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ORIGINAL RESEARCH

Physico-chemical changes and maturity evaluation of composts from wood residue mixed with sewage sludge and chicken manure

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Abstract

Purpose Using the effective approaches for modifying the recycled wood as a novel bulky agent improves the quality of soil amendment. This study aimed to compare the stability and maturity of the soil amendments produced by the compostation of forest industrial waste and sewage sludge on seed germination.

Method Three materials, namely sawdust, sewage sludge, and chicken manure were mixed at different ratios (dry weight basis) to reach the initial bulk density of 0.40 $Kg.L^{-1}$, the temperature of 30 °C, the C/N ratio of 25, and the moisture content of 60 %. A pilot-scale composting process was applied to monitor the aeration rate, temperature, and moisture contents during the process over time. The comparison of physico-chemical, phytotoxicity, and germination indices among the samples was performed in three repetitions.

Results The results of this study indicated that the sustainable conditions (i.e., the temperature of 70 °C, aeration rate of 0.30 $L.Kg^{-1}DM.min^{-1}$, and moisture content of 50-60 %) can have a significant effect on the thermophilic stage for compost curing without any inhibitory repercussion. Increasing the germination index of cress (*Lepidium sativum*) up to 79 % proved that the toxicity of industrial sewage sludge was declined through the elimination of heavy metals.

Conclusion This study revealed that the availability of bulky agents such as wood residue can reinforce the microbial activity by continuously decreasing the C/N ratio to the minimum value of 13.2.

Keywords Wood residue, Industrial sewage sludge, Co-composting, Phytotoxicity, Germination Index

Introduction

Forest residue valorization is becoming a promising issue due to the socio-economic status emanating from the reuse of waste and residues. Most of the forest industrial wastes are abundant without any appropriate utilization, which causes an increase in environmental risks in developing countries. The Iranian industrial forest sector generates more than 50000 tons of wood residue and 35000 tons of wastewater sludge annually (Ghorbannezhad et al. 2016). The modification of environmental obligations relating to industries has led to the assignment of significant attention to the construction of wastewater treatment plants and implementation of the waste management program in Iran since recent decades (Ghorbannezhad et al. 2011). The biodegradability and high moisture content of industrial wastes ensure the necessity of converting forest residues into soil amendments and fertilizers. Forest residue such as wood waste and sewage sludge is a crucial source of organic matter and nutrients (Lee et al. 2018; Li et al. 2018; Mahon et al. 2017). It is essential to develop an eco-efficient technique for valorizing biomass wastes (de Souza Machado et al. 2018). Composting is applied as an attractive method for converting organic matter into sanitized products in the soil under aerobic

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conditions (Meena et al. 2016; Alvarenga et al. 2015). The thermophilic stage is a suitable way to convert organic matter by means of mineralization and humification (Chang et al. 2017; Lim et al. 2016). However, the hygienic instability, immaturity of sewage sludge, and pathogenic microorganism are compensated for during the thermophilic conditions of composting (Jara-Samaniego et al. 2017). To achieve an appropriate compost maturity, several fundamental factors like temperature, moisture content, C/N ratio, particle size, and pH level should be controlled (Ge et al. 2015; Onwosi et al. 2017; Kim et al. 2016).

The optimum conditions for the fabric preparation and composting processes are under investigation to ensure the compost stabilization and maturity (Brandon et al. 2018; Yang et al. 2018; Weithmann et al. 2018). In this regard, Brewer and Sullivan (2003) have reported that the lack of plant growth arises due to the decline of oxygen availability and it results in the inappropriate biodegradation of organic matter. The high-temperature support to convert to NH_3 leads to the inhibition of nitrification (Nigussie et al. 2017). The temperature of ammonia volatilization will increase during the composting process by around 70 °C (Nigussie et al. 2017). Aeration rate plays a vital role in controlling the temperature, moisture content, emissions, and supplying sufficient oxygen for the biological process (Zhang et al. 2016). To obtain the conventional composting, it is of importance to adjust the oxygen supply from the aeration system where the heterogeneity noticeably enhances the quality of compost (Faverial et al. 2016; Rasapoor et al. 2016; Shen et al. 2011).

Carbon (C) and nitrogen (N) are the fundamental materials for building the microbial cells and the synthesis of protein (Sweeten and Auvermann 2008). The seed germination (SG) is affected by the C/N ratio and inevitably the final product costs (Prasad et al. 2010). Carbon is the most dominant compound of microorganism cells and nitrogen is a required element for the microbial growth and recreation of protein construction. The consumption of bulking agents and the compost expenditure are declined by the low C/N ratio (Zhu 2007). Notwithstanding, the need for the stability and maturity of the ultimate compost should be explored to assure a low C/N ratio (Bernal et al. 2009). The low initial C/N ratio and the low amount of bulking agent lead to the successful production of high-quality composting (Zhu 2007). The moisture content is determined as an important parameter that allows the transport of the dissolved nutrients in order to enhance the metabolic liveliness of microorganisms during the composting process (Petrica et al. 2009). However, physical criteria can determine the compost quality, which can be defined by the compost stability and maturity (Bernal et al. 2009).

The analysis of biological stability firmly depends on the phytotoxicity due to the microbial activity of organic matter for producing phytotoxic compounds. The stability and maturity of bio-compost have been investigated in a pilot study (Oviedo-Ocana et al. 2015). The results indicated that there is no significant correlation between the suggested criteria. It was also reported that the appropriate biological degradation happened during the aerobic bio-stabilization when both stability and maturity were taken into account at the same time. Hence, recognizing the process parameters and implementing the corrective conditions have led to access to high-quality compost. Consequently, the effective approach relies on efficient as well as cost-effective practical operations.

To date, few studies, if any, are found about the optimum condition of co-composting industrial wastes because of the complex interaction of process parameters. Thus, the aim of this study was to investigate the effect of physico-chemical criteria on the characterization of stability and maturity of co-composting from industrial wastes in an *in*-situ reactor. Industrial wastes such as wood residue and sewage sludge are characterized by high-reach carbon and low-density materials, which can make them suitable as a bulking agent during the composting.

Materials and methods

Feedstock preparation and collections

The wood residue was collected from a wood-based industry located in the north of Iran, Golestan Province. The chicken manure was also obtained from a local farmland around the factory. The company generates around 35 tons of biomass from production lines on a daily basis. The wood residue categories are placed in two groups: the wood that was generated with chipper instruments and did not contain the resin and the other group of woods that is impregnated with resin. Moreover, the C/N ratio of 11.5 and moisture content of 87 % was obtained for the dewatered sewage sludge associated with the wastewater treatment plant. The characterization of wastewater treatment is presented in Table 1 and the design of the wastewater treatment plant is illustrated in Fig. 1.

The primary influence of manufacturing wood-based wastewater was subjected to lagoons due to the settlement of the large molecular organic matters and their transference to a storage tank. In this process, the wastewater is regularly injected into other processes such as anaerobic, aerobic, and post-treatment, respectively. The removal efficiencies of wastewater pollutants generate sewage sludge which is potential for being reused as novel products in wood-based manufacturing.

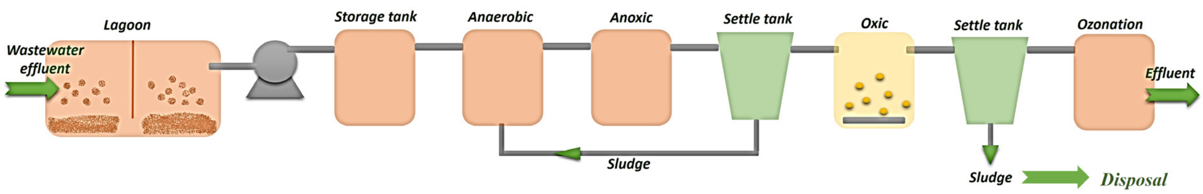

Fig. 1 Design of wood-based wastewater treatment plant

Table 1 Characteristics of untreated wastewater generated from wood-based composite mill

Some characteristics of untreated wastewater					
COD (mg/l)	BOD (mg/l)	TSS (mg/l)	Turbidity (NTU)	TS	pH
4800 ± 150	1700 ± 37	4500 ± 115	3500 ± 64	5250 ± 180	5.5 ± 0.07

Composting experimental pilot-scale setup

Several treatments have been designed to consider the influence of physico-chemical changes on composting stability and maturity (Table 2). Three materials, including sawdust, sewage sludge, and chicken manure were mixed at different ratios (dry weight basis) to reach the initial bulk density of 0.40 $Kg.L^{-1}$, the temperature of 30 °C, the C/N ratio of 25, and moisture content of 60 %. According to the related literature, the continuous aeration was set at 0.30 $L.Kg^{-1}DM.min^{-1}$ and measured every day (Talib et al. 2014).

Table 2 Characterization of materials before the start of treatments

Parameters	Control Sample (C)	Mixture 1 (SWIR)	Mixture 2 (SW)	Mixture 3 (SWC)
MC%	62 ± 0.5	71 ± 1.15	69 ± 0.8	65 ± 0.8
pH	7.1 ± 0.01	7.7 ± 0.01	7.3 ± 0.01	7.5 ± 0.01
TOC (%)	43.1 ± 0.35	41.9 ± 0.3	44.9 ± 0.35	48.5 ± 0.35
OM (%)	77 ± 0.3	75 ± 0.55	79 ± 0.45	83 ± 0.4
TKN (%)	1.73 ± 0.05	1.75 ± 0.1	1.8 ± 0.06	1.93 ± 0.06
C/N	24.91 ± 1.05	23.97 ± 1.75	24.96 ± 1.5	25.1 ± 1.5

Control Sample (Wood residue; 100 wt%) = C; Sewage Sludge (60 wt%) + Wood residue impregnated with resin (40 wt%) = SWIR; Sewage Sludge (60 wt%) + Wood residue without resin (40 wt%) = SW; Sewage sludge (60 wt%) + Wood residue without resin (30 wt%) + Chicken manure (10 wt%) = SWC

A full pilot-scale setup was designed to operate the composting under the adjusted conditions. To this end, four reactors were taken into consideration to operate four treatments simultaneously. The schematic view of the pilot-scale is depicted in Fig. 2. The air store conducted the airflow rate of 0.30 $L.Kg^{-1}DM.min^{-1}$ which was dispensed from the bottom of an air compressor. The airflow rate was controlled by an airflow meter and pressure regulator during the composting procedure. To obtain the homogenous compost and keep the sustainable oxygen level, the composting piles were circulated regularly (once every 3 days) for three months. The primary curing was set up to form the bio-cell with aeration for 35 days and to transfer it to a static pile system for secondary curing around 55 days.

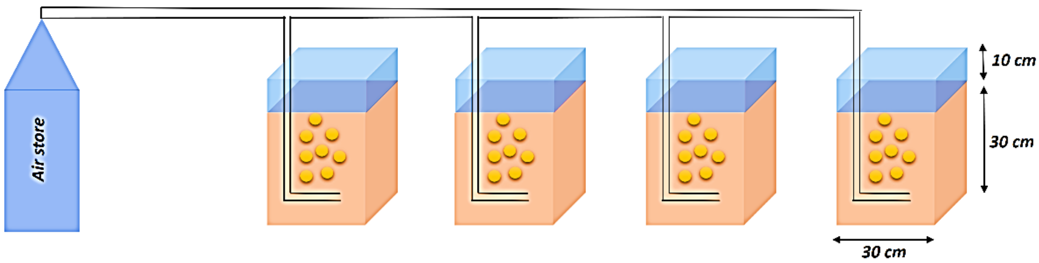

Fig. 2 Schematic view of the pilot-scale composting pile

The comparison of physico-chemical and phytotoxicity analyses among control sample (C; 100 wt% of Wood residue); SWIR (Sewage Sludge (60 wt%) + Wood residue impregnated with resin (40 wt%); SW (Sewage Sludge (60 wt%) + Wood residue without resin (40 wt%); and SWC (Sewage sludge (60 wt%) + Wood residue without resin (30 wt%) + Chicken manure (10 wt%)) was performed in three repetitions.

Physico-Chemical and Phytotoxicity analyses

The sample was oven-dried at the temperature of 105 °C to constant weight for measuring the moisture content (MC %). Then, the pH was evaluated after aqueous compost to distilled water in the ratio of 1:10 (w/v) by means of a benchtop pH meter. The incineration of the sample was done at a temperature of 550 °C for 5 hours in a furnace (Ghorbannezhad et al. 2018). Thereafter, the elemental analysis was performed for measuring the content of C, H, N, and S by VaroElcube, Elementary from Germany. The subtraction of the C, H, N, and S summation from 100 was recognized as the oxygen content of the treated compost (O). The total organic carbon (TOC) was estimated based on the Chinese national standard (NY 525-2002). Moreover, the total Kjeldahl nitrogen (TKN %) was measured as in the method described by Nejabat et al. (2017). The division of TOC (%) by TKN (%) was ascertained by the C/N ratio. The P and K were measured by colorimetric and flame photometry analyzers, respectively. The use of inductively coupled plasma mass spectrometry makes it possible to analyze the trace metallic elements (Cu, Cd, Zn) as well as mineral elements (Mn, Fe).

To determine the germination index (GI) of cress (*Lepidium sativum*) by the phytotoxicity test, one gram of aqueous compost was mixed with 10 ml of distilled water, and then it was shaken for 1 h. The mixture was centrifuged at 4000 rpm for 20 min and filtered by 45 µm membrane filters. The root length was measured after incubation at 25 °C in a dark room for three days. The GI was calculated as follows:

$$GI = \frac{Seed\ germination\ of\ treatment\ (\%) \times root\ length\ of\ treatment}{seed\ germination\ of\ control\ (\%) \times root\ length\ of\ control} \times 100 \quad \text{Eq. (1)}$$

The one-way analysis of variance (ANOVA) was run to analyze the data and a significant difference was observed by LSD-t-test. Pearson's correlation coefficient test was also used to analyze bivariate correlation and determine the empirical relationship of variables. In doing so, SPSS 19 was used for statistical analysis.

Results and discussion

Assessment of composting parameters

The temperature of treatments was systematically enhanced within the first week up to the thermophilic stage (more than 55 °C). The maximum temperature (over 65 °C) was achieved in the third week and then the temperature was rapidly declined on the 25th day (Fig. 3a). It was observed that it took a long time to increase the temperature for non-treatment samples. Moreover, the peak temperature was lower in non-treatment compost, whereas the highest temperature was observed at 42 °C compared to the mixture of wood residue and sewage sludge that the maximum temperature was 70 °C. It was shown that the addition of sewage sludge had no inhibitory influence on the temperature boosting during composting. The temperature was proved to play a critical role in the succession of microbial activities and resulted in the biodegradation rate of the compost (Wang et al. 2017). Substrates show the expected biodegradation consequence of favorable microbial operations at thermophilic conditions (Meng et al. 2017). The sewage sludge, as an herbaceous substrate, enables the reinforcement of the degradation because it contains higher and easily biodegradable compounds (Zittel et al. 2018). Zhong et al. (2018) indicated that biomass residues make it possible to produce a qualified compost with a low C/N ratio at higher temperatures and in longer thermophilic phases. The authors suggested that the physical and chemical properties of compost would be improved by using the materials containing effective microorganisms like peat.

The final compost revealed that the moisture content is a parameter that exerts a significant effect on microbial activities. At the outset of the composting process, the moisture content was approximately 69 % while it dropped gradually until 25 days (Fig. 3b). To adjust a constant range of moisture content (50-60 %), water was added to the compost on days 5, 9, and 17. The thermophilic stage led to the evaporation of water because of heat generation through microbial actions (Gomez-Brandon et al. 2008). Moreover, the aeration can strengthen this evidence whereas the addition of water not only increases the moisture contents but also improves nitrogen conservation during the composting process (Chang et al. 2016; Diaz and Savage 2007). In this regard, it has also been proved that biological activities should be stopped to stabilize the compost matter by keeping the moisture content at a low content (around 30 %). In fact, the indication of organic matter decomposition led to a continuous decrease in moisture content during the composting process (Guerra-Rodriguez et al. 2003). At the end of the composting process, the moisture contents decreased to 35 %.

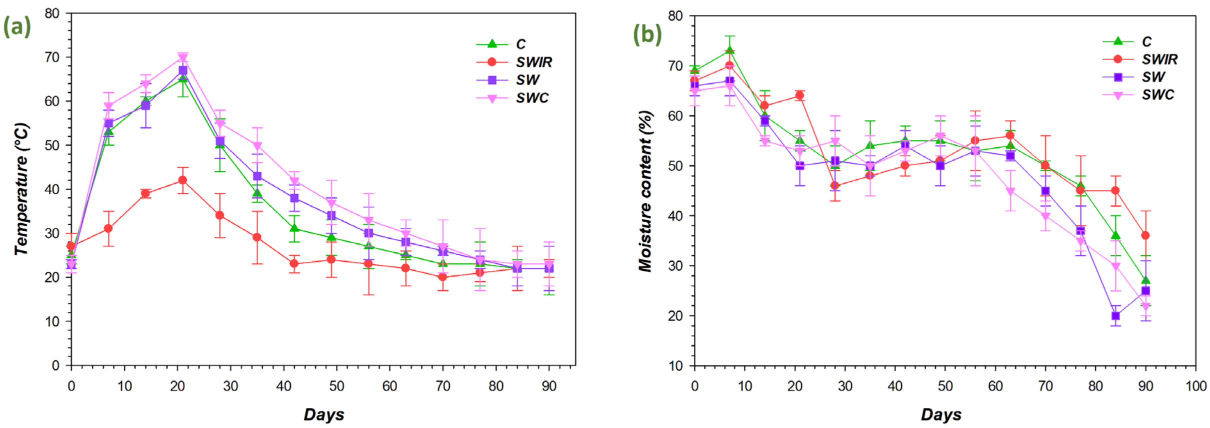

Fig. 3 Variation of temperature (a) and moisture contents (b) during the composting process

In Fig. 4, it has been shown that the pH has changed over the composting progress. Moreover, a short-term decrease was illustrated in the first few days and it was followed by a long cyclic increase. Ivankin et al. (2014) reported that the pH changes are associated with the degradation of organic matter for producing organic acids. The addition of sewage sludge could increase the pH through buffer characterization and the neutralization of the acid compounds (Yuan et al. 2016). Yin et al. (2018) reported that there is a correlation between pH value and the C/N ratio. The increase of pH value led to the increase of microbial activities and, consequently, the ammonia emissions increased. The results of this study revealed that the pH value decreased at the start of the composting process while adding sewage sludge enhanced the decomposition of organic matters and temperature. As a result, the ammonia emissions experienced a dramatic increase.

Characterization and phytotoxicity analysis

The C/N ratio initially increased, but it then decreased rapidly in a continuous pace to reach a maximum of 13.2. It is confirmed that with the reduction of the C/N ratio, the nitrogen content increases by an average of 2.9 % at the final product (Table 3). The fluctuation trend of carbon content was dependent on the CO_2 emission during carbon mineralization at the curing stage (Zhou et al. 2018). The denitrifying bacteria are responsible for nitrogen loss with the addition of carbon sources to the sewage sludge composting. Thus, the incorporation of bacteria was associated with the immobilization of and resulted in the acceleration of nitrogen loss and, thereby, the soil amendment was enhanced. The addition of bulky agents and carbon sources such as wood residue noticeably increased the nitrifying bacteria at the mesophilic stage. On the other hand, the availability of inhib-

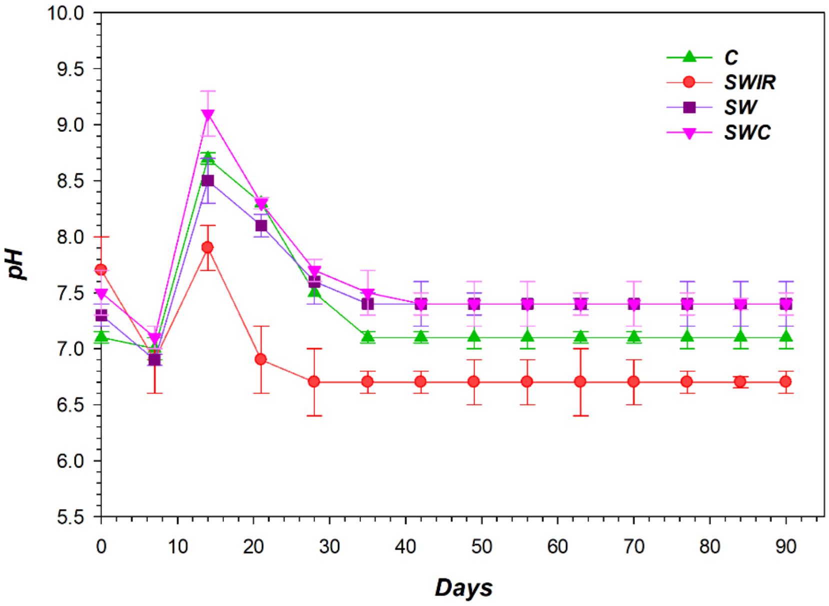

Fig. 4 Properties of pH changes during the composting process

itors such as resin leads to the eradication of mesophilic bacteria during composting. Therefore, the promotion of ammonia incorporation and nitrifying bacteria was closely related to carbon sources during the composting process. With the degradation of organic compounds, organic nitrogen was formed. The ammonia was also oxidized into (by the mineralized aeration system. Finally, the denitrification of microorganisms reduces the to N_2 gas under anaerobic conditions (Wang and Zeng 2018).

Table 3 The amount of C/N ratio of different composting mixtures on different days

Days	C/N ratio			
	Control Sample (C)	Mixture 1 (SWIR)	Mixture 2 (SW)	Mixture 3 (SWC)
5	25.7 ± 1.8	24.6 ± 2.4	25.3 ± 2.2	26.1 ± 2
15	22.7 ± 1.5	22.6 ± 2.2	21.3 ± 2.1	20.2 ± 1.5
30	20.4 ± 1.6	21.7 ± 2.1	19.1 ± 1.7	16.3 ± 1.6
45	16.8 ± 1.7	20.5 ± 1.9	13.7 ± 1.9	12.4 ± 0.7
60	13.5 ± 0.9	15.7 ± 1.4	10.1 ± 1.3	9.8 ± 0.5
90	10.8 ± 0.6	13.2 ± 1.1	8.7 ± 0.5	7.7 ± 0.4

It is observed that the available impurities such as resin and plastic waste can strongly disturb the microbial efficiency. Nevertheless, mixing the bulky materials fulfilled the compost quality (Table 3). According to Table 4, the variation of Cd, Cu, Mn, and Fe indicated the metal loss during composting. The comparison of the initial value of total P and K (1.23 % and 0.96 %) reveals that their content increased in the final product (1.53 % and 1.16 %). The enhancement of TP and TK contents confirmed that the concentration effect is responsible for these events simultaneously where there is a higher rate of carbon loss than that of the P, K during the composting process. Although the degradation of organic compounds may lead to the concentration of metals, the addition of sewage sludge causes the reduction of heavy metals in the final composting product because of its leaching during the composting process (Cesaro et al. 2019; Kebibeche et al. 2019). Moreover, the increase of soil pH restricts the heavy metals aggregation; and phytotoxic substrates in the soil improves the degradation rate and depletion of heavy metals retentions (Hazarika et al. 2017).

Table 4 Characterization of compost regards to Iranian Standard of soil regulations

Parameters	Value	Threshold Limit Value
MC(%)	22	≤ 50
pH	7.4	6.5-8.5
TOC (%)	14	NA
OM (%)	23.5	NA
TKN (%)	1.83	≤ 5
C/N	7.7	≤ 25
TP (%)	1.53	1-5
TK (%)	1.16	0.5-5
Mn (ppm)	25.7	15-25
Fe (ppm)	2169	2000-3000
Cd (ppm)	0.69	≤ 1.5
Cu (ppm)	29.55	≤ 200
Zn (ppm)	176.9	≤ 600
GI (%)	79.2	≤ 55

The evaluation of the germination index (GI) showed that there is an effective difference between the treated sample and non-treated compost in GI. The trend of GI showed that the phytotoxic parameter positively influences the plant growth. The difference of GI represents that the effect of bulky agents on the phytotoxicity results in the maturity and stability of the compost. In the same way, the experimental analysis indicated that the maximum GI of 79 % was obtained by mixing the sewage sludge and chicken manure, which indicates the maturity of sewage sludge compost. The germination index indeed increased over 63 days and then it came to a decreasing state (Fig. 5). Increasing the germination index implies the absolute effect of adding bulky agents and sewage sludge on the compost maturity and stability under the optimum processing conditions. The low germination index at the beginning of the composting process is connected to inhibitors such as the biological decomposition of microbial microorganisms (Kazemi et al. 2016). A single parameter is not representative of compost quality (maturity and stability). Relevant research findings have reported that different germination indices indicate the disappearance of photoxicity compounds in mature composts (Tiquia et al. 1996; Huang et al. 2004; Chang et al. 2019). Wei et al (2000) also reported that the germination index above 80% is indicative of the considerable maturity of compost while Nolan et al (2011) believed that C/N ratio is more representative of the compost quality where even GI index was obtained above 100 %. The results of the current study confirmed the considerable maturity of final treated-compost, especially wood residue of 30%, sewage

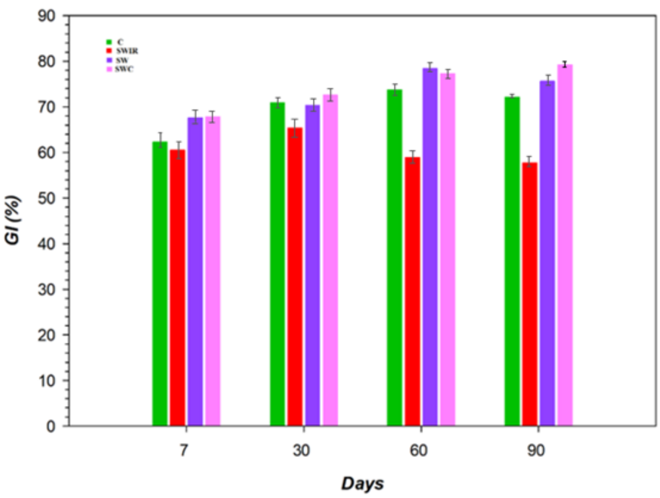

Fig. 5 Evaluation of germination index (GI) over the composting procedure

sludge of 60 %, and chicken manure of 10 %. The elimination of phytotoxic materials indicated the enhancement of maturity along with the germination index of the treated compost compared with control. Although the wood residue impregnated with resin showed a promotion in the germination promotion, it could not obtain the mature compost based on the Iranian standard criteria (the GI above 60 %). Nevertheless, the higher germination index indicates the lower concentration of phytotoxic substances of compost, which favors agricultural utilizations. However, the results of this study showed that there is a significant difference between the mixture of pure wood residue and industrial sewage sludge and the compost from wood residue impregnated with resin. The treatments applied in this study were proved suitable for producing value-added products from industrial wastes as agricultural compost. Furthermore, the integrated monitoring of the conventional process during the curing process can provide useful information to obtain a higher value of GI.

Conclusion

Using a sustainable method to create a value-added product is a promising approach for recovering industrial organic wastes. The mentioned composting process is recognized as a worldwide technique for the biological stabilization of organic compounds as a soil amendment. However, considering the parameters of the degradation procedure to obtain the proper quality of compost, namely maturity and stability, has still remained the main challenge. This study was indeed applied to an effective strategy in terms of co-composting from wood residue and sewage sludge by monitoring the temperature and moisture contents. Mixing bulky agents such as wood residue and sewage sludge not only can adjust the moisture content through providing adequate porosity but also would increase the temperate up to 70 °C compared to the control compost (the peak temperature of 42 °C). The increase of pH generates a higher acidic compound, which helps to improve the degradation of organic matter, which results in a decline of the C/N ratio and the reduction of phytotoxic compounds. The relevant outcome of the high germination index (GI) indicates the enhanced confidence of in-situ pilot-scale application toward the market of agricultural fertilizers.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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