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Waste to Carbon: Preliminary Research on Mushroom Spent Compost Torrefaction

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Abstract
Mushroom production in Poland is an important and dynamically developing element of diverse agriculture. Mushroom spent compost (MSC) is major waste generated during production, i.e., MSC: mushrooms is ~5:1. To date, the main use of MSC is soil application as organic fertilizer. To date, several methods of MSC treatment have been researched and developed including production of compost, bioethanol, biogas, enzyme lactase, xylo-saccharides, and hydrogen. Torrefaction may be considered a novel approach for biomass valorization. Thus, we are pioneering the potential use of MSC valorization via torrefaction. We explored valorizing the waste biomass of MSC via thermal treatment – torrefaction ('roasting') to produce biochar with improved fuel properties. Here for the first time, we examined and summarized the MSC torrefaction thermogravimetric analyses, fuel properties data of raw biomass of MSC and biochars generated from MSC via torrefaction. The effects of torrefaction temperature (200~300 °C), process time (20~60 min), on fuel properties of the resulting biochars were summarized. The dataset contains results of thermogravimetric analysis (TGA) as well as proximate analyses of MSC and generated biochars. The presented data are useful in determining MSC torrefaction reaction kinetics, activation energy and to further techno-economical modeling of the feasibility of MSC valorization via torrefaction. MSC torrefaction could be exploited as part of valorization resulting from a synergy between an intensive mushroom production with the efficient production of high-quality renewable fuel.

Keywords
mushrooms, mushroom spent compost, renewable energy, biochar, biomass valorization, torrefaction, fuel properties, proximate analysis, carbon sequestration

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Oil, Gas, and Energy

Comments
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Data Descriptor

Waste to Carbon: Preliminary Research on Mushroom Spent Compost Torrefaction

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Abstract: Mushroom production in Poland is an important and dynamically developing element of diverse agriculture. Mushroom spent compost (MSC) is major waste generated during production, i.e., MSC: mushrooms is ~5:1. To date, the main use of MSC is soil application as organic fertilizer. To date, several methods of MSC treatment have been researched and developed including production of compost, bioethanol, biogas, enzyme lactase, xylo-saccharides, and hydrogen. Torrefaction may be considered a novel approach for biomass valorization. Thus, we are pioneering the potential use of MSC valorization via torrefaction. We explored valorizing the waste biomass of MSC via thermal treatment – torrefaction ('roasting') to produce biochar with improved fuel properties. Here for the first time, we examined and summarized the MSC torrefaction thermogravimetric analyses, fuel properties data of raw biomass of MSC and biochars generated from MSC via torrefaction. The effects of torrefaction temperature (200~300 °C), process time (20~60 min), on fuel properties of the resulting biochars were summarized. The dataset contains results of thermogravimetric analysis (TGA) as well as proximate analyses of MSC and generated biochars. The presented data are useful in determining MSC torrefaction reaction kinetics, activation energy and to further techno-economical modeling of the feasibility of MSC valorization via torrefaction. MSC torrefaction could be exploited as part of valorization resulting from a synergy between an intensive mushroom production with the efficient production of high-quality renewable fuel.

Dataset: This dataset is available in the supplementary file 'Data_MSC_torrefaction.xlsx.zip'.

Dataset License: CC-BY

Keywords: mushrooms; mushroom spent compost; renewable energy; biochar; biomass valorization; torrefaction; fuel properties; proximate analysis; carbon sequestration

1. Summary

Poland is the largest grower of mushrooms in Europe and the third in the world. The production of mushrooms in Poland is growing rapidly and has become an important branch of regional agriculture. The production of mushrooms increased from 196 thousand Mg·year^{-1} to 325 thousand Mg·year^{-1} from 2006 to 2018, which currently accounts for ~24% of the total production in European Union [1,2]. One of the residual wastes generated during the cultivation is mushroom spent compost (MSC, low nutrient substrate), which accounts as 5:1 MSC: mushrooms (kg·kg^{-1}) [3]. This waste amounts to ~5,527 thousand Mg·year^{-1} of MSC [1]. It is estimated that the MSC [4] generation may reach up to 1.3 million tons per year in Poland by year 2018 [1]. MSC is classified according to European Waste Classification, as an industrial waste (02 01 99 code), which belongs to the group of wastes from agriculture, horticulture, hydroponics, fisheries, forestry, hunting and food processing [5].

Potential MSC waste treatment methods result from its properties. For example, a white mushroom (*Agaricus bisporus*) is grown on a soil consisting mainly straw and chickens' manure. Poultry manure also contains gypsum, urea, peat, coconut, and soy proteins [6]. The production cycle of mushrooms on this bedding takes 6 to 8 weeks, during which, three harvests of mushrooms may be obtained. After this period, the MSC cannot be regenerated and used again for production. It is a waste which requires to be treated [7].

To date, several methods of managing of MSC have been developed and used. Those methods were aimed to obtain compost [7], bioethanol [8], biogas [9], enzyme lactase [4], xylo-saccharides [10], or hydrogen [11]. Torrefaction may be considered a novel approach for biomass valorization [12]. Thus, we are pioneering the potential use of MSC valorization via torrefaction.

Torrefaction is sometimes called a 'low temperature pyrolysis' in the range of 200-300 °C [13]. The process residence time depends on many factors, such as the moisture or volatile content, as well as the type of reactor or substrate [14]. The residence time usually does not exceed 60 min. The products of torrefaction are: solid biochar and gas 'torgas'. Torgas consists non-flammable and flammable gases such as water vapor, CO_2, CO, CH_4 and H_2 [15]. The ratio of flammable to non-flammable gases depends on process and substrate parameters [13]. Thus, torgas is a less attractive product of torrefaction compared with biochar [16,17]. The solid product of the torrefaction – biochar, could be considered as a renewable source of energy according to Polish law if its calorific value is >21 $MJ \cdot kg^{-1}$ d.m. and the feedstock originates from solid biomass and biowaste [18].

During the torrefaction process the loss of mass as well the loss of chemical energy from raw material is observed. However, the degree of mass loss is higher (30-40%) than the energy loss (10%). and the energy densification in solid fuels (biochars) occurs [13]. To date, research has been carried out on the torrefaction of the following wastes: parts of industrial and municipal wastes [19, 20], sewage sludge derived from wastewater treatment [21]. Also, the brewers' spent grain [22], oxytree biomass [23] straw, woodchips, olives waste, Virginia mallow have already been torrefied [24].

To date, the torrefaction of MSC has not been attempted yet. This dataset includes the novel results of properties including thermogravimetric analyses (TGA), proximate properties of MSC and generated biochars. The presented data are useful in determining the MSC torrefaction reaction kinetics and to further the techno-economical modeling of the feasibility of MSC valorization via torrefaction, including a comparison with other torrefied types of biomass and waste.

2. Data Description

2.1. The properties of raw MSC

The raw biomass of MSC was characterized for moisture content, volatile solids (VS) and ash content, and higher heating value (HHV) (Table 1).

Table 1. The properties of raw MSC

Parameter	Unit	Mean ± Standard Deviation
Moisture	%	65.32 ± 0.05
VS	% d.m.	71.60 ± 2.31
Ash	% d.m.	28.40 ± 2.31
HHV	$MJ \cdot kg^{-1}$ d.m.	13.79 ± 0.50

The obtained data are presented in the Supplementary Material file "MSC torrefaction data.xlsx" in six sheets summarizing properties of raw and torrefied MSC (biochars):

- Read me (guide)
- MSC Moisture (2nd sheet)
- Higher Heating Value (3rd sheet)
- Volatile Solids (4th sheet)

- Ash (5th sheet)
- TGA (6th sheet).

The first "Read me" sheet is a guide on how to read the data with short information about each type of treatment.

3. Methods

The samples of MSC originated from mushroom farm in Gogołowo, Poland. Before the experiment, MSC samples were dried for 24 h in a WAMED laboratory dryer, model KBC-65W (Warsaw, Poland) at 105 °C. Then, dry MSC sample was ground through a 0.1 mm screen and the laboratory knife mill TESTCHEM, model LMN-100 (Pszów, Poland).

3.1. The MSC torrefaction and biochar generation

The MSC torrefaction was carried out according to procedure described by Świechowski et al. [23] in a muffle furnace (Snol 8.1/1100, Utena, Lithuania). CO_2 was used as an inert gas with a flow of 10 $dm^3 \cdot h^{-1}$. The process was carried out at the setpoint temperatures of 200 °C to 300 °C with intervals of 20 °C and 20, 40, and 60 min retention time. The samples were heated from 20 °C to the torrefaction setpoint temperature at a 50 $°C \cdot min^{-1}$ heating rate. The dry mass of the samples used for the tests was 10 g (± 0.5 g). The biochars were removed from the muffle furnace when the interior temperature was lower than 200 °C. The approximate times of cooling from 300 °C, 280 °C, 260 °C, 240 °C, and 220 °C to 200 °C were 38, 33, 29, 23, and 13.5 min, respectively. The approximate cooling time from 300 °C to room temperature (~20 °C) was around 6 h. Analyses of three replicates were carried out.

3.2. MSC torrefaction - thermogravimetric analysis

The thermogravimetric analysis (TGA) of the MSC torrefaction process was conducted according to the protocol described elsewhere [21]. Briefly, to ensure that the inert atmosphere was maintained, the CO_2 gas was introduced from the bottom of the reactor at a rate of 0.6 $mL \cdot min^{-1}$. The investigated MSC sample was placed in the cuvette and introduced inside the reactor. The cuvette was integrated with the electronic balance with 0.01 g resolution to enable the measurement of the mass loss during the torrefaction process. The parameters of the torrefaction process were registered by a PC and exported to a file. Approximately 2.25 g of dried MSC samples were placed in the reactor and heated at constant temperatures of 200, 220, 240, 260, 280, and 300 °C for up to 1 h. Temperature range and intervals were typical for torrefaction temperatures [26] and based on the methodology described by Bialowiec et al. [19].

3.3. Proximate Analysis of raw MSC and biochars generated

Raw and torrefied MSC samples were tested in three replicates for:

- Moisture content, determined in accordance with [27], by means of the laboratory dryer (WAMED, model KBC-65W, Warsaw, Poland).
- Volatile solids, determined in accordance with [28], by means of the SNOL 8.1/1100 muffle furnace (Utena, Lithuania).
- The ash content, determined in accordance with [29], by means of the SNOL 8.1/1100 muffle furnace (Utena, Lithuania).
- High heating value (HHV), determined in accordance with [30], by means of the IKA C2000 Basic calorimeter.

4. User Notes

The dataset represents a novel work on the MSC biomass torrefaction. The dataset consists of results of raw MSC and biochars produced from MSC, i.e., fuel properties in relation to torrefaction temperature and residence time in the reactor. The torrefaction TGA analyses results were given for MSC biomass. These data can be used for calculating MSC torrefaction kinetics and activation energy and can also be used to propose mathematical models describing the influence of torrefaction, temperature, and residence time on fuel properties. The presented data may serve as reference values for comparative analyses with other types of biomass and waste and renewable fuels from agriculture.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, File S1: Data_MSC_torrefaction.xlsx.zip.

Author Contributions: Conceptualization, A.B.; methodology, A.B., E.S.; software, E.S..; validation, E.S., A.B., and J.K.; formal analysis, E.S.; investigation, E.S..; resources, E.S., A.B., and J.K.; data curation, E.S., A.B..; writing—original draft preparation, E.S., A.B..; writing—review and editing, E.S., A.B. and J.K.; supervision, A.B and J.K.; project administration, A.B.; funding acquisition, A.B., and J.K.

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