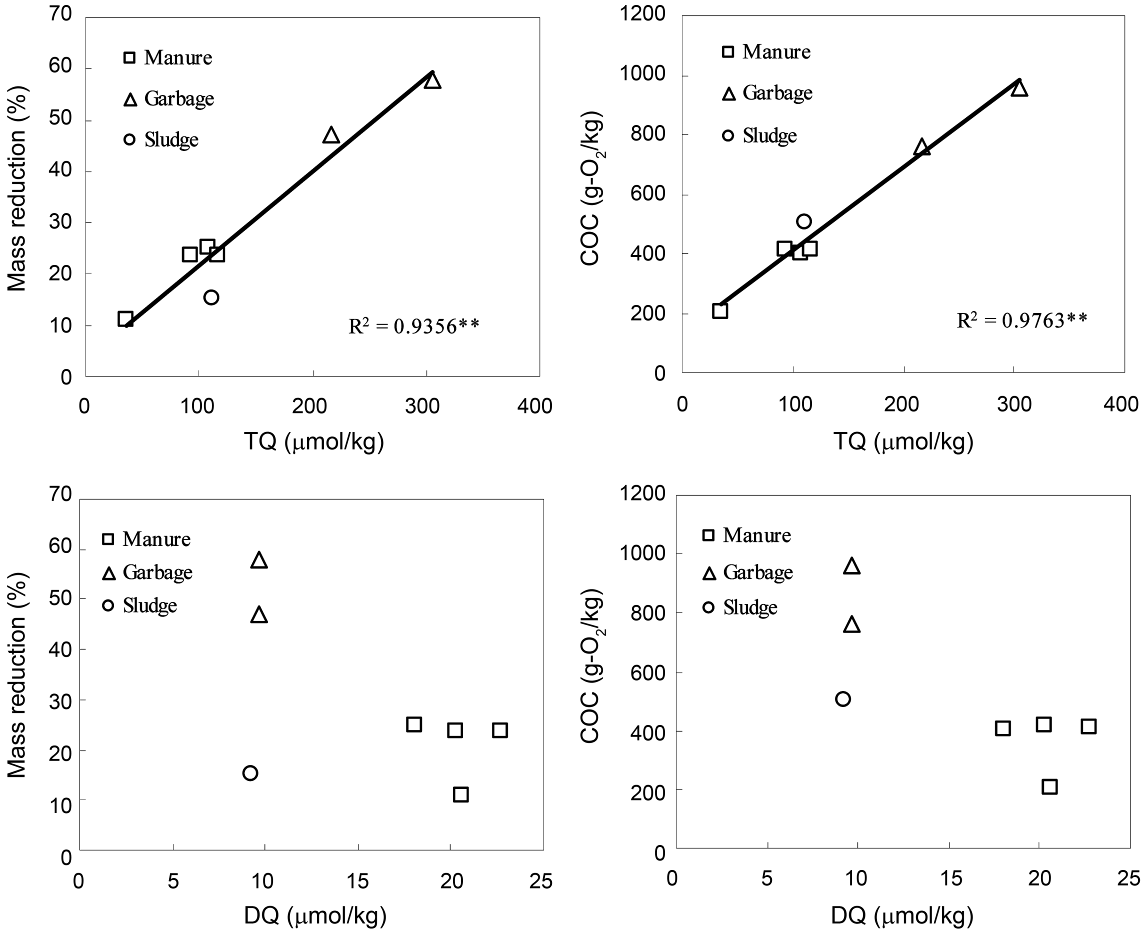

Fig. 4. Relationship between microbial properties of quinone content and DQ and composting activity parameters of mass reduction and cumulative oxygen consumption (COC) during the composting process of different raw materials.
**indicates 0.01 level of significance.

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