Composting with Industrial and Domiciliary Ashes in Temuco, Chile

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Abstract. Chilean urban areas generate around 3.12 Mton year⁻¹ of organic residues. Besides, power plants near to these urban areas produce mainly about 0.42 Mton year⁻¹ associated to ashes. Both residues contribute to the introduction of pollutants in a liquid and solid phase into the natural environment. This study proposes the composting process of organic/inorganic domiciliary residues and industrial ashes which involves minimizing the volume of residues to be disposed, incorporating the circular economy concept. Composting is a biological decomposition process of organic waste by bacteria, fungi, worms and other organisms under controlled aerobic conditions and its use is considering a good strategy for its simplicity, low cost, and environment-friendly process. Their final product is considered a natural alternative to chemical fertilizers for use in agriculture, gardening and plant nurseries. In this context, the main goal of this research was to study the incorporation of industrial and domiciliary ashes to domiciliary organic residues. The experimental procedure consisted of bioreactors of 22.5 L with the addition of mass fractions of 0, 5 and 10% of ashes. During the experiment, pH, temperature, humidity, and weight were controlled. After composting, the physico-chemical parameters and maturity degree (NCh2880) of the final product were evaluated. The results showed that all reactors loss weight between 30.0% and 70.4%, which agrees with data reported in the scientific literature. The reactors reached a temperature higher than 55 °C evidencing the thermophile phase. During composting, values of pH oscillated between 5 and 7. However, humidity values showed high variability, increasing with the higher dose of ashes assayed. Compost with the addition of domiciliary ashes could not meet physico-chemical parameters fixed in NCh2880. Only the treatment which a 5% of industrial ashes was added to the composting process evidenced acceptable physico-chemical parameters and maturity degree, corresponding to a class B compost.
1. Introduction
Between 2012 and 2017, the generation of residues in Chile has increased by 19% [1]. Among the household wastes, organic fraction account for 15%, corresponding to 3.12 Mton per year. Besides, the number of industrial residues from thermal plants have also raised due to increased energy demand, accounting for 0.42 Mton per year. Management of residues in Chile is weak compared to countries of the Organization for Economic Cooperation and Development (OECD). A 76.4% of Chilean residues are disposed in landfills, affecting natural landscapes, and polluting soils and groundwater by leaching of toxic substances. However, the Chilean Environmental Ministry (MMA) attempts by policies favoring recycling and valorization of residues to improve the environmental situation [2].

Composting is the common treatment for the organic fraction of household residues [3]. This process involves a biological transformation of the organic component by bacteria, fungi, worms, and other organisms under aerobic conditions and its use is considering a good strategy for recycling organic waste by his simplicity, low cost, and environment-friendly process [4]. Their final product is considered a natural alternative to chemical fertilizers for use in agriculture, gardening and plant nurseries. For improve the chemical composition and structure of the compost, the incorporation of different additives are used as activators, inoculants or enrichers during the composting process [5]. Regarding enrichers, they are used to increase the macro- and micro-nutrients content and to improve the quality of compost [6]. In this sense, the use of ashes as an additive in the composting process has been previously proposed by some authors [7, 8, 9]. They reported that among the favorable effects its incorporation are (i) higher degradation rates of the organic fraction and (ii) the increase of nutrients content in composts, because ashes contain macro- (P, K) and micro-elements (Ca, Mg, Fe, Mn, Zn, Cu), being all necessary for plants growth [10]. Other experiences indicate that an application range between 8 and 9% of wood ashes on a mixture with organic wastes may be optimal for increasing nutrient levels in compost [8].

In the region of La Araucanía, Chile, almost all ashes come from the combustion of agro-forestry biomass in thermal plants and firewood combustion in domiciliary stoves [11]. These residues generally are disposed in the landfill; however, the composting could be an eco-friendly and low-cost alternative for the reuse of these ashes, and an option to improve the compost performance.

This study proposes to establish the optimum percentages of both industrial biomass and domiciliary ashes doses which could improve compost quality concerning to physicochemical parameters and compost maturity.

2. Materials and procedures

2.1. Materials
The mixture for the composting process contained ovine manure and household waste composed by leftover of potatoes, bananas, tomatoes, lettuce, and cut grass. Two samples of ashes were used. The first was a bottom ash from different types of heating stoves (DE) in Temuco (Chile). The other sample was an industrial biomass fly ash (BI) from COMASA S.A. near to Temuco. Both samples were used without any treatment.

2.1.1. Elemental analysis of ashes samples
Carbon, N, S and H contents were determined using elemental analysis, to obtain information about the C/N ratio present in both ashes, needed information for the composting process.

2.1.2. Procedure of composting process
Three proportions (% w/w) with contents of domiciliary ashes or industrial biomass ashes and organic waste were proposed (0, 5 and 10% w/w). The sizes of the household wastes were reduced to particle size less than 3 cm, size recommended by [12]. The required mass of each organic residue was weighed on a digital scale (± 5 g) taking an apparent reference density of 0.35 kg cm⁻³. It was then mixed for homogenization.
2.1.3. Evaluation of composting process
The determination of temperature and humidity parameters were recorded through automatic data logger sensors (Temperature and humidity measuring range: -40 to 85°C; 0 to 99% RH), whereas the pH (3.5 to 9.0) was carried out using a digital soil sensor with a probe of 20 cm. Also, the mass of containers was measured by a digital scale (± 5 g).

2.1.4. Determination of physicochemical parameters of composts obtained
All measurements of the parameters were performed in triplicate (n=18). Bulk density and humidity (at 70°C ± 5) values of composts were obtained according to the procedures describes in NCh2880 [13]. The measurements of the electrical conductivity and pH were obtained from extracts 1/5 (w/v) of the composts: water mixture on orbital shaker during 20 min at constant temperature. After filtration, pH value and electrical conductivity were obtained using a digital pH meter (Thermo Scientific Orion Star A221) and conductivimeter (Thermo Scientific Orion Star), respectively.

2.1.5. Evaluation of compost maturity: Seed germination test with compost leachates
It was determined through the germination of radish seeds (Raphanus sativus) described by [14]. This test allows to detect the presence of phytotoxic substances. Ten mL of extracts were placed in transparent plastic boxes containing 10 radish seeds on filter paper and compared with a control with distilled water. Once the seeds were placed in the boxes, they were kept in a germination chamber for seven days at constant temperature of 22°C ± 3. The level of phytotoxicity was determined through equations 1 to 3, which correspond to the percentage of relative germination (RG), percentage of relative radicle growth (RRG) and the germination index (GI).

\[
RG = \frac{\text{N° of seeds germinated in extract}}{\text{N° of seeds germinated in the control}} \times 100 \tag{1}
\]

\[
RRG = \frac{\text{Size of radicle in the extract (cm)}}{\text{Size of radicle in the control (cm)}} \times 100 \tag{2}
\]

\[
GI = \frac{\text{RG} \times \text{RRG}}{100} \tag{3}
\]

2.1.6. Evaluation of compost maturity: Seed germination test in compost
This test was performed based on the procedure proposed in NCh2880 [13], using radish species (Raphanus sativus). First, wet samples of each compost were transferred onto seedlings. Then, 10 seeds were distributed at a depth of 1 cm. Subsequently, it was incubated at a temperature of 22 °C for 7 days. Humidity was daily dosed with distilled water. Finally, the germinated and non-germinated seeds were counted and the level of phytotoxicity was determined through equations 1 and 4, which correspond to the percentage of relative germination (RG) and the percentage of relative stem growth (RSG).

\[
RSG = \frac{\text{Size of radish stem in composts with ashes (cm)}}{\text{Size of radish stem in compost without ashes (cm)}} \times 100 \tag{4}
\]
3. Results and Discussion

3.1. Results of elemental analysis of ashes samples

The elemental analysis of both ashes samples is shown in Figure 1, appreciating that nitrogen and sulphur are not present in both samples. Regarding total carbon, industrial biomass ashes presented a higher content (21.2%) compared to domiciliary ashes (6.1%). This is corroborated by the color of the samples. The black color indicates a high content of unburned matter (organic carbon) due to inefficiency in the combustion process in the boiler, whereas a yellow color is attributed to a low organic carbon content [15].

![Figure 1. Photos with results of elemental analysis of domiciliary ashes (a) and biomass industrial ashes (b)](image)

Studies indicate that it is possible to obtain composts with the incorporation of ashes which contained a carbon content between 1.3 and 4.6%. In this study, both ashes presented carbon content higher than the previous range, which could be indicated that the initial C/N ratios of the composting process are not compromised [9, 7].

3.2. Evolution of mass, temperature, pH and humidity during composting process

Figure 2 evidence an important mass loss for all treatment during the first 15 days of the composting process. The mass loss in all containers with and without ashes was between 30% and 70.4%.

![Figure 2. Evolution of mass loss of compost bins expressed as percentage during a time period of 90 days.](image)
The containers with domiciliary ashes achieved 61.9% (C5-DE) and 30% (C10-DE) of mass loss during all the process. In the case of containers with industrial biomass ashes, the internal humidity decreased in certain periods, which was corrected by providing more water to adjust the internal humidity values in the compost bins. This issue promoted that the mass loss in this treatment was lower than for domiciliary ashes, achieving 55.3% and 51.1% for C5-BI and C10-BI, respectively. As seen in Figure 2, the incorporation of ashes affects the degradation rate of organic matter, observing that mass loss was smaller when the dose of ashes was increased. This trend was also observed by other authors [16].

In all compost bins, a gradual increase in temperature was observed (Figure 3), indicating an increasing microbiological activity. However, only the container with 0% of ashes reached a temperature higher than 60 °C between the 15th and 20th day which indicates that the addition of ashes affects the composting process. However, the presence of domiciliary ashes affects more than the addition of industrial biomass ashes. The temperature measurements showed that the highest temperatures for composting with domiciliary ashes were 41°C (C5-DE) and 43°C (C10-DE), achieving only the mesophilic phase. In case of industrial biomass ashes, the mesophilic phase began approximately at 10th day for all compost bins. The highest recorded temperatures were 55.3°C and 53.8°C for C5-BI and C10-BI at 15th day, respectively.

The thermophilic phase (40-75°C) was not detected in the containers with domiciliary ashes, whereas in the containers with industrial biomass ashes and control was possible to differentiate the mesophilic, thermophilic, cooling and maturation phases [17]. However, the thermophilic phase did not reach temperatures above 55°C, which indicates that the effect of the reduction of pathogenic microorganisms was not totally achieved [13].

![Figure 3. Development of temperature during composting with 0, 5 and 10% of domiciliary ashes (DE) and biomass ashes (BI).](image)

The evolution of pH in all compost bins was similar as reported by [8], obtaining end-pH values between 6.5 and 7.5. Based on these pH ranges, the composts obtained can meet preliminary but not conclusively the requirements according to the Chile regulations for compost quality which establish a pH range between 5.0 and 8.5 [13].

Regarding humidity, containers with domiciliary ashes presented at least in the first 30 days an appropriate humidity (50-60%). After 90 days of composting the humidity content was close to 40%. The containers with industrial biomass ashes needed a humidity correction by water addition at 20th and 50th days due to a decrease of humidity by evaporation caused by increasing internal temperature [18]. However, at the end of the composting process, all containers met the proposed humidity range of 40 to 65% [12].
3.3. Determination of physicochemical parameters of compost based on Chilean Norm Nch2880

The composts obtained with and without incorporation of ashes were evaluated under the parameters established in NCh2880 [13]. Table 1 shows that pH values from composts extracts with domiciliary (8.0-9.0) and industrial biomass ashes (7.1-7.8) were close to those reported in the study by [7]. However, only composts with industrial biomass ashes and C10-DE reached the pH range (between 5.0 and 8.5) established by the Compost Chilean norm [13].

### Table 1. Physicochemical parameters of the composts obtained

| Compost | pH  | SD   | Humidity (%) | SD   | CE  (dS m⁻¹) | SD   | ρ  (kg m⁻³) | SD   |
|---------|-----|------|--------------|------|--------------|------|-------------|------|
| C0      | 7.3 | ±0.006 | 49.8         | ±0.005 | 4.7         | ±0.008 | 290.0       | ±0.10 |
| C5-DE   | 9.0 | ±0.01  | 60.7         | ±0.005 | 5.9         | ±0.006 | 295.3       | ±0.02 |
| C10-DE  | 8.0 | ±0.01  | 57.9         | ±0.004 | 6.5         | ±0.008 | 305.4       | ±0.03 |
| C5-BI   | 7.8 | ±0.02  | 49.2         | ±0.005 | 4.9         | ±0.003 | 314.9       | ±0.03 |
| C10-BI  | 7.1 | ±0.006 | 44.7         | ±0.003 | 6.4         | ±0.008 | 321.4       | ±0.02 |

*Note: CE: electrical conductivity, ρ: bulk density.*

The humidity contents were high for all composts. Especially, composts with domiciliary ashes (57.9-60.7%) did not comply with humidity content established in NCh2880 of 30 to 45% [13]. This result implies a lack of compost maturity, which can cause additional biological activity during compost use. Regarding, compost with industrial biomass ashes, their humidity content (44.7-49.2%) indicated also a lack of maturity. However, the values were close to the limit of 45% established by NCh2880. Similar results (~50%) were reported by [7], which tested biomass ashes doses between 2% and 8%.

The results of the electrical conductivity measurements for all composts with ashes showed an increase with the higher dose of ashes. This trend is attributed to the presence of soluble salts in ashes [19]. Nevertheless, all EC values were between 3 and 8 dS m⁻¹ (4.9-6.5 dS m⁻¹), which means that all compost belongs to class B compost [13]. The values of bulk densities (ρ) presented a similar tendency as electrical conductivity. Moreover, all bulk densities were below 700 kg m⁻³, meeting the requirement fixed by NCh2880.

3.4. Determination of Maturity

3.4.1. Seed germination test with compost leachates.

The tests with domiciliary ashes/compost leachates reached high values between 93.3 and 100% of germination percentage (RG). Similar behavior was found for the leachates from compost with industrial biomass ashes, achieving RG between 96.7% and 100%. The Chilean regulation states that PGR >80% is an indicator factor for compost maturity [13]. Therefore, all composts fulfilled the requirements according to NCh2880.

### Table 2. Germination test with radish seeds in leachates of the composts obtained.

| Compost | RG  (%) | SD   | RRG (%) | SD   | IG  (%) | SD   |
|---------|---------|------|---------|------|---------|------|
| C0      | 100     | ±0.0 | 88.2    | ±48.1| 88.2    | ±48.1|
| C5-DE   | 93.3    | ±5.7 | 20.0    | ±4.0 | 18.7    | ±3.2 |
| C10-DE  | 100     | ±0.0 | 30.4    | ±3.2 | 30.3    | ±13.2|
| C5-BI   | 100     | ±0.0 | 92.6    | ±36.1| 92.6    | ±36.1|
| C10-BI  | 96.7    | ±5.7 | 77.1    | ±33.0| 74.5    | ±34.5|

Regarding the percentage of relative radicle growth (RRG), the values obtained with domiciliary ashes were lower than RG, which indicates that the presence of phytotoxic substances in the composts
did not inhibit the germination of seeds but did limit the growth of plant roots [20]. On the other hand, the RRG values of composts with industrial biomass ashes (77.1-92.6%) were higher than with domiciliary ashes. However, RRG values were also lower than RG.

The germination index percentages (GI) for composts with domiciliary ashes evidenced a strong presence of phytotoxic substances (Table 2: GI < 35%), whereas GI of composts with industrial biomass ashes indicated a higher degree of compost maturity, being the GI of C5-BI > 80%. According to [7], GI > than 70% indicates that there are no phytotoxic substances, or these are in a very low concentration.

3.4.2. Seed germination test with compost.

The results of the germination or recovery test of radish seeds were made by the direct application in the composts with or without ashes (Table 3). Percentage of relative germination (RG) values of composts with domiciliary ashes were below 80% and did not meet with the NCh2880, whereas RG values of compost with industrial biomass ashes were > 80%. In addition, the RG value of C5-BI compost suggests that the use of 5% of industrial biomass ashes is favourable for the germination of radish seeds.

| Compost | RG (%) | SD | RRG (%) | SD |
|---------|--------|----|---------|----|
| C0      | 86.7 ±15.2 | 100 | ±55.5   |   |
| C5-DE   | 0.0 ±0.0     | 0.0 | ±0.0    |   |
| C10-DE  | 43.3 ±45     | 5.4 | ±9.4    |   |
| C5-BI   | 96.7 ±5.7    | 134.2 | ±31.4 |   |
| C10-BI  | 86.7 ±23.0   | 72.8 | ±39.0   |   |

A similar trend was detected for the relative stem growth percentage values (RSG) as for RG, suggesting that the inhibition of germination and growth of radish plants is caused by phytotoxicity [21]. The RSG value of C5-BI compost was higher than RG, which could indicate a positive effect to stem growth. Instead, the stem growth was slightly affected with the C10-BI compost. Therefore, the use of a 5% incorporation of biomass ashes would imply better conditions for the development of plants, considering the obtained results.

4. Conclusions

The use of industrial biomass fly ash increased the duration of the thermophilic phase during the composting process contrasted with the heating stoves ashes applied, which generated a final product with betters physicochemical and maturity properties. Also, the quality of the compost obtained using 5% of industrial biomass ashes, mostly meets the requirements to classify it as a Class B compost according to the Chilean Standard of Compost. The results evidence a beneficial effect of the ashes application in the composting process, obtaining a quality stabilized material for use as a soil amendment.

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