sustainability

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*Editorial*

# Sustainability: Recovery and Reuse of Brewing-Derived By-Products

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The great global challenge in order to achieve sustainable and inclusive growth over the coming decades is the promotion of the efficient use of resources, favoring a transition to a cleaner and circular economy. The exponential growth in demand for natural resources, in particular for raw materials, especially from developing countries and for a world population of 9.7 billion people expected by 2050, requires the adoption of policies and actions for sustainable consumption and production so that the needs of present and future generations can be met.

In this context, the reorientation of production processes by pursuing solutions towards "zero waste" operations, with subsequent closure of cycles, can strongly contribute to a reduction in agro-industrial waste, maximizing the conversion of feedstock and its by-products, side streams and residual streams into higher added-value products. To do this, industries must take action to make existing value chains more cost-competitive and create new, resource- and energy-efficient value chains, developing innovative processing steps, valorizing residual and secondary flows, obtaining different products and minimizing the disposal of their residuals in the environment.

Among all industrial processes, the brewing process has one of the greatest impacts on the environment due to the huge amount of waste it generates. In fact, for every 1000 tons of beer produced, about 10,000 tons of liquid and 137 to 173 tons of solid waste are created in the form of wastewater (about 10 L of water for 1 L of beer), spent grain (about 20 kg for 1 hL of beer), spent yeast (about 0.3 kg for 1 hL of beer), spent hops (about 0.3 kg for 1 hL of beer), germ/rootlets (about 3–5% of the total amount of barley) and unwanted material [1,2]. Considering that the world beer production was around 1.9 billion hectoliters in 2019 [3], the disposal of this waste represents a crucial management issue from both an ecological and an economical point of view. Landfill for solid wastes and disposal via sewage for liquid wastes are unsustainable and expensive options. For this reason, most brewing industries have adopted disposal options for their waste streams that are within their financial and geographical reach, often favoring their use as animal feed. Industries are interested in new solutions, and they are been adopting technological advances to reduce the amount of waste produced and to generate useful materials from brewing-derived by-products.

These by-products are heterogeneous substances, depending on cereal variety, time of harvesting, type of hops and yeast added, the malting and mashing regime, and whether adjuncts were employed during brewing [4]. Consequently, the reincorporation of these by-products into the production process as raw materials is strongly related to the chemical composition of the waste. A large amount of wastewater (about 48%) results from the cleaning and disinfection of industrial plants, and can contain residues of the cleaning agent system and waste alkalis and acids. The other part of brewery wastewater usually contains sugars, soluble starches, ethanol, volatile fatty acids and suspended solids [5].

Most of the solid wastes arise from the seed coat–pericarp–husk layers that covered the original cereal grain, and this represents insoluble components remaining after lautering, just before fermentation. The chemical composition of spent grain can vary. However, it is mainly constituted by lignocellulosic material rich in fibers (20–70%), proteins (19–30%), lipids (about 10%), minerals (2–5%), and vitamins and phenols (0.7–2.0%) [4]. Among the fibers, non-starch polysaccharides represent a variable fraction (30–50%) constituted mainly by hemicellulose (20–25%, consisting principally of arabinoxylan) and cellulose (12–25%, mainly made up of β-(1,4)-linked glucose residues) [4]. Another significant constituent of fibers is lignin (about 10–28%), characterized by a polyphenolic macromolecule of complex structure, important in maintaining the structural rigidity and integrity of plant cell walls [6]. Among the proteins, the most abundant are hordeins, glutelins, globulins and albumins, mainly consisting of histidine (26% of total proteins), glutamic acid (17% of total proteins), lysine (14% of total proteins) and leucine amino acids (14% of total proteins) [4]. Phosphorous (0.46%), magnesium (0.24%), calcium (0.22%) and silicon (0.14%) are minerals in spent grain. Regarding the vitamins, choline, niacin and pantothenic acid are the more abundant (1800, 44 and 8.5 ppm, respectively) [2]. Phenolic compounds, mainly ferulic acid, are a broad group that has recently attracted a lot of attention due to their antioxidant properties, and that are mainly found in the seed bran [7].

Spent brewer's yeast is an inactive yeast rich in fibers (non-cellulose carbohydrates 25–35%, cellulose 17–25% and lignin 8–28%), proteins (15–24%), minerals (5%), vitamins and enzymes. Among the non-cellulose carbohydrates, the main constituents are β-glucans, recently approved by the European Food Safety Authority (EFSA) as a new food ingredient with potential use suggested, which range between 50 and 200 mg per serving [8]. The most abundant amino acids found in proteins are alanine (9.29 g/100 g protein), arginine (6.00 g/100 g protein), aspartic acid (5.98 g/100 g protein) and cysteine (2.19 g/100 g protein) [9]. Spent yeast is abundant in sodium (about 1228 mg/100 g dw), potassium (91.5 mg/100 g dw), and calcium and magnesium (27.1 mg/100 g dw and 273.6 mg/100 g dw, respectively). Finally, only vitamins B3 (77.2 mg/100 g dw), B6 (55.1 mg/100 g dw) and B9 (3.0 mg/100 g dw) are found in considerable quantities [9].

Spent hops is characterized by higher proportion of fiber (22–23%), essential oils, lipids (4.5%), proteins (22–23%) and minerals (6–6.5%). In comparison with the other by-products, spent hops recovery is becoming increasingly important as it is a rich source of essential oil, mainly made up of sesquiterpene hydrocarbons (37%), monoterpene hydrocarbons (27%), non-terpene derivatives (18%), oxygenated sesquiterpenes (8%) and oxygenated monoterpenes (4%) [2].

Germ/rootlets form during the malting process (germination stage) and are removed during the kilning process by deculmer. The chemical composition of the germ/rootlets depends on the grain and germination conditions. They are considered a good source of protein, minerals, vitamins, polyphenols and selenium.

Being such a heterogeneous material, brewery by-products are very attractive for applications in food technology, energy production, agriculture, and chemical and biotechnological processes [1,10–19]. The advantages of reusing them include the reduction of organic wastes, contribution to environmental preservation, the preservation of bio-resources, the production of value-added foods at low cost, the production of molecules for reuse in food and pharmaceuticals or cosmetics, and the promotion of technological development. The recovery and reuse of brewing industry by-products to extract functional compounds and to develop innovative products is a good approach of circularity in this industrial sector from the perspective also of the food–health relation.

This Special Issue aims to develop valuable knowledge that will be useful for companies and to propose new value chains for converting brewery wastes into valuable products. This can provide companies with a novel alternative to value their main wastes, in a sustainable and profitable way. The application of green methodologies and low-cost processes can lead to the quick application of such process in industrial facilities. It can also open the door to the creation of new value chains and the production of new products (such as functional ingredients or extracts for cosmetic and pharmaceutical applications), which nowadays have high added value in the market, developing new revenue streams for the producers. At the same time, this Special Issue can provide a new perspective on:

- the reduction of the negative economic and environmental impacts of the disposal of brewing-derived by-products, reducing the production of $CO_2$;
- the development of land-efficient crops and the increase in the sustainability of the agricultural sector, by using spent grain and spent hops for agricultural applications;
- the creation of new ingredients with added value (health-promoting properties) compared with traditional ones commonly marketed as flavor enhancers, as a base for culture medium or as a protein source in animal feed;
- the development of innovative and modern industries and companies that are more in tune with the environment, potentially reducing the consumption of energy and materials;
- the environmental, economic and social impacts or benefits of implementation of such technologies and innovations.

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