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Increasing the Value of Spent Grain from Craft Microbreweries for Energy Purposes

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The beer brewing process is one of the most polluting industrial processes, generating a huge amount of wastewater effluent and solid wastes (i.e. spent grain and yeast), which must be disposed of or treated in the least costly way to meet strict discharge regulations set by government entities. Particularly, spent grain, the leftover malt and adjuncts after the mash has extracted most of the sugars, proteins, and nutrients, can constitute as much as 85 % of a brewery's total by-product. However, sustainability is a hallmark of the craft beer industry and therefore there is a great interest to find innovative ways to prevent spent grain from going to waste.
At this regard, the "Birraverde" project, coordinated by CREA and funded by the National Rural Network, aimed to develop some technical solutions for the recovery and reuse of brewer's wastes (spent grain, spent yeast and wastewaters), according to the principles of circular economy. In particular, for the recovery and valorisation of spent grain two alternative solutions were proposed: 1) conversion of dried spent grain into pellets that can be used for heat generation to be reused in the beer production cycle; 2) production of biochar (charcoal) from dried spent grain through a thermochemical process of pyro-gasification. In the latter case, a preliminary trial was carried out using a lab-scale pyrolytic reactor. The first proposed model, if integrated within the brewing process pipeline, can reduce the costs of buying pellets on the market, producing gain margins even under low rate of plant utilisation (160 h y^{-1}). On the other hand, the second model, the conversion of spent grain into biochar, a new organic amendmen, can offer the possibility to realize a diversification of the farm activities opening to new markets.

1. Introduction

Beer is the fifth most consumed beverage in the world. The latest data, available for 2015 on the Italian beer production chain, estimate a total consumption of 18.7 million hectolitres, with an internal production of 14.0 million hectolitres. In terms of employment we are talking about 137.000 workers amongst direct and indirect employees. Over the last few decades, Italy has been assisting to the rise and the establishment of a new type of business in the brewing industry: the craft beer industry, which gained great success and credibility, becoming one of the most significant phenomena of the Italian agri-food sector. The direct, indirect and induced contribution of the craft brewing sector to the Italian economy is becoming considerable, with approximately 600 microbreweries operating in the country, for an average annual beer production of 445,000 hectolitres, accounting for about 3 % of the total volume of beer produced. However, the brewing industry generates huge quantities of by-products (i.e. spent grain, spent hops and surplus yeast; Mussatto, 2009), which account for about 90% of the starting materials. In particular, the entire production process, which

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requires a total energy consumption of about 112 millions of kWh, generates about 10,882 tons of yeasts and about 194,754 tons of spent grain; the latter representing about 85% of the total by-products generated (Mussatto et al., 2006). One of the main challenges of the brewery sector is therefore the recovery and valorisation of these wastes through the application of a circular economy model.
In light of that, the aim of the present study was the design of two different technical models (pellet and biochar production) for the recovery and valorisation of brewers' spent grain (BSG) as an alternative to the current practice consisting in their use as animal feed, especially as feed for ruminants (Santos Mathias et al., 2014). The paper also reports the technical and economic analysis of the design solution feasibility linked to the production of BSG pellets for energy use.

2. Materials and Methods

2.1 BSG treatments

Wet BSG were kindly provided by different craft breweries located in Latium (central Italy) and immediately transported under refrigerated conditions to the '*Experimental activities Renewable Energy and Biomass'* laboratory of CREA-ING (Monterotondo, Rome, Italy) for the analysis. Samples (three replicates of about 1kg each) were dried in an oven at 105 ± 1 °C for 78 hours. To assess the Lower Calorific Value (LCV), also referred to as Net Calorific Value (NCV), dried BSG samples were subjected to elemental analysis for the determination of the CHNS content. The assessment of the energy conversion type is made on the basis of the given C/N ratio. To evaluate the Gross Calorific Value (GCV), the spent grain samples were placed in a Mahler bomb calorimeter. Ash content was analysed by heating ground dried BSG samples (maximum grain size 2 mm) at 550°C ± 1 °C for 8 h in a muffle furnace. GCV and NCV were determined according to the relevant domestic industrial standards (UNI EN 14918: 2010), the content of C, H and N according to UNI EN 15104: 2011, and ash content according to UNI EN 14775: 2010. Three analytical replicates were performed for all parameters analysed and for each sample.

2.2 Pellet production with BSG

In the present study, a small-scale pellet plant was used. The pellet maker used a 3kW electric motor, which operated at full capacity (100 kg h^{-1} of 6 mm diameter pellets) on a three phase electrical supply. Three different types of pellet were produced. In the first trial, BSG pellets were prepared starting from BSG at 20 - 25% moisture content (MC) using three milling cycles. In the second trial, BSG pellets were prepared starting from BSG at 15 – 18 % MC with only one passage in the pellet maker. In the third trial, pellets were produced from dried spent grain (15 – 18% MC) by adding a suitable binder (starch at 3%, w/w) with only one passage in the pellet maker.

2.3 Preliminary tests for the BIOCHAR production

In the present study, biochar was produced from BSG using a particular thermochemical (pyrolysis and/or micro-gasification) process that can reach carbonization temperatures of 400 - 500 °C (Sorgonà et al., 2016). The tests of carbonization were carried out using the pyrolytic reactor Elsa D17 (pat. BLUECOMB) using both bulk spent grain and pelletized spent grain. Yield percentage of biochar was determined by following equation:

$$Yield\ (\%) = (weight\ of\ biochar)/(weight\ of\ feedstock) \times 100\ \%.$$

Experiments were carried out in triplicates.

2.4 Economic sustainability of the heat production by BSG pellets

The economic analysis is referred to a model for the self-production of fuel pellets, using BSG from craft breweries as starting material. A pelletizing plant of small size having 30 kWh of power represents the example considered. The cost of raw material is practically eliminated because the BSG is a waste coming directly from the activity of the brewery. The analysis aimed to demonstrate the economic viability of the model adopted for pellet self-production in small sized plants. The lifetime of the pellet plant was considered to be of 12 years, assuming three possible values of intensity of use for the plant *per* year and, consequently, three different productions *per* year: a) 800 h y^{-1} and 160 t y^{-1} of pellets produced; b) 1,600 h $year^{-1}$ and 320 t y^{-1}; c) 2,400 h and 480 t y^{-1}. The basic components of the small pelletizing plant were a drying system, a refining system, a pellet press, a dedusting system, a cooling system, control units, and electrical connections. The economic analysis evaluated, through an analytical methodology, the annual management costs of the small pellets production plant, taking into account the annual depreciation of the invested capital, other annual fixed costs and operating costs related to the maintenance and repairs, electricity, labour, and overheads.

3. Results

Sustainable economic development and environmental management are some of the highest priorities of the modern world as these are concerned with the present and future generations. Besides, agro-industrial biomass is one of the major promising energy resources in the world. Brewing process produces a huge quantity of residual biomass, mainly spent grain, which can be recovered for energy production. However, spent grains are characterized by a high moisture content, and, in order to be used in combustion processes, a reduction of moisture at least to 55 % is needed (Weger et al., 2014). In the present study, analysed BSG showed an average moisture content of 72.88 ± 0.04 %.
BSG elemental analysis showed an average content of carbon equal to 45.7 ± 0.5 %, and an average content of hydrogen equal to 9.0 ± 0.6 % (Table 1). The value of wood as fuel is mainly determined by the H/C and O/C index. A high content of C and H results in a higher calorific value. In the present study, BSG showed a mean LCV of 13.7 MJ kg^{-1}, and a mean HCV of 16.9 MJ kg^{-1}, values close to those found in the most common forest species used for energy purpose.

Table 1: Report of BSG chemical, elemental and physical analysis (M.U. = Measure Unit; SD = standard deviation)

Trial	Method	M.U.	mean	SD
Moisture on dry mass	UNI EN 14774:2010	%	8.8	3.4
Ash content	UNI EN 14775:2010	%	5.3	2.4
C	UNI EN 15104:2011	%	45.7	0.5
H	UNI EN 15104:2011	%	9.0	0.6
N	UNI EN 15104:2011	%	4.2	0.2
Gross calorific value (GCV)	UNI EN 14918:2010	MJ/kg	16.9	0.3
Net calorific value (NCV)	UNI EN 14918:2010	MJ/kg	13.7	0.7

A major challenge in the production of both fuel and feed pellets is the high cost associated with drying biomass generally up to 10% (wb). BSG biomass is available at higher moisture content (50 – 80%) depending on the brewing plant. To be implemented into a valorisation route according to a circular economy approach, biomass needs to be dried to make it aerobically stable and to prevent dry matter loss during storage. In the pellet production process, both pellet mill process variables and biomass variables influence the quality of the pellets and the specific energy used in the process. Moisture content is a feedstock variable that plays an important role in determining the qualities of pellets (density and durability) and specific energy consumption of the pelleting process. In the present study, BSG pellets were produced at different moisture contents, with and without adding starch as binder, evaluating the impact of these variables on the physical characteristics and shelf life of final products. The pellets produced herein, characterized by different BSG moisture content showed the same ability to keep their physical characteristics unchanged over time, showing a good shelf life in the medium and long term without observing deterioration phenomena.
Results of the economic analysis of the proposed model for the valorisation of BSG through the production of fuel pellets were summarized in Table 2, Figures 1 and 2.

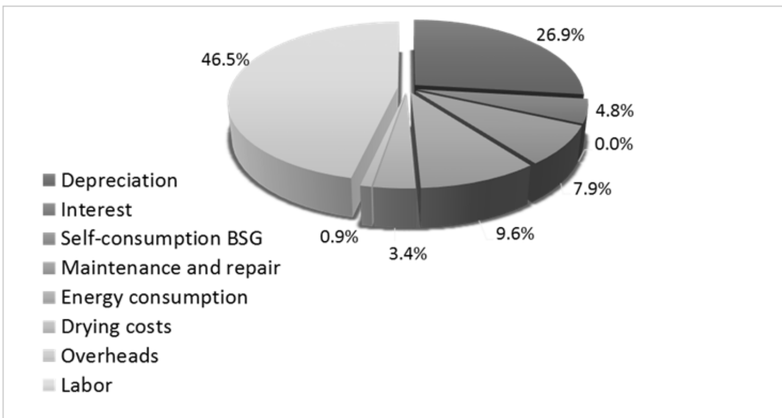

Figure 1: Percentage breakdown of annual operating costs of the small plant of pellets production in relation to 1,600 h y^{-1} of usage

Figure 1 shows the relative contribution of the single items on the managing costs of the pelletizing plant, whereas Table 2 shows the main elements and the costs calculated for three different levels of plant capacity utilisation. Calculated management costs pointed out that the production cost of the pellets obtained from BSG ranged from 140 to 115 and 110 € t^{-1}, with the most economically advantageous results relating to the more intensive usage of the pellet plant (2,400 h y^{-1}).

Table 2: Technical and economic elements considered and simulation of the production costs related to three level of annual usage of the plant (800, 1,600 and 2,400 h y^{-1})

Elements	**800 h y^{-1}**	**1,600 h y^{-1}**	**2,400 h y^{-1}**
Pellets production (t h^{-1})	0.20	0.20	0.20
Total installed power (kW)	30	30	30
Service period (h y^{-1})	800	1,600	2,400
Lifetime (years)	12	12	12
Pellets production (t y^{-1})	160	320	480
Plant costs			
Purchase price (€)	85,000	85,000	85,000
Salvage value (€)	12,750	12,750	12,750
Interest rate (%)	3	3	3
Management costs			
Depreciation charge (€ y^{-1})	6,021	6,021	6,021
Interest charge (€ y^{-1})	1,084	1,084	1,084
Biomass supply (BSG)	0	0	0
Maintenance and repair	1,771	2,833	5,667
Electric energy consumption (€ y^{-1})	2,160	4,320	6,480
Drying costs	752	1,504	2,256
Overheads (€ y^{-1})	200	200	200
Labor (€ y^{-1})	10,400	20,800	31,200
Production costs			
Total production costs (€ y^{-1})	22,388	36,762	52,908
Unit production cost (€ t^{-1})	140	115	110

In Figure 2, the results in terms of economic sustainability were reported. Considering as hypothetical economic reference the current wholesale and retail market prices for the lower quality categories, it is possible to highlight a discreet economic advantage for this specific activity. In the case of the difference between the retail prices and the unit production cost of pellets, an increasing economic advantage was showed, with values between 68 to 98 € t^{-1} in function of a higher use of the pellet plant, whereas, for the retail price, this difference is reduced to 25 - 55 € t^{-1} (Figure 2).

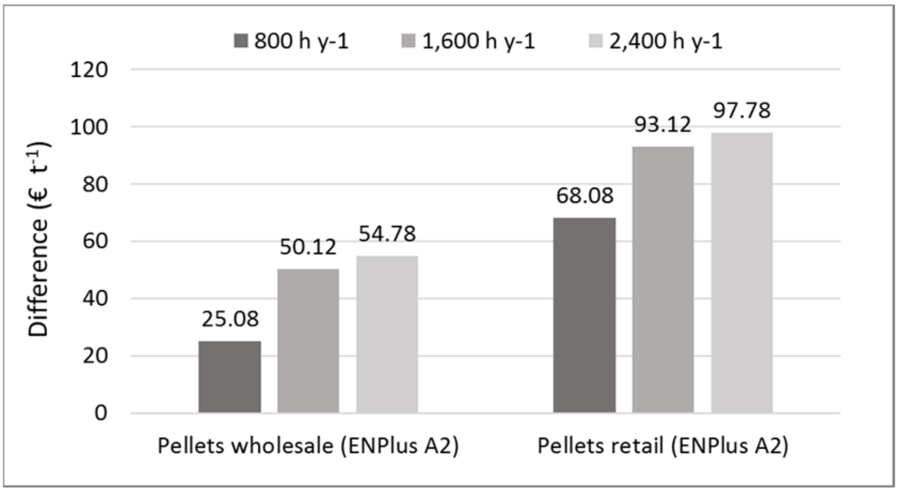

Figure 2: Economic difference between market price (wholesale and retail) and production cost in relation to different level of usage of the small pellet plant

BSG is a low-cost material produced throughout the year, whose primary application is chiefly tied to animal feeding. However, due to the chemical composition, a new approach to using BSG as a feedstock for carbonization has been explored.
In the present study, we evaluated the potential of dried BSG to be used as raw material at the temperature from 400°C to 500 °C and limited oxygen conditions to prepare biochar (BC) as a sustainable alternative in the use of spent grain. Biochar is defined as carbonised biomass obtained from sustainable sources and sequestered in soils to sustainably enhance their agricultural and environmental value. It is considered a good agricultural soil improver, with high content of carbon and nitrogen, able to promote water and nutrient retention, thus reducing the need of water and chemical fertilizers.
Morevoer, due to its adsorption ability, some biochars have the potential to immobilise heavy metals, pesticides, herbicides, and hormones; prevent nitrate leaching and faecal bacteria into waterways, reducing N_2O and CH_4 emissions from soils.
Figure 3 shows the preliminary results on the biochar production using both bulk spent grain and pelletized spent grain (Figure 4). Results pointed out no significant differences in terms of yield (18.6%, w/w) due to the different kind of BSG used. A further in-depth characterization of BC samples produced as well as their use as amendments in the hop cultivation is still on-going.

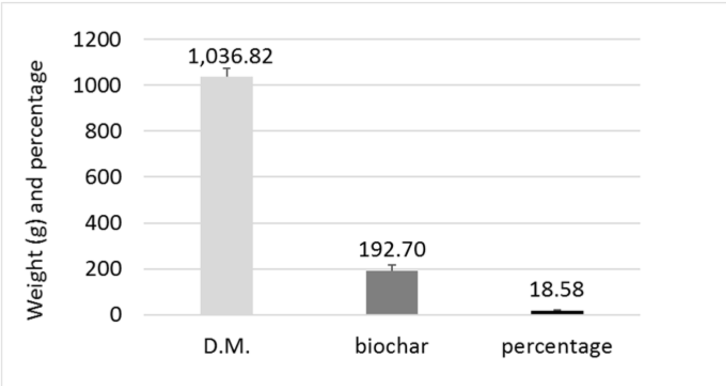

Figure 3: Biochar production from BSG (mean values and standard deviation)

Figure 4: Biochar production from BSG-pellets and bulk BSG

4. Conclusions

Brewers' spent grain (BSG) is the major by-product of the brewing industry produced throughout the year, which is currently not properly taken care of, both in environmental and economic terms. Besides, if valorised, this biomass can be an inexpensive source of bio-energy and valuable and innovative bio-products.
The present study has confirmed, from both a technological and economical point of view, the feasibility of using BSG as fuel for energy uses thanks to its content of carbon and hydrogen, which give it a good calorific value. The proposed model offers the possibility to achieve discrete benefits able to enhance the enterprise's economic balance, avoiding at the same time the problem of the disposal of this waste, which sometimes could represent an increase of costs for the microbreweries.

Acknowledgments

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