Fast Treatment of Food Waste Utilizing a Smart Food Recycle Bin (S-FRB)

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Abstract

Food waste treatment technology should be simple to maintain, quick, economical, affordable, environmentally friendly, and socially acceptable. However, biological treatment of food waste takes about 30 days. Therefore, this research aims to accelerate treating food waste and quickly produce high-quality fertilizer products using a smart recycle bin (S-FRB). S-FRB is a portable household-appropriate technology, consisting of a semi-automatic chopper, stirrer, and drying unit. In this smart bin a highest matrix temperature of 57°C can be achieved. To start compost production, addition of a combination including a bioactivator (16 g) + dolomite lime (1 g) + bulking agent to the food waste in a ratio of 70:30 (v/v) is needed. During utilization, the water content decreased from 78.94 to 30% in seven days, and the pH matrix turned from initially 7.5 to 8.0. Compost produced from food waste using the S-FRB has matured within seven days and meets quality standards of SNI 19-7030-2004. The produced compost has 18.41% C-organic, 1.23--1.63% total N, smells like soil, and is black. Overall, the used combination of bulking agent/bioactivator/lime is effective for processing food waste into compost. The S-FRB system is a practical approach to overcoming the problem of not recycling food waste further. With this system, household food waste can now be turned into compost without having to be taken to a final processing plant.

Keywords: Compost; Fertilizer; Food waste; Household-scale; Waste

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1. Introduction

According to Adani et al. [1], food waste treatment technology should be technically simple to implement, socially acceptable, cost-effective, reasonably priced, environmentally friendly, and compatible with the physical environment. A portable waste processor will make it easier for everyone to process food waste at a minimum on a household scale. Food waste is processed immediately after the disposal in the kitchen, and it is mostly generated from households and restaurants in the form of meat, fish, cooked food scraps, moldy bread, bone scraps, cakes, expired meals, dairy products, fruit, and vegetables [2]. A foul smell and decaying food waste are inevitable outcomes of disposing in the garbage. As a result of the pollutants produced in the form of leachate, odor, pollution of the air, and slurry, the waste can quickly become anaerobic. The anaerobic processes produce a foul odor due to the release of H_2S, NH_3, and other volatile compounds [3] and leachate from the decaying process, which weakens the structure/fiber of food waste [4].

The fundamental principle of overcoming foul odors and leachate generation is to reduce the water content and decompose food waste aerobically. An appropriate technology is biodrying, where the waste will undergo mechanical-biological bioconversion [5,6]. The presence of aeration increases the partial disintegration and hydrolysis of macromolecular organic compounds such as organic carbon (C-organic), cellulose, hemicellulose, lignin, and total nitrogen. According to the California Compost Quality Council [7], C-organic content directly estimates the amount of carbon biologically degraded (C) in compost. The results of a study conducted in 2018 demonstrated that aeration at a rate of 3 L/min per kilogram of waste is the most effective method for reducing water content and waste volume. Based on the maturity test results, food waste products (compost) matured within three days. The success of this research is a combination of a bulking agent, additive microorganisms, and biodrying technology. A bulking agent in a ratio of 7:3 (v/v) with food waste was used with local organisms (fermentation of 10 mL/500 g) and dolomite as a pH regulator to accelerate the compost maturation process.

According to Eitzer [8], the decomposition process of solid waste can be accelerated by adjusting the particle size. The larger the particle size, the more the microorganisms cannot reach the middle of the solid waste, resulting in slow decomposition. The first step is to chop the food waste into smaller and more homogeneous pieces. At the portable waste treatment plant, it is necessary to add microorganisms from the outside, and the addition is more efficient when conducted using an automated system.

A clearer understanding of the process of compost maturation is needed. This research aims to realize an appropriate technology in the form of a smart food recycle bin (S-FRB) which can significantly reduce the amount of food waste. Besides, the system is technically easy to implement, socially acceptable, economical, affordable, and environmentally friendly. Food waste can be transformed into compost by means of S-FRB.

2. Materials and Methods

2.1 Smart Food Recycle Bin (S-FRB) design

The smart food recycle bin (S-FRB) is made of stainless steel with dimensions of 50 cm (L) × 30 cm (W) × 100 cm (H). The S-FRB consists of a chopper unit and a biodrying unit, where the chopper unit is cylinder-shaped (20 cm high and 15 cm in diameter) and equipped with a drive motor of 250 W. The purpose of the biodrying unit is to process food waste according to the principle of biodrying, in which food waste is aerobically decomposed. This method is used in mechanical–biological treatment (MBT) plants to dry and partially stabilize residual food waste. According to previous research, the biodrying unit (30 cm high and 23 cm in diameter) also has a cylindrical shape with vertical orientation [9]. This unit was equipped with a blower (Resun LP-100) for air circulation and a silicon hose, Ø 5 mm, to remove leachate. The bottom of the biodrying unit was equipped with a stainless-steel pipe of Ø 3 mm to ensure uniform air distribution. An air filter containing nano-activated charcoal is installed at the top of the biodrying unit. The purpose of adding this air filter is to adsorb volatile organic compounds (VOCs), causing odors from the decomposition of food waste. Spiral stirrers are manually installed in the biodrying unit. Figure 1 shows the S-FRB scheme.

2.2 Waste Sample Preparation

Food waste was taken from the canteen around Diponegoro University, Tembalang, Semarang, Central Java, Indonesia, and the Environmental Laboratory, Department of Environmental Engineering. The components of solid waste (w/w) are 1.73% uneaten meals, 6% uneaten vegetables, 0.27% fruit peels, and uneaten rice (92%). Furthermore, bioactivators were made by fermentation of rice, vegetables, corncobs, meat, and bone. The bioactivator was dried in the sun and ground into a powder with a size of 100 mesh. Mature compost and bulking agent were obtained from Diponegoro University TPST, while dolomite was obtained from a farm shop in the city of Semarang. Variations in food waste treatment using the S-FRB system are shown in Table 1.

2.3 Experimental Setup

The research process begins with turning on the motor drive and aerator, then inserting the bioactivator + bulking agent + dolomite according to the variations specified in Table 1. Subsequently, food waste is fed into the chopper unit through the hole at the top, and the drive motor is switched off shortly after the food waste is chopped homogeneously. Automatically, food waste will enter the biodrying unit. The biodrying process is conducted by turning on the aerator with a discharge of 3 L/min per kg until the end of the study [10].

The level of degradation of food waste was analyzed daily, and the samples of ±50 g were collected from the top, middle, and bottom of the biodrying unit. The parameters were analyzed in triplicate, and the standard deviation was <10%. The temperature was recorded automatically every 24 h, while the data recording was saved on an SD card in xlsx format. The range of temperature of the probe was --50 to 200°C with an accuracy of 0.1°C, and the sample's moisture content was measured by heating at a temperature of 70°C for 48 h. The pH value was measured using a pH meter (HP 9010, WalkLAB Professional) (trans instrument) with an accuracy of ±0.02. Using UV-vis spectrophotometry [11] (Genesys 10s, ThermoFisher Scientific), the quick and efficient Walkey-Black method was used to assess C-organic and the research data were analyzed statistically to determine the level of significance.

3. Results and Discussion

3. 1 Temperature

Temperature is the most important factor affecting the degradation of organic matter and evaporation of water during the biodrying process. The process will undergo three decomposition phases of mesophilic, thermophilic, and curing [12], as shown in Fig. 2. Ambient temperature (greenhouse) at the time of the study ranged between 26 and 27°C. Based on Fig. 2, the temperature of waste due to the addition of a bulking agent and bioactivator at the beginning of the study was 33°C. The same temperature occurred in the control reactor (K). An increase in temperature appeared on day 1 for K, B1, B2, and B3, to 49.8, 48.0, 35.0, and 43.0°C. Reactor K contained food waste + bulking agent + dolomite, reactors B1, B2, and B3 contained additionally bioactivator (additive microorganisms) in a concentration of 8, 16, and 32 g, respectively. On the second day, reactor K experienced a drastic decrease to 31°C, while the others increased to 57°C (B1), and the temperature in reactors B2 and B3 increased to 39 and 49°C. The temperature data showed that the impact of bulking agents and bioactivators on reactors B1, B2, and B3 can maintain continuous thermophilic. Increased biodrying temperature indicates severe material degradation by microorganisms [12,13]. The temperature difference shows different levels of waste decomposition, and the presence of the bulking agents increases the pores of free air in the reactor, while decreasing water content. Air-filled porosity plays a role in increasing the decomposition of organic matter.

Reactor K, containing pure food waste, had high water content and low porosity, which caused low organic matter decomposition. Similar results were given by Yang et al. [14] that bulking agents function to create microbial activity and increase the degradation of organic matter in food waste.

On day 3, the temperature in reactor B1 decreased to 45.2°C, and the downward trend continued until day 7, reaching a temperature of 26.7°C, and on days 8 to 14, the temperature tended to be stable near ambient air. Decomposition of organic matter at a slow rate, with cellulose and hemicellulose being the primary decomposers, lowers waste temperatures, according to Bernal et al. [15]. Cellulose and hemicellulose are organic ingredients and are difficult to degrade biologically [16].

An important finding is that the portable S-FRB can produce thermophilic temperatures in the biodrying unit up to 57°C. According to Sarkar et al. [17], the thermophilic phase is very dynamic, where high microbial activity causes accelerated degradation of organic matter, and this phase also kills pathogenic bacteria in compost.

3. 2 pH

Food waste raw materials are acidic with an average pH of 5.0--5.2. Measurement of the degree of acidity (pH) was conducted every day for 14 days using a digital pH meter. pH is a critical factor for the growth of microorganisms in compost [18]. The pH during processing food waste using S-FRB is shown in Fig. 3a.

Based on Fig. 3a, the pH values of the reactors K, B1, B2, and B3 were 5.2, 5.2, 5.0 and 5.0, respectively, but decreased to 4.6, 4.5, 4.5, and 4.7 the following day, respectively. According to Noor [19], at the beginning of the food waste's degradation process, the pH will decrease due to the activity of microorganisms that form organic acids. Thereafter, the pH value increased every day until it reached the highest pH of 8.2 for reactor B1 on day 8. NH_3 is formed during the decomposition process, and the dolomite lime content has increased soil pH due to lime dissociating into Ca^{2+}, Mg^{2+}, and CO_3^{2--} in the soil. The composting process's odor is also reduced to a level similar to that of soil because of this increase in pH [20]. In order to balance the acidity of the soil, dolomite lime raises the pH of the soil because it contains Mg and Ca, which neutralize the acidity of the soil.

On days 10 to 14, the pH levels in reactors K, B1, B2, and B3 were stable at 7.5, 8.3, 7.5, and 7.3, respectively. For reactors K, B1, B2, and B3, it could be shown that the heat generated by the decomposition process decreased as the compost matured. This decrease is probably due to the fact that the microorganisms present in the composting process are in a stationary phase, in which the degradation activity is stable, and the heat generated tends to be stable [19]. The pH of the compost produced by reactors K, B1, B2, and B3 meets the requirements given in the Minister of Agriculture's Regulation No. 70/2011 by a range of 4 to 9.

An important finding from the results is that the portable S-FRB can produce compost in the biodrying unit with an optimal pH to be safe for microorganisms. Chew et al. [21] stated that food waste compost could be used as a source of organic nutrients to cultivate *Chlorella vulgaris* with a pH range of 7.2–7.4. Based on the pH data, compost from food waste processed using the portable S-FRB can be used as a source of organic nutrients.

3. 3 Water content

According to Som et al. [22], water content is one of the key factors that show that composting works quickly. According to Chang [23], water content is critical in composting engineering because organic material decomposition depends on the availability.

In this composting process, the main ingredients used were food waste, which was chopped using a chopper and a moisture content of 78.94%. Water content that is too high will result in anaerobic conditions in the composting process because water is more dominant in filling pores than air, hence, oxygen availability is limited [24–26]. It is necessary to add bulking agents because food waste has high water content. The bulking agent used was compost, and the function was to provide a supporting structure for the pile of material. Furthermore, it provides air pores between the particles and facilitates the movement through the material mixture to obtain an initial moisture content of 50--60%. The main ingredient is calculated with a bulking agent because 50--60% water content is the optimum condition for development microbes. The balance between the pore space and the amount of water allows microbes to develop well in degrading organic matter [27]. Changes in water content in the composting process can be seen in Fig. 3b, and it can be seen that the water content for each reactor decreased during the composting time.

The highest and the lowest water content was in the reactors B1 and K. Differences in water content with the same composition can be caused due to the lack of optimal stirring. There are still some ingredients that are not exposed to aeration, and in this composting process, the aeration discharge used was 3 L/min. A related study shows that aeration 3 L/min can produce small leachate, which slightly indicates the water content contained in the composting is also small. The presence of aeration affects the production of leachate produced [28], and the water content in waste is reduced through two phases. First, the water molecules evaporate from the surface of the waste to the surrounding air. Second, the evaporated water will be transported by airflow from aeration and transferred to the outside air. In this composting process, the aeration discharge used was 3 L/min.

Based on research, the water content for all reactors is in agreement with the value determined by SNI 19-7030-2004 with maximum water content of 50%. The research results on day 7 showed that the water content in all reactors reached ±30% until day 14. The decrease in water content that occurs during the aerobic composting process is caused by the consumption of microorganisms of water and the activity of reversing or stirring [29].

An important finding is that the portable S-FRB with the biodrying unit can significantly reduce the water content from 78.94 to ±30% until day 14.

3. 4 C-Organic

According to the California Compost Quality Council [7], organic carbon content (C-organic) shows a direct estimate of the amount of carbon that can be biologically degraded (C) in compost. During composting, carbon is converted into more complex organic compounds such as humus and mineralized into CO_2 gas. According to Siswanto [30], carbon is used as an energy source for the decomposition process and cell formation. It is an important parameter during the process of compost decomposition and determining the maturity of compost [31]. Organic C-content in mature compost ranges from 9.8--32% (SNI 19-7030-2004).

The C-organic content on day 0 in the four reactors ranged from 32.55 to 37.29%. According to SNI 19-7030-2004, the maximum C-organic content is 32%, hence, it needs to be reduced in the reactors. The results for 14 days are shown in Fig. 3c. In reactor B2 the C-organic levels were reduced from 32.89 to 30.08% within three days, and this shows that the food waste is mature. On the same day, the levels of C-organic in reactors K (42.14%), B1 (32.48%), and B3 (31.88%) were all above the standard (32%), which indicated that the compost was not yet ripe. The food waste in reactor K (without the biodrying unit) ripens on day 10.

C-Organic levels tend to decrease until the end of composting, a decrease in the levels is due to microorganisms degrading organic matter in food waste such as carbohydrates, proteins, and fats into simpler forms such as glucose, amino acids, and fatty acids [32]. The addition of bioactivators also causes the decomposition process of organic material to proceed quickly.

The C-organic content in all reactors has met the SNI 19-7030-2004 standard, which is between 9.8 and 32%. This indicates that the C-organic contained in the compost material has been decomposed by microorganisms into humus and mineralized into CO_2 [7].

The S-FRB system accelerated the C-organic degradation process compared to the control. The best composition could be obtained for reactor B2 which consisted of food waste/mature compost, 7:3 (v/v), 1 g dolomite, and 32 g bioactivators. Although the S-FRB system could accelerate the decomposition of C-organic, it was not significant ($p > 0.05$) (Table 2).

3. 5 Total Nitrogen

According to Siswanto [30], nitrogen is an element microorganisms need for protein synthesis. Total nitrogen on day 0 in the four reactors ranged from 1.10--1.24%. Total nitrogen during composting was measured on days 0, 3, 7, 10, and 14 and is shown in Fig. 3d. On day 3, total nitrogen increased to 1.90, 1.77, 1.98, and 1.70 % in reactors K, B1, B2, and B3, respectively, probably caused by the conversion of organic nitrogen to ammonia. At the time of decomposition, total nitrogen increased due to the activity of microorganisms that produce ammonia and nitrogen [33]. The total nitrogen during the composting process has decreased and increased based on the existence of an equilibrium between the need for nitrogen [7]. When composting occurs at high temperature, pH, and adequate aeration, excess total nitrogen is emitted as NH_3 gas. When bioactivators are added to the composting process, more nitrogen is turned into NH_3 gas, which lowers the total nitrogen content [34]. According to Cesaria et al.[35], microorganisms break down proteins into ammonia and aerate. This is consistent with the statement of Bernal [15] who mentioned that the concentration of N will increase in the composting phase until the active phase and appears in the form of NH_4-N. The N concentration will decrease during the composting process, and according to Iswanto [36], the value of total nitrogen decreases due to the lack of organic acids in the compost. For days 10 to 14, the total nitrogen was increased. This was likely the result of microorganisms decomposing organic materials and producing NH_4-N [37].

In general, the total nitrogen values of all compost variations at the end of composting are in agreement with SNI 19-7030-2004 mature compost with total nitrogen of ≥0.4%. According to statistical testing ($p > 0.05$), addition of a bioactivator did not significantly change the total nitrogen content.

3. 6 Physical and Odor

Mature compost has a blackish-brown color, a humus-like smell [38], and a crumbly texture [39]. Chew et al. [40] suggested that pelletizing of compost can be conducted to prolong shelf life, allows easy transportation and ease compost handling. Apart from being a fertilizer for plants, compost can generate electricity and energy [41]. The compost matrix on day 0 in all reactors was dark, wet, and smelled unpleasant due to food waste. The addition of food waste with a water content of 78.94% causes wetness of the matrix. An unpleasant smell emanating from every reactor can be detected up to 2 m away. On day 10 of composting food waste, it begins to smell like soil. On day 14, the compost smells like soil in all the reactors.

Starting on the third day, there was a change in matrix color to a blackish-brown, but it was unevenly distributed from top to bottom of the reactors. On day 10 of the composting process, the compost showed a color change to blackish-brown, homogeneously. On day 14, the compost in all reactors has a blackish-brown color, smells like soil, and has a crumbly texture. The S-FRB produced compost fulfills SNI 19-7030-2004 according to color and odor parameters.

4. Concluding Remarks

Food processing was improved to produce high-quality products using smart food recycle bins (S-FRB). Based on Indonesia's SNI 19-7030-2004 standards for compost quality, the compost made from food waste was mature in only seven days. The significant finding of the study is that the maximum matrix temperature can be reached at 57 °C. The initial pH matrix changed from 7.5 to 8.0. The water content drops significantly from 78.94 to 30% by day 14. The compost contains 18.41% C-organic and 1.23--1.63 % total nitrogen. The final compost is brownish-black in color, smells like soil, and has a crumbly texture. The process was achieved using a combination of a bioactivator (16 g) + dolomite lime (1 g) + bulking agent added to the food waste in a ratio of 70:30 (v/v), and a total volume of 5 kg. The S-FRB system is a practical approach to overcoming the problem of household-scale food waste being processed into compost without being taken to a final processing site. More research is needed to find out how other parts of the relevant environment affect the process, and the process should be used continuously.

Conflict of Interest

The authors declare no conflict of interest.

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Table 1. Variations on food waste treatment using S-FRB

Reactor	Additive microorganism (g)	Food waste/bulking agent (v/v)	Dolomite (g)	Total volume (kg)
Control (K)	0	7:3	1	5
B1	8	7:3	1	5
B2	16	7:3	1	5
B3	32	7:3	1	5

Table 2 Table of ANOVA test results for the C-Organic parameter

No	**Model**	**Sum of squares**	**df**	**Mean square**	**F**	**Sig.**
1.	Regression	66.48	1	66.48	0.438	0.517[b]

b. Predictors: (Constant), additive microorganism

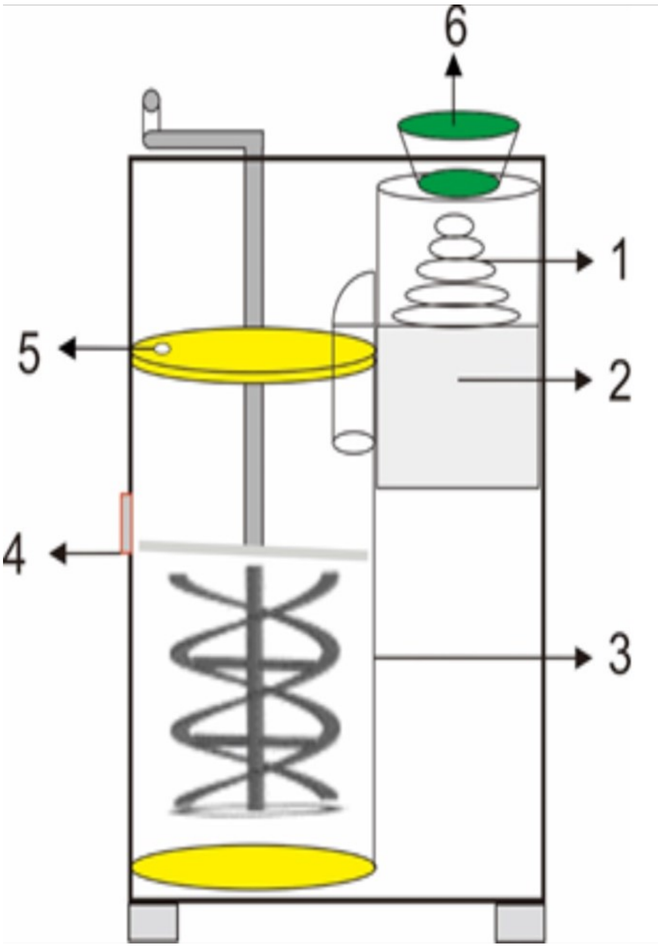


Fig. 1 The portable S-FRB with dimensions of 50 cm × 30 cm × 100 cm, equipped with (1) a chopper knife, (2) a grinding motor, (3) a biodrying unit, (4) a door for removing mature and stable compost, (5) activated carbon, (6) and inlet for adding food waste.

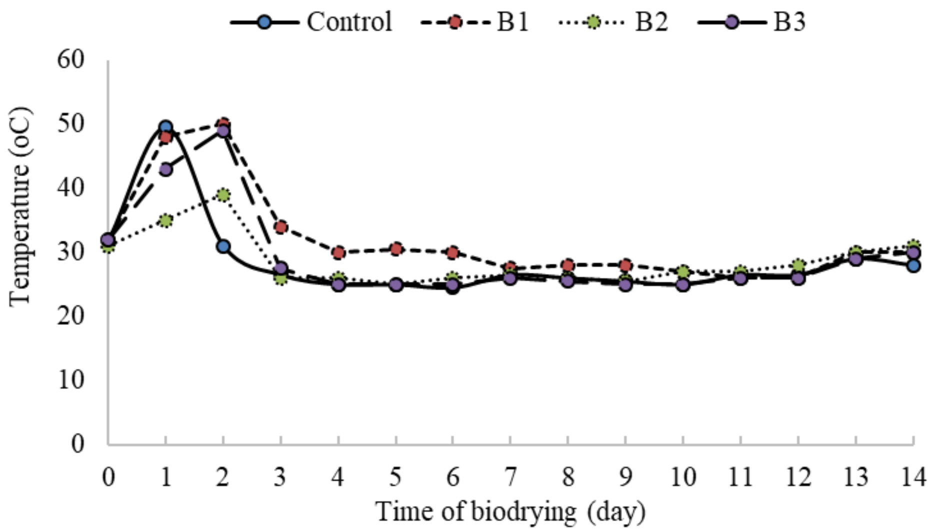


Fig. 2 Temperature for all reactors during 14 days after addition of bioactivators and compost bulking agents.

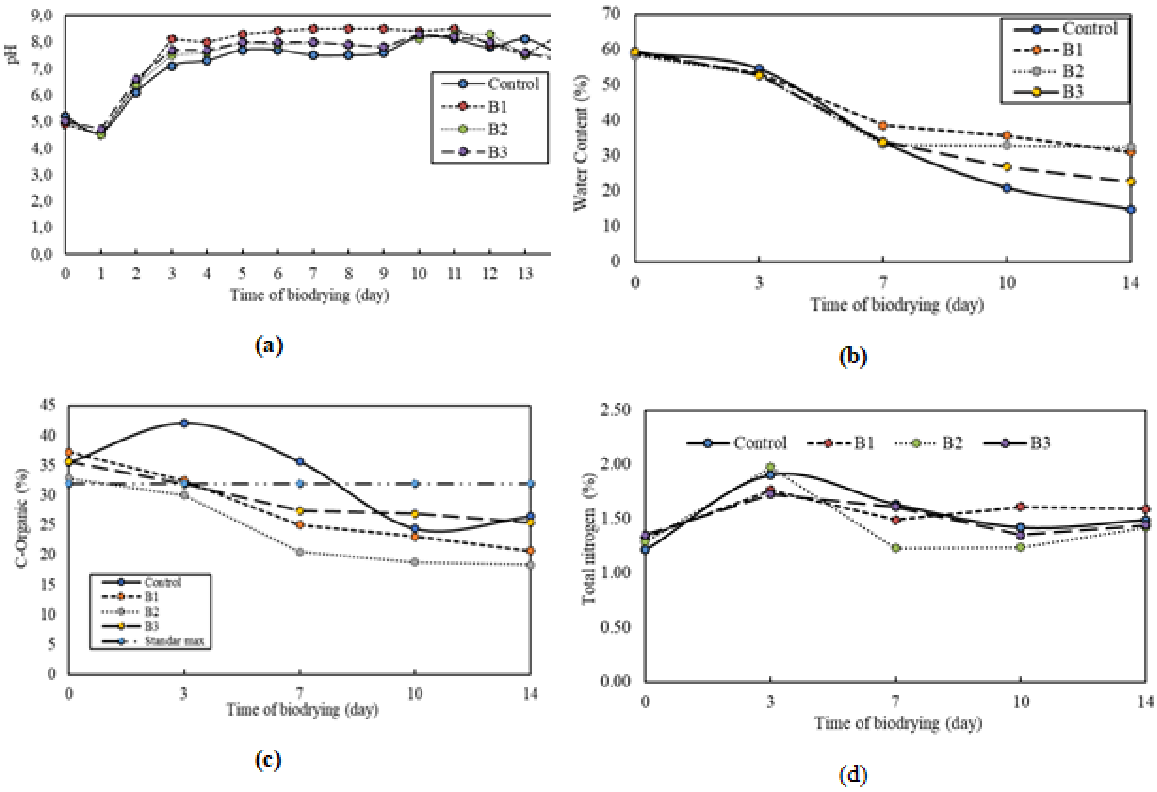
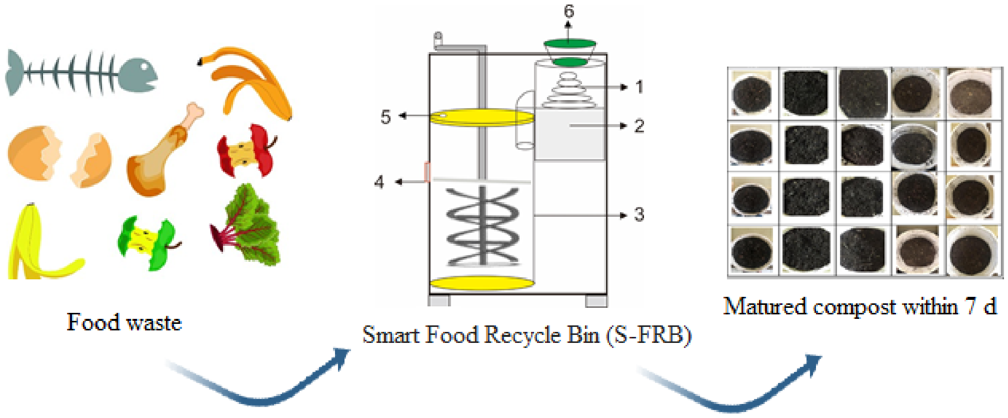


Fig. 3 Graph of correlation between a) pH and biodrying time, b) moisture content and biodrying time, c) C-organic and biodrying time, and d) total nitrogen and biodrying time.

Graphical abstract



Highlights

A portable food waste processor will make it easier for everyone to process food waste at a minimum on a household scale. Food waste is processed into compost quickly using smart food recycle bin (S-FRB). After being processed for seven days, the food waste compost made from S-FRB can be utilized as plant fertilizer.