Chapter 9
Vermicomposting Treatment of Fruit and Vegetable Waste and the Effect of the Addition of Excess Activated Sludge

Wenjiao Li, Sartaj Ahmad Bhat, Yongfen Wei, and Fusheng Li

Abstract Fruit and vegetable waste (FVW) is generated in large quantities during production, processing, and consumption. Several conventional methods are used for treating the FVW, such as incineration, landfill, anaerobic digestion, and composting. Compared to these methods, vermicomposting has the advantages of effective stabilization of the organic wastes like FVW through joint action of earthworms and microorganisms in decomposition of the easily decaying organic constituents and of higher reuse value for its final product as organic fertilizer. However, treating fresh FVW directly by vermicomposting is difficult to be conducted because of higher water content and C/N ratio of FVW. Excess activated sludge (EAS), as the main by-product of sewage treatment process, is also an organic waste consisting of microorganisms that can be treated by vermicomposting. Vermicomposting of fresh FVW with the addition of EAS is not only reported as a feasible option to solve the problem caused by the higher water content and C/N ratio of FVW but also can enhance the treatment process. The rich content of microorganisms, nitrogen, and phosphorus in EAS can promote the growth of earthworms and enhance the microbial activity, thus improving the decomposition efficiency of FVW and improving the utilization value of the final product as fertilizer. The present chapter summarizes the several conventional treatment methods of FVW and proposes a more feasible and sustainable treatment method of FVW by vermicomposting with the addition of EAS.

W. Li
Graduate School of Engineering, Gifu University, Gifu, Japan

S. A. Bhat · Y. Wei
River Basin Research Center, Gifu University, Gifu, Japan

F. Li (✉)
Graduate School of Engineering, Gifu University, Gifu, Japan

River Basin Research Center, Gifu University, Gifu, Japan
e-mail: lifs@gifu-u.ac.jp

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9.1 Introduction

With the rapid economic development, the lack of resources and energy and environmental issues have become more serious. The concept of recovery, recycling, and reuse from waste resources has been widely accepted for the sustainable treatment of wastes in large quantities and attracted the attention of many researchers. The fruit and vegetable waste (FVW), as one of the major components of wastes, is generated in large quantities during production, processing, and consumption. The FVW is characterized by high water content and rich biodegradable organic substances, normally with water content of about 90 and 85% corresponding to organic matters (Edwiges et al. 2018). These characteristics indicate that the FVW may contribute to negative environmental issues without proper treatment (e.g., leachate and greenhouse gas) and provide a great potential for reuse, recycling, and recovery (Hartmann and Ahring 2006; Plazzotta et al. 2017). Therefore, it is important to find a sustainable method for the treatment and recycling of FVW.

Several conventional methods are used for treatment and recycling of FVW, such as incineration, landfill, anaerobic digestion, and composting. Compared to these conventional methods, vermicomposting has the advantage of effective stabilization of the organic wastes through the joint function of earthworms and microorganisms in decomposition of easily decaying organic constituents and of high utilization value for its final product as fertilizer. On the other hand, excess activated sludge (EAS), as the main by-product of sewage treatment process, is an organic waste mainly consisted of microorganisms which can be treated by vermicomposting. Li et al. (2020) proposed that the wide variety of microorganisms presented in EAS can enhance the microbial activity and positively contribute to the decomposition of FVW since the complex microbial communities play a key role during the vermicomposting (Chen et al. 2018a, b). In addition, the rich content of nitrogen and phosphorus in EAS can promote the growth of earthworms and specific bacterial species, thus improving the stabilization efficiency of FVW and will also improve the utilization value of the final product.

Accordingly, the main objectives of this chapter are to summarize several conventional treatment methods for FVW and to propose a more feasible and sustainable method for treating FVW with the addition of EAS by vermicomposting.

9.2 Fruit and Vegetable Waste

9.2.1 Generation and Characteristics of Fruit and Vegetable Waste

About 1.3 billion tons of food that accounts for 32% of the total food produced for human consumption across the whole food supply chain is lost and wasted every year in the world (Du and Li 2016). The FVW, which account for the largest proportion (45%) of the total lost and wasted food (Abubackar et al. 2019a), are also generated in large quantities along with the entire food supply chain, from production, processing to the consumption. According to the statistical data published by the Food and Agriculture Organization (FAO), about 1.8, 6.5, 32, and 15 million tons of FVW are produced each year in India, the Philippines, China, and the United States, respectively (FAO 2013). From the same information source, it is reported that at least 15% of fruits and 25% of vegetables are wasted at the bottom of the food supply chain globally (FAO 2014). Diverting our attention to the FVW from households, approximately ten million tons of FVW are generated every year in Japan alone (Ministry of Agriculture, Forestry and Fisheries, Japan 2012). All the statistical data indicate that the FVW are a very important class of wastes since they are produced in great amounts from all wholesale markets and other activities in the world (Scano et al. 2014).

The characteristics of FVW can be highly variable depending on its source and are closely dependent on the eating habits of consumers (Cerda et al. 2018). In general, the FVW are characterized by high water content and rich biodegradable organic substances (e.g., carbohydrates, lipids, and organic acids), normally with water content about 90 and 85% (Edwiges et al. 2018; Li et al. 2020). Thi et al. (2015) also reported that the FVW contains 74–90% of water and has a volatile solid to total solid ratio (VS/TS) of 80–97% and a C/N ratio of 14.7–36.4. Edwiges and Frare (2017) investigated the physical and chemical characteristics of FVW sampled monthly during 1 year in Brazil, as summarized in Table 9.1. These characteristics indicate that the FVW has a great potential for reuse, recycling, and recovery (Plazzotta et al. 2017) and should be treated with proper methods.

9.2.2 Treatment Methods of Fruit and Vegetable Waste

The FVW is well-known as liquid and/or semi-liquid waste due to high water content. These kinds of wastes are conventionally disposed by non-scientific methods such as transported to landfill or incineration plants mixed with other municipal solid waste (Liu et al. 2012). In most industrialized countries, incineration is widely used to treat burnable municipal solid waste including FVW (Du and Li 2017). The exhaust gas and ash generated in incineration plant during burning have serious dangerous effects on the human health and the environment (Cangialosi et al.

Table 9.1 Physical and chemical characteristics of fruit and vegetable waste

	Min	Max	Mean
pH	3.9	4.5	4.2
Higher calorific value (MJ/kg)	14.8	21.2	16.5
Total solids (%)	7.2	13.8	9.5
Volatile solids ($\%_{\text{-TS}}$)	89.9	93.4	92.0
Proteins ($\%_{\text{-VS}}$)	9.6	25.5	15.9
Lipids ($\%_{\text{-VS}}$)	1.0	22.3	4.5
Cellulose ($\%_{\text{-VS}}$)	13.8	26.9	17.1
Hemicellulose ($\%_{\text{-VS}}$)	3.1	15.3	9.4
Lignin ($\%_{\text{-VS}}$)	3.0	12.0	6.4
Non-lignocellulosic carbohydrates ($\%_{\text{-VS}}$)	20.1	60.1	46.7

TS total solids, *VS* volatile solids

2008). Moreover, the incineration plant is also recognized as a pollution source of heavy metals for the surrounding environment. In many developing countries, however, landfill and direct dumping are still practiced. The landfill and dumping can deteriorate the soil and water environments. Direct dumping to urban rivers or garbage collection stations near domestic areas may cause foul smelling and leachate that affect the living environment of humans (Du and Li 2017). Therefore, it is necessary to overcome the relevant defects of landfill or incineration for treatment and recycling of FVW, concurrently developing an environment-friendly method which can convert FVW to high value products.

Currently, anaerobic digestion and composting are recognized as two efficient and environmentally friendly methods to recycle/recover available resources from organic waste and are used extensively worldwide (Cerda et al. 2018). Diverting organic waste like FVW from landfill or incineration to anaerobic digestion or composting has many environmental benefits, such as reduction of greenhouse gas emission and improvement of soil properties through the application of compost (Bernstad Saraiva Schott et al. 2016). Anaerobic digestion is a biological process in which stabilization of organic waste is achieved by microorganisms in the absence of oxygen. The main products of this process are biogas (a mixture of CH_4, H_2, and other gases) and the digested sludge as the main by-product (Moukazis et al. 2018). The biogas can be used to generate heat and/or electricity or can be used as transport fuel or injection into the natural gas system (Singh et al. 2010). However, it is reported that the required range of pH, carbon to nitrogen (C/N) ratio, and moisture for anaerobic digestion are around 7.0 (Khalid et al. 2011), 20–30, and 70–80% (Hernández-Berriel et al. 2008), respectively. Therefore, it is necessary to introduce a pretreatment process for FVW before the anaerobic digestion. Composting, as one of the most sustainable options for the treatment of organic waste including the FVW, can not only cut down the volume of organic waste but also produce a useful product as fertilizer (Lou and Nair 2009; Cerda et al. 2018). Since the composting is an aerobic biochemical process via the function of thermophilic microorganisms, it is important to maintain the requirements for the growth of microorganisms. Some environmental factors that may influence the microbial activity, like temperature, oxygen concentration, pH, water content, C/N ratio, and particle size, need to be adjusted by a pretreatment process before composting (An Ceustermans et al. 2009). Besides these two methods, some other sustainable treatment methods are being developed (e.g., fermentation, microbial fuel cell). Table 9.2 summarizes some published investigations on the treatment of FVW by using different methods.

Vermicomposting is attracting researchers' attention in recent years owing to the reason that it can degrade organic wastes like FVW and can recycle and convert the valuable nutrients into organic fertilizer (Li et al. 2020). Compared to composting, vermicomposting has more effective functions of biodegradation and stabilization of the organic wastes through the joint action of earthworms and microorganisms (Domínguez 2004). In general, there are two operation systems that are widely used for vermicomposting, namely, mixed system and separated system. The substrate and bed material are mixed together in the mixed system, while the substrate and bed material are simply separated into two layers or separated by using a mesh with holes in the separated system (Li et al. 2020). Many researchers investigated the vermicomposting of FVW with different operation systems and conditions which are summarized in Table 9.3. It is worth to note that these previous studies used dry FVW or the addition of other bulking materials for earthworms. The pretreatment for drying the fresh FVW usually takes 7–21 days before vermicomposting process (Li et al. 2020). This kind of pretreatment not only increases the whole time needed for vermicomposting but also leads to the loss of significant amounts of nutrients through leachate (Huang et al. 2012). Moreover, limited literatures related to the vermicomposting of fresh FVW reported that the earthworms cannot live in the fresh FVW due to the high water content and high electrical conductivity of the generated leachate (Gunadi and Edwards 2003; Huang et al. 2012; Li et al. 2020). Therefore, it is necessary to enhance the efficiency of the treatment of FVW by vermicomposting; owing to that, the sustainable treatment methods are regarded as one of the key approaches to achieve the urban sustainability by recycling resources and recovering energy (Wang et al. 2020).

The excess activated sludge (EAS) is a kind of organic waste generated from wastewater treatment process and can be treated by vermicomposting. However, it is reported that the high content of nitrogen in EAS can give rise to a higher ammonia concentration environment, thus leading to the death of earthworms (Fu et al. 2015; Li et al. 2020). To solve this problem, a pretreatment is required to adjust the C/N ratio by mixing some bulking materials with rich carbon content, such as paper mulch (Ndegwa et al. 2000), straw (Contreras-Ramos et al. 2005), and sawdust (Zhao et al. 2018). Adding these kinds of bulking materials can not only improve the living environment for earthworms by increasing the C/N ratio but also cause a longer decomposition process (non-degradable substrate) and lower utilization value (lower nitrogen content) of final product as fertilizer (Li et al. 2020). Moreover, other pretreatment methods like air drying, airing, creating pellet, and pre-composting could also increase the whole period of vermicomposting. On the other hand, Li et al. (2020) suggested that the high content of nitrogen in EAS not only has negative effects but also has some positive effects if co-vermicomposted with the FVW. The

Table 9.2 Different methods for treating fruit and vegetable waste and their final products

Treatment method	Types of FVW	Pretreatment	Treatment volume	Treatment time (days)	Final products	References
Anaerobic digestion	Mixture of different fruits and vegetables	Inoculation of pig manure	3550 kg (wet basis)	174	Biogas (216 m^3)	Scano et al. (2014)
Anaerobic digestion	FVW from municipal central supply	Drying at 60 °C Ground to a diameter smaller than 2 mm	ND	32	Biogas (CH_4: 377 ± 67 L/kg$_{-VS}$)	Edwiges and Frare (2017)
Anaerobic digestion	FVW from municipal market	Without any pretreatment for FVW, while the digester was initially loaded with cow rumen	108 kg/day (wet basis)	365	Biogas (CH_4: 0.11–0.15 m^3/kg$_{-VS}$)	Martí-Herrero et al. (2019)
Composting	Vegetable waste	Mixed with hyacinth/garden prune/sawdust Inoculation of cow dung Adjusted C/N ratio Chopped to a size of 1–2 cm	100 kg	30	Fertilizer (N increased by 14.83%)	Rich et al. (2018)
Composting	Household food waste	Mixed with air-dried and cut cornstalks Mixed with mature compost as bulking agent	ND	35	Fertilizer	Yang et al. (2019)
Fermentation (mesophilic condition)	Mixture of different fruits and vegetables	Ground or cut into small pieces of size <5 cm	ND	8–14	Biogas (H_2: 10.77–23.53 NmL/g$_{-VS}$)	Abubackar et al. (2019a)
Fermentation (thermophilic condition)		Autoclaved at 120 °C for 20 min Inoculation of sludge from biogas plant	6.5 kg (wet basis)	9–10	Biogas (H_2: 20.81–27.19 NmL/g$_{-VS}$)	Abubackar et al. (2019b)
Microbial fuel cell (two chambers)	Potato	Boiled and cut into small cubes (length of 5 mm) Inoculation of anaerobic bacterial consortia	2.5 g (wet basis)	52	Electricity (highest current density: 160.1–253.9 mA/m^2)	Du and Li (2016)

FVW fruit and vegetable waste, *ND* no data

EAS can promote the growth of earthworms and specific bacterial species, thus improving the decomposition efficiency, and could improve the nutritional content of the final products as fertilizer (Li et al. 2020). Moreover, the EAS consists of microorganisms with large population and diversity, for example, various nitrogen-fixing bacteria and the phosphate-accumulating bacteria, which can enhance the microbial activity and the decomposition process of FVW, thus accelerating the nitrification and mineralization process and leading to higher content of nitrogen and phosphorus in the final product (Li et al. 2020). This novel idea has been proven to be a more feasible and sustainable method for treating FVW and EAS at the same time.

9.3 Effects of Excess Activated Sludge on Vermicomposting of Fruit and Vegetable Waste

To clarify the effects of EAS on vermicomposting of FVW, comparative experiment was conducted by Li et al. (2020). A novel vermireactor consisting of substrate and bed compartment was used for treating five types of FVW (banana peels, cabbage, lettuce, carrot, and potato) with and without the addition of EAS. The operation condition could be found in Table 9.3, and the vermireactor conditions are displayed in Table 9.4.

The addition of EAS obviously increased the total nitrogen, total phosphorus, copy numbers of 16S rDNA, and the dehydrogenase activity of substrates (FVW) before starting the vermicomposting, as could be seen in Table 9.5. It is well-known that the content of nitrogen and phosphorus in the initial substrate strongly affects the nutrient value of the final product as fertilizer (Huang et al. 2012; Li et al. 2020). Furthermore, the great number and high activity of bacteria in the initial substrate inoculated through the addition of EAS could enhance the vermicomposting since the complex microbial communities are reported to play a key role during vermicomposting (Chen et al. 2018a, b). On the other hand, Zhao et al. (2018) reported that the healthy growth status of earthworms directly reflects a successful vermicomposting since the earthworms are considered as crucial drivers of the process. Body weight changes of the earthworms were monitored over vermicomposting, as displayed in Fig. 9.1. In general, earthworms in the treatment of FVW with the addition of EAS showed a better capability of weight gain compared to the treatment of FVW alone. Moreover, Li et al. (2020) also reported that the cocoon production of earthworms was also promoted by adding EAS.

The total carbon in the substrate compartment of the treatment with addition of EAS was lower than that of the treatment for FVW alone (except for cabbage), as could be seen in Fig. 9.2. The possible reasons of lower total carbon are explained as the better growth of earthworms and higher microbial activity caused by the addition of EAS. However, no significant changes in the total carbon were demonstrated in bed compartments (except for cabbage). The mass reduction rate of substrate in each

Table 9.3 Operation condition and final product value of vermicomposting for fruit and vegetable waste

Types of FVW	Pretreatment	Earthworm species and density	Operation system	Temperature and time	Initial content of N and P	Final content of N and P	References
Vegetable market solid waste	Dried at 60 °C in hot air oven Chopped and sieved (<2 mm) Mixed with cow dung/biogas slurry/wheat straw Thermal stabilization for 3 weeks	*Eisenia fetida*; 26.7 worms/kg-dry (258–278 mg/worm)	Mixed system	26.9 ± 0.36 °C; 105 days	5.82–17.1 g-N/kg 2.73–5.74 g-P/kg	8.24–30.6 g-N/kg; 3.92–8.9 g-P/kg	Suthar (2009)
Vegetable greenhouse waste	Over-dried at 25 °C and chopped Mixed with cow dung or straw Aerated for a week	*Eisenia andrei*; 100 worms/kg-dry (0.17–0.31 g/worm)	Mixed system	24 °C; 12 weeks	15.0–22.8 g-N/kg 3.9–5.8 g-P/kg	14.1–23.0 g-N/kg; 6.9–8.4 g-P/kg	Fernández-Gómez et al. (2010b)
Tomato-fruit wastes	Pre-composting of bed material for 15 days	*Eisenia fetida*; 50 g/kg-wet	Separated system Sheep manure was used as bed material	25 °C 210 days	Sheep manure: 9.6 g-N/kg; 2.6 g-P/kg	12.9 g-N/kg; 2.04 g-P/kg	Fernández-Gómez et al. (2010a)
Vegetable waste	Mixed with cow dung Pre-composting for 21 days	*Eisenia fetida*; 20 worms/kg-dry (adult earthworms)	Mixed system	105 days	Vegetable waste: 17.1 ± 0.46 g-N/kg, 4.4 ± 0.17 g-P/kg; Cow dung: 8.7 ± 0.12 g-N/kg, 7.5 ± 0.12 g-P/kg	15.4–18.5 g-N/kg; 9.5–11.7 g-P/kg	Garg and Gupta (2011)

Banana peels; cabbage; lettuce; potato; watermelon peels	Chopped and wetted by tap water	*Eisenia fetida*; 200 worms/kg-wet (juvenile earthworms)	Separated system FVW and vermicompost as a bed layer was separated by a plastic mesh with holes	25 ± 2 °C; 28 days	6.6–21.6 g-N/kg; 2.7–5.5 g-P/kg	5.8–7.7 g-N/kg; 3.8–5.2 g-P/kg	Huang et al. (2012)
Apple pomace	Mixed with chopped wheat straw (soaked in water for 1 month) Pre-composting at 25 °C for 14 days under aerobic condition	*Eisenia*; 150 worms/L	Mixed system	4 months	13–19 g-N/kg; 5.53–6.43 g-P/kg	N increased by 58%; 10.18–17.79 g-P/kg	Hanc and Chadimova (2014)
Vegetable waste	Mixed with cattle manure Pre-composting for 20 days	*Eisenia fetida*; 65 worms/kg (adult earthworms)	Separated system Chopped hay, banana pulp, and tree leaves were used as bed material	25 °C; 45 days	13–19 g-N/kg; 5.31–6.30 g-P/kg	29–31 g-N/kg; 7.95–9.33 g-P/kg	Varma et al. (2015)
Vegetable market waste	Chopped into pieces (1 cm × 1 cm) Mixed with rice straw	*Eisenia fetida* and *Perionyx excavatus*; 10 worms/kg-wet	Mixed system	2 months	100.8–129.7 mg-N/kg; 35.5–56.6 mg-P/kg	103.3–784.0 mg-N/kg; 88.1–227.5 mg-P/kg	Hussain et al. (2016)
Kitchen vegetable waste	Mixed with paddy straw Pre-composting for 5 days	*Eisenia fetida*, *Eudrilus eugeniae*, and *Perionyx excavates*; 10 worms/kg-wet (juvenile earthworms)	Separated system Cow dung was used as bed material	27–30 °C; 120 days	ND	N increased by 5.86–6.6-fold; P increased by fivefold in maximum	Hussain et al. (2018)

(continued)

Table 9.3 (continued)

Types of FVW	Pretreatment	Earthworm species and density	Operation system	Temperature and time	Initial content of N and P	Final content of N and P	References
Kitchen waste	Dried at 65 °C Smashed and passed 10 mesh sieves Mixed with rice straw	*Eisenia fetida*; 5 worms/kg-wet (300 mg/worm)	Mixed system	20–25 °C; 45 days	19.2–22.2 g-N/kg; 1.36–1.75 g-P/kg	Both N and P decreased	Zhi-wei et al. (2019)
Banana peels; cabbage; lettuce; carrot; Potato	Cut into pieces with a width of about 1 cm	*Eisenia fetida*; 100 worms/kg-wet (adult earthworms)	Separated system. A novel reactor with two compartments (substrate and bed compartments) was used	25 °C; 12–26 days	10.0–40.9 g-N/kg; 1.3–7.0 g-P/kg	16.8–57.8 g-N/kg; 2.0–9.2 g-P/kg	Li et al. (2020)

FVW fruit and vegetable waste, *N* nitrogen, *P* phosphorus

Table 9.4 Vermireactor conditions for investigating the effect of excess activated sludge on vermicomposting of fruit and vegetable waste

	Substrate compartment			Bed compartment	Earthworms	
No.	Composition	Mixing ratio (FVW:EAS)	Weight (g-wet basis)	Weight (g-wet basis)	Individual weight (mg)	Numbers (worms)
1	Banana peels		100	100	350–500	10
2	Banana peels + EAS	3:2	100	100	350–500	10
3	Cabbage		100	100	350–500	10
4	Cabbage + EAS	3:2	100	100	350–500	10
5	Lettuce		100	100	350–500	10
6	Lettuce + EAS	3:2	100	100	350–500	10
7	Carrot		100	100	350–500	10
8	Carrot + EAS	3:2	100	100	350–500	10
9	Potato		100	100	350–500	10
10	Potato + EAS	3:2	100	100	350–500	10
11	EAS		100	100	350–500	10

FVW fruit and vegetable wastes, *EAS* excess activated sludge

vermireactor was calculated for better understanding of the decomposition state of substrates. The calculation equation is described as the following (Li et al. 2020):

$$\text{Mass reduction rate} = \frac{\begin{array}{r}\text{Initial dry weight of substrate} - \text{Final dry weight of substrate} \\ +\text{Sampled dry weight of substrate}\end{array}}{\text{Experimental days}} \ (\text{g/day}).$$

A significantly higher mass reduction rate was recorded in the treatment with the addition of EAS (Fig. 9.3). The conversion of substrates into earthworms cast/ excreta or body and the production of CO_2 emission closely related to the higher mass reduction (de Lima Rodrigues et al. 2017; Li et al. 2020). It is reported that the dehydrogenase activity (DHA), as a parameter reflecting total microbial activity, showed an increasing trend in the beginning followed by a decreasing trend at the end of vermicomposting in substrate compartments. Overall, the DHA in substrate compartment of the treatment for FVW with the addition of EAS was markedly higher than the treatment for FVW alone (except for carrot). The enrichment of microbial population and activity by adding EAS can lead to a rapid turnover of microorganisms and the nitrogenous substrates or the encouraged grooming of

Table 9.5 Effect of excess activated sludge on initial properties of fruit and vegetable waste

	Total carbon (g/kg)	Total nitrogen (g/kg)	C/N ratio	Total phosphorus (g/kg)	16S rDNA ($\times 10^{12}$ copies/kg)	Dehydrogenase activity [mg-TF/(kg ·h)]
Banana peels	413.5 ± 1.3	10.5 ± 0.1	39.6 ± 0.3	1.3 ± 0.0	1.3 ± 0.1	0.0 ± 0.0
Banana peels + EAS	424.2 ± 1.1	33.8 ± 0.7	12.6 ± 0.2	6.0 ± 0.4	22.5 ± 3.6	1568.8 ± 113.3
Cabbage	386.6 ± 0.5	28.8 ± 0.0	13.4 ± 0.0	3.0 ± 0.1	9.8 ± 2.2	31.5 ± 7.4
Cabbage + EAS	405.8 ± 0.1	52.7 ± 0.3	7.7 ± 0.0	6.3 ± 0.9	11.1 ± 0.2	1036.5 ± 35.5
Lettuce	376.7 ± 6.9	33.9 ± 0.4	11.1 ± 0.3	4.5 ± 0.1	18.6 ± 0.2	73.1 ± 7.4
Lettuce + EAS	405.4 ± 0.4	58.5 ± 0.3	6.9 ± 0.0	9.7 ± 0.1	25.6 ± 0.3	1447.1 ± 195.6
Carrot	384.5 ± 1.1	15.0 ± 0.3	25.7 ± 0.4	2.3 ± 0.1	17.2 ± 1.2	0.0 ± 0.0
Carrot + EAS	404.7 ± 0.5	46.1 ± 0.5	8.8 ± 0.1	8.0 ± 0.0	32.7 ± 0.05	1567.1 ± 11.0
Potato	417.0 ± 1.5	10.0 ± 0.2	41.9 ± 0.6	1.3 ± 0.0	15.1 ± 0.1	0.0 ± 0.0
Potato + EAS	418.2 ± 0.1	28.2 ± 1.0	14.9 ± 0.5	4.5 ± 0.4	21.3 ± 0.1	861.4 ± 55.7
EAS	422.1 ± 2.7	70.7 ± 0.8	6.0 ± 0.1	12.9 ± 0.3	24.4 ± 2.2	3642.8 ± 213.1

FVW fruit and vegetable wastes, *EAS* excess activated sludge
Data are shown as means ± standard deviation, $n = 3$

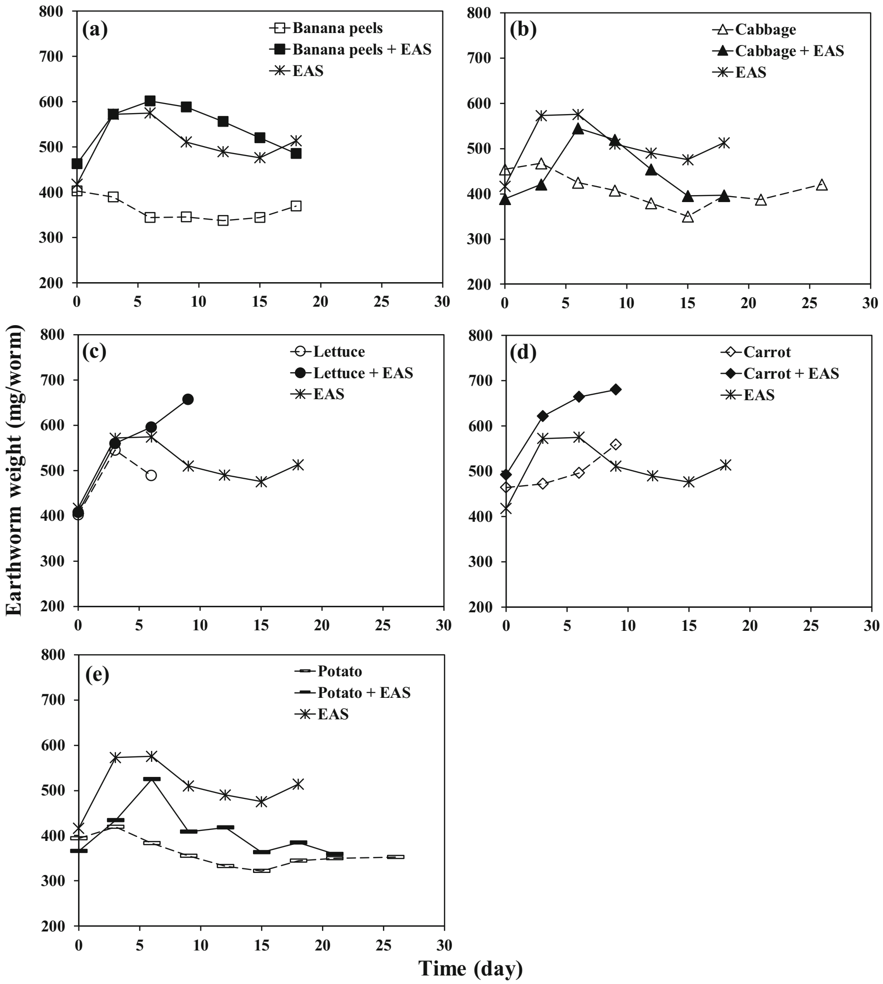

Fig. 9.1 Body weight changes of earthworm during vermicomposting of five types of FVW including (**a**) banana peels, (**b**) cabbage, (**c**) lettuce, (**d**) carrot, and (**e**) potato with and without the addition of EAS. *FVW* fruit and vegetable waste, *EAS* excess activated sludge

earthworms (e.g., mucus or casts), thus enhancing the decomposition efficiency of FVW (Li et al. 2020).

As displayed in Fig. 9.4, the addition of EAS significantly increased the content of total nitrogen in both substrate and bed compartments, except the bed compartment of the treatment for carrot. Similar results of the total phosphorus were also revealed. The mineralization of the higher content of nitrogen and phosphorus in substrate brought about by the addition of EAS, faster mass reduction rate of substrate with the addition of EAS, the higher microbial activity, etc. are the main reasons for the higher fertilizer value of the final product (Li et al. 2020).

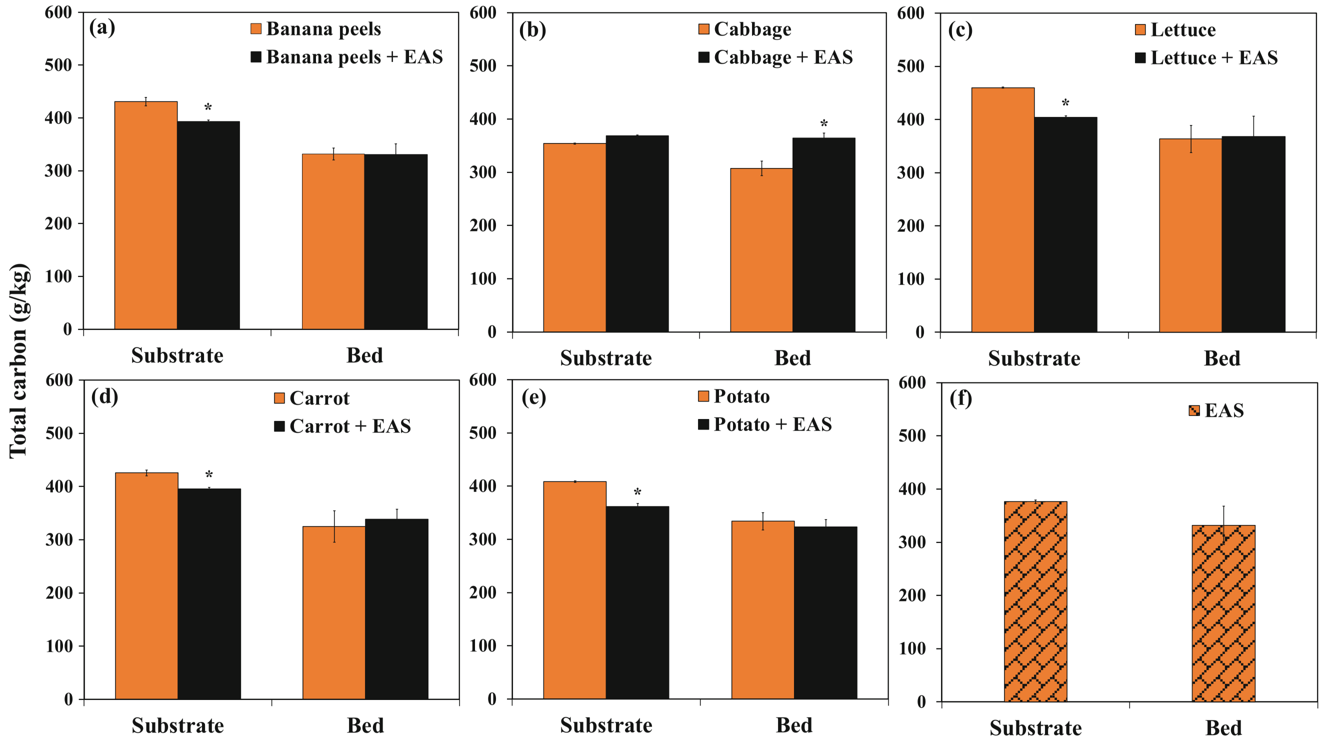

Fig. 9.2 Total carbon in substrate and bed compartments after vermicomposting of FVW and FVW + EAS: (**a**) banana peels; (**b**) cabbage; (**c**) lettuce; (**d**) carrot; (**e**) potato; (**f**) EAS. Data are presented as mean and standard deviation, $n = 3$. The asterisk ($*$) denotes the difference between vermicomposting of FVW and FVW + EAS is statistically significant at 0.05 level (Statistics 21 software). *FVW* fruit and vegetable waste, *EAS* excess activated sludge

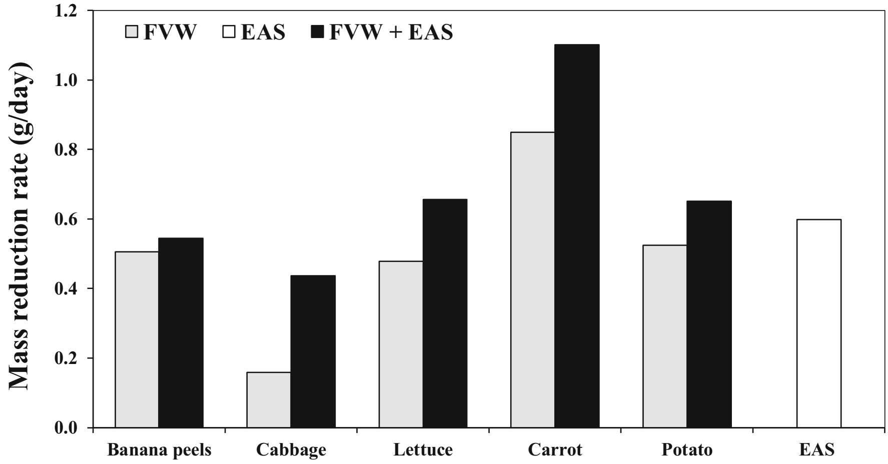

Fig. 9.3 Mass reduction rate of substrates used for vermicomposting. *FVW* fruit and vegetable wastes, *EAS* excess activated sludge

9.4 Conclusion

The large amounts of FVW generated during the whole food supply chain should be treated, recycled, and recovered properly. The vermicomposting is considered as one of the most sustainable methods for the treatment of FVW. However, the vermicomposting of fresh FVW without any pretreatment still has some problems due to the higher water content and C/N ratio of FVW. The addition of EAS could be a feasible option to solve the problems and enhance the vermicomposting of FVW. The EAS can promote the growth and cocoon production of earthworms and the microbial activity, thus enhancing the decomposition efficiency of FVW. Moreover, the content of nitrogen and phosphorus in final product as fertilizer can also be improved by the addition of EAS.

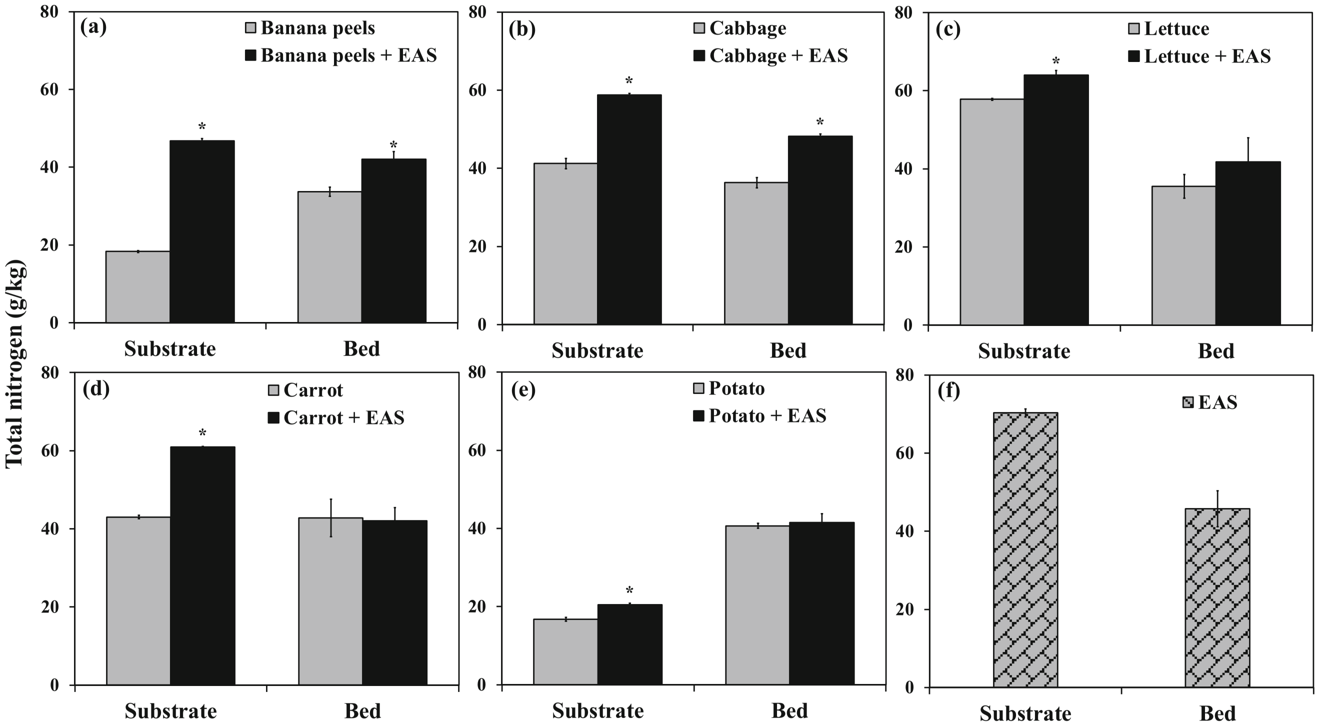

Fig. 9.4 Total nitrogen in substrate and bed compartments after vermicomposting of FVW and FVW + EAS: (**a**) banana peels; (**b**) cabbage; (**c**) lettuce; (**d**) carrot; (**e**) potato; (**f**) EAS. Data are presented as mean and standard deviation, $n = 3$. The asterisk ($*$) denotes the difference between vermicomposting of FVW and FVW + EAS is statistically significant at 0.05 level (Statistics 21 software). *FVW* fruit and vegetable waste, *EAS* excess activated sludge

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