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Valorization of spent coffee ground with wheat or miscanthus straw: Yield improvement by the combined conversion to mushrooms and biomethane

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ABSTRACT

Spent coffee grounds mixed with wheat straw or miscanthus straws were used as substrates for oyster mushroom (*Pleurotus ostreatus*) production. The biomethane potential of spent mushroom composts was determined, and the influence of fungal digestion (FD) on the overall conversion balance of the substrates to valuable products, i.e. edible mushroom carpophores and biomethane (CH_4) was investigated. Only 3–7% of the chemical oxygen demand (COD) of the initial substrates was recovered as harvested carpophores, while about 50% was recovered as CH_4 by anaerobic digestion (AD) of the fungal compost. Anaerobic digestibility of the fungal compost after FD was very close to the anaerobic digestibility of the initial substrates, but the amount of matter was reduced by 17–22% as dry matter, 20% as volatile solids and 12–27% as COD, most probably by fungal respiration. As a consequence, the CH_4 production per amount of initial substrate was lower. However, owing to the much higher economic value of edible carpophores as compared to CH_4, a rough assessment of the economic balance was largely in favour of FD prior to AD. As compared to wheat straw, miscanthus straw presented both a lower final conversion to biomethane and a lower amount of harvested carpophores. Valorization through FD before AD is to be preferred as compared to direct biomethanation of the initial substrates.

Introduction

Coffee is a drink consumed all over the world. This plant is now widely cultivated in nearly 80 countries mainly from Africa (continent of origin), Latin America and Asia, where its fruits contribute to socio-economical life (Adler, Noirot, Fock-Bastide, Citerne, & Mouille, 2015; Mussatto, Machado, Martins, & Teixeira, 2011). Coffee is a general term embracing a number of species or hybrids in the genus *Coffea* of the family *Rubiaceae*. *Coffea arabica* (Arabica) and *Coffea canephora* (Robusta) are the two-main species cultivated for the production of coffee (Murthy & Madhava Naidu, 2012). With a world production estimated at 9.3 million tons in 2016, coffee is the second most traded commodity in the world after oil, in terms of plant market value (Campos-Vega, Loarca-Piña, Vergara-Castañeda, & Dave Oomah, 2015; USDA-FAS, 2016). About 50% of this production is used for the production of soluble coffee, generating about 6 million tons of spent coffee grounds per year (Ballesteros, Teixeira, & Mussatto, 2014; Mussatto et al., 2011). Large quantities of spent coffee grounds are also produced and discarded in the catering sector. Spent coffee grounds are a very heterogeneous material whose differences in chemical composition reflect the variety of grains and processes used for roasting and extraction in the case of instant coffee manufacturing (Campos-Vega et al., 2015). They are rich in cellulose and hemicellulose polysaccharides and can be considered as lignocellulosic residues (Ballesteros, Cerqueira, Teixeira, & Mussatto, 2015; Mussatto et al., 2011). Valorization of the spent coffee grounds can help to increase the overall sustainability of the coffee agro-industry.

Spent coffee grounds are mainly constituted of fermentable organic matter content, that can be responsible for environmental burdens (Silva, Nebra, Machado Silva, & Sanchez, 1998). They also contain environmentally problematic components like caffeine, tannins and polyphenols (Mussatto et al., 2011). Despite the potential negative impact of the discarded spent coffee grounds on the environment, very few works related to their valorization have been reported. Some results have been published on the extraction of some specific components such as dietary fibers and sugars, for the further production of food supplements (Campos-Vega et al., 2015; Passos, Moreira, Domingues, Evtuguin, & Coimbra, 2014). Hudeckova, Neureiter, Obruca, Fruhauf,

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and Marova (2018) have reported that spent coffee grounds could be a promising raw material for the production of lactic acid after acid treatment and application of cellulase. Other results have been reported on the extraction, transesterification, and purification process to produce biodiesel from oil extracted from spent coffee grounds (Blinova, Bartosova, & Sirotiak, 2017; Caetano, Caldeira, Martins, & Mata, 2017; Kondamudi, Mohapatra, & Misra, 2008). However, the process yields of the conversion of oil extracted from spent coffee grounds to biodiesel were only in the range of 10 to 15% w/w (Kondamudi et al., 2008). Furthermore, the cost of the biodiesel process (collection and transportation of spent coffee grounds, drying, energy and solvents used for oil extraction) is very expensive and the esters content of the biodiesel obtained from oil extracted from spent coffee grounds does not meet the EN 14214:2009 standard quality requirements (Blinova et al., 2017; Caetano et al., 2017).

Some oyster mushroom (*Pleurotus ostreatus*) producers valorize locally available spent coffee grounds mixed with wheat straw or miscanthus straw as substrate. *Pleurotus ostreatus* is a white-rot fungus of interest owing to its production of edible carpophores (Dashtban, Schraft, Syed, & Qin, 2010; Pointing, 2001; Wong, 2009). White-rot fungi are known to degrade lignin and improve the digestibility of lignocellulosic substrates. Fungal treatment using white-rot fungi to degrade lignin is a cheaper alternative to improve the anaerobic digestibility, as compared to other physico-chemical and mechanical treatments (Schroyen, Vervaeren, Vandepitte, Van Hulle, & Raes, 2015). This treatment does not produce inhibitory compounds and is reported to improve the methane yields of the pretreated substrates up to 50% of their production without pretreatment, along with an increase of methane content in biogas (Rouches, Herpoël-Gimbert, Steyer, & Carrere, 2016; Schroyen et al., 2015). To take full advantage of the mushroom production process, oyster mushroom producers are interested in the anaerobic digestion to convert their spent compost to methane. The question was then whether the fungal digestion of the substrate, that is naturally included in mushroom production, would improve the digestibility of the fungal compost and allow a better conversion of the compost to biomethane through an anaerobic digestion process.

The aim of the present paper was to determine the biomethane potential of the various spent mushroom composts. With the perspective to optimize the sustainability of the process, the aim was also to assess the influence of fungal digestion on the overall conversion balance of substrates to valuable products, i.e. edible carpophores and biomethane. Mushroom producers use several proportions of coffee grounds and wheat or miscanthus straw as substrates. To be representative of the real life, investigations were performed with these substrates and commercial *Pleurotus ostreatus* strain used in practice, i.e. not fully controlled.

Material and methods

Substrates

Air dry wheat straw and miscanthus straw were obtained from organic farmers in the province of Walloon Brabant (Walloon region, Belgium). Coffee grounds were collected from local restaurants (Louvain-la-Neuve, Belgium) and stored at −20 °C until use.

Fungal digestion: oyster mushroom production

The protocol of the mushroom producers was followed, using their equipment. The straw was soaked in water before use in order to soften it and to adjust the water content to the fungal requirements. Coffee grounds were thawed and mixed with wheat straw and miscanthus straw. The mixed substrates were sterilized in a soil sterilizer at 100 °C for about 3 h just before the preparation of different cultures, to decrease the competition naturally present undesired microorganisms against the desired mushroom. Three substrate mixtures were prepared to feed the mushroom production, with, on a fresh matter basis, 50% coffee grounds and 50% water-soaked wheat straw (further referred to 50C/50W), 30% coffee grounds and 70% water-soaked wheat straw (further referred to 30C/70W), and 30% coffee grounds and 70% water-soaked miscanthus straw (further referred to 30C/70M). After cooling, the substrate mixtures were inoculated with 5% mycelium (from the Belgian company Mycelia) and incubated at 100% relative humidity and 20 °C for 8 weeks. The oyster mushroom production was performed under saturated air humidity conditions. The harvested mushroom carpophores and residual fungal composts were weighted and characterized to establish the material balances. Substrate mixtures were sampled after sterilization and before inoculation with mycelium.

Anaerobic digestibility assay (BMP)

Anaerobic inoculum

The anaerobic digestion assay was performed according to the method described by Awedem et al., 2017 and Awedem et al., 2017. The anaerobic inoculum was amplified by incubating for 10 days at 35 °C under anaerobic conditions, a methanogenic primary inoculum maintained in the laboratory and fed with freshly collected activated sludge as a substrate, in a ratio of $0.3 g_{COD\_activated\_sludge\_substrate} / g_{COD\_methanogenic\_primary\_inoculum}$, where COD is the chemical oxygen demand. The activated sludge was collected at the Chastre municipal wastewater treatment plant (Mont-Saint-Guibert, Belgium). Upon arrival in the laboratory, the sludge was left to settle in the dark at 4 °C for 24 h and the clear supernatant was removed. The sludge concentration was 15–20 g_{COD}/l, measured accurately before use (Awedem, Happi, et al., 2017, Awedem, Korangi, et al., 2017).

Equipment

Bioreactors consisted of 1 L Schott Duran GL 45 bottles, with a glass tube at the top side. A two-way Luer polycarbonate valve (Fisher Scientific) was connected at the extremity of this glass tube. The bioreactor bottles were capped with a PBT screw-cap, containing a PTFE-coated silicone seal. Each bioreactor was checked to be airtight and resistant to internal pressure before each use.

Anaerobic digestion

Three identical experiments were performed, one for each substrate mixture. Each experiment was performed in triplicate, with a negative control consisting of water replacing the sample, in order to determine the biogas produced by the inoculum alone. The protocol followed the VDI 4630 guidelines. Each bioreactor was filled with the inoculum ($7.5 g_{COD}$), and incubated at 35 °C for at least 2 h in order to allow the rebalancing of CO_2 between the liquid phase and the gas phase. A known mass of substrate at 35 °C was added in order to reach a COD ratio of $0.2 g_{COD\_substrate} / g_{COD\_inoculum}$ (Awedem, Happi, et al., 2017, Awedem, Korangi, et al., 2017). Demineralized H_2O was added to complete the volume to 580 mL. The initial pH in each bioreactor was 7.3 ± 0.2 and no buffer was added as the inoculum provides its own natural bicarbonate buffer. Each bioreactor headspace was flushed for 2 min with nitrogen gas in order to ensure the absence of oxygen in the bioreactors prior to hermetic closure. The bioreactors were incubated at 35 °C in the dark under anaerobic conditions for 132 days. The end of anaerobic digestion was determined when the biogas production rate of the bioreactor with substrate plus inoculum did not exceed any more the biogas production rate of the bioreactor with only the inoculum.

The biogas production was monitored using a UNIK type manometer (5000 PTX5072-TA-A3-CA-H0-PA, GE Measurement & Control Solutions) connected to the bioreactor through a 2-way valve. The manometer was equipped with a display (DMS-40LCD-4/20S, Datel Inc., USA) calibrated for absolute pressure ranging from 900 to 1300 mbar with accuracy of 0.1 mbar. The pressure was converted to gas production under Normal Temperature and Pressure NTP conditions ($T = 0$ °C, $P =$