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Some Alternative Strategies Applied to Brewery Spent Grains for the Development of Sustainable Recycling Solutions in the Agro-Food Industry

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Abstract: *Brewer's spent grain (BSG) is a raw material produced during beer production that has a high potential for sustainable reuse. BSG is considered an important feedstock for producing several products. Brewer's spent grain (BSG) is the main by-product obtained after wort production commonly used as animal feed. Recently research work has focused on application in different areas, because of BSG's low cost, large availability, and valuable chemical composition. Brewer's spent grain forms 85% of the total by-products generated.*

Of the breweries that produce potential by-products, their recovery is another cost-effective pollution prevention option that can provide a facility with significant economic benefits while simultaneously reducing waste production.

BSG water content is around 80 - 85 %. Dry BSG content has around 60-63% hemicellulose, cellulose, and lignin, protein content is around 22-25%, lipids 8-9%, phenolic compounds 1.7-2%, ash 2.5%.

In Albania spent grain is used as feed for animals without any other pretreatment. Our experiment is focused on spent grain pretreatment and stabilization techniques to extend BSG's life. BSG pretreatment/stabilization techniques can be employed as a function of their future destination such as energy production, food additives production, using BSG as a substrate for enzyme production, etc. In this paper, we have used three different pretreatment/stabilization procedures. Thin layer drying technique, alginate treatment of BSG, and vacuum filtration of BSG with cold and hot water. For each sample, we have monitored drying kinetics based on the remaining water content and BSG's life.

1. INTRODUCTION

Recently, many interesting and advantageous processes for the application of BSG in foods, energy production, chemical, and biotechnological processes have been reported (Arranz et al., 2018). The brewery industry generates enormous amounts of waste, the management of which is economically troublesome. Their accumulation in the environment is an ecological issue as well. The increasing public concerns about environmental pollution have prompted the search for ways to reduce the production of industrial waste. The food industry is trying to find new applications that will change the traditional approach to 'waste' products and make them 'co-products' (Rachwał et al., 2020). With their properties, by-products generated by the brewing industry have the potential to be applied as materials exploited in the food industry, but their use is still quite limited. Modern food science and technology aim to valorize the food industry

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by-products to produce chemicals, raw materials, and other value-added compounds (Rachwał et al., 2020). Although studies focused on the reuse of brewery by-products are being conducted, there are no comprehensive review articles concerning all three types of brewery waste showing its potential to be used in the food industry (Amoriello & Ciccoritti, 2021).

BSG is a raw material of interest for application in different areas, because of its low cost, large availability throughout the year, and valuable chemical composition (Mussatto, 2014).

Brewer's spent grain (BSG) is an insoluble solid residue obtained after wort production and is the most abundant brewing industry byproduct forming 85% of total byproducts generated. BSG for human consumption has gained attention, mainly because of its health-related bioactive components. These bioactive compounds include secondary metabolites, such as alkaloids, antibiotics, plant growth factors, food-grade pigments, and phenolic acids. BSG is considered also a source of phenolic compounds, particularly hydroxycinnamic acids (HCAs), which include ferulic, *p*-coumaric, sinapic, and caffeic acids. BSG is also considered a source of dietary fiber for humans, especially viscous fibers, which aid in increasing cholesterol and fat excretion (Ikram et al., 2017).

Several attempts have been made to utilize BSG in the production of value-added compounds (xylitol, lactic acid), microorganisms' cultivation, or simply as raw material for extraction of compounds such as sugars, proteins, acids and antioxidants BSG can be used as a substrate for enzyme production and could be one of the ways which substantially reduces the enzyme production cost (Mussatto, 2014).

Several methods have been proposed to prolong brewer's spent grain (BSG) storage time because of its high moisture content. Drying has been the most effective method of preserving BSG (Aboltins & Palabinskis, 2015). Drying as a preservation method has the advantage of reducing the product volume and decreasing transport and storage costs. There exist different techniques to decrease moisture content including pressing, rotary-drum drying, freeze-drying, thin layer drying, etc... (Mallen & Najdanovic-Visak, 2018).

The polysaccharide, protein content, and high moisture contents of BSG make it sensitive to microbial growth and degradation. The presence of resident microflora initiates these processes within the shortest time, to utilize it as the sole carbon source. This substrate is suitable to perform solid-state fermentations and submerge fermentations. BSG is a suitable medium for the isolation and maintenance of unknown strains and highly suitable for screening and production of new biologically active substances (Mitri et al., 2022).

To preserve the quality of BSG can be used also chemical preservatives such as lactic, formic, acetic, benzoic acid, and potassium sorbate.

2. EXPERIMENT

2.1. Expected Achievements and Benefits

We intend to set up a chemical/physical pre-treatment stabilization method to reduce the perishability of BSG. We intend to compare three pretreatment techniques and propose the most suitable technique to reuse BSG in the food/feed industries.

2.2. Characterization of Raw and Stabilized Materials

Collection of BSG samples was carried out by "Stefani & Co.", a brewery situated in Tirana. Solid waste produced by this brewery is summarized in Table 1. Spent grain is the most abundant waste followed by yeast. Spent grain in this brewery goes for animal feeding. Despite this, a pretreatment and stabilization procedure are needed to ensure a safe and long-life product.

In this paper, we have proposed and compared three pre-treatment/stabilization methods. Regarding their final moisture content and BSG's life, we are going to propose one of the most suitable methods.

Breweries produce potential by-products; their recovery is another cost-effective pollution prevention option that can provide a facility with significant economic benefits while simultaneously reducing waste production. The most important by-products come from brewhouse and fermentation stages.

- **spent grains**, which are used for animal feed.
- **spent hops, hot trub** and other solid proteinaceous materials are combined with spent grains and sold as animal feed.
- **yeast** (which can be collected from fermentation and storage tanks, and the filter line) is sold for animal or human consumption.

Table 1. Impact of Different Brewing Stages on Environmental Concerns

STAGE	ENVIRONMENTAL CONCERN
BREWHOUSE	High amounts of discharged organic matter (BSG) High water consumption High energy consumption Caustic and acidic wastes from CIP cleaning
FERMENTATION/STORAGE	High amounts on discharged of organic matter High water consumption High energy consumption Caustic and acidic wastes from CIP cleaning Yeast discharged. Solid waste discharge (trub) CO_2 emission
FILTRATION	High amounts on discharged of organic matter High water consumption High energy consumption Caustic and acidic wastes from CIP cleaning Solid waste discharge (trub)
PACKAGING LINES	High amounts on discharged of organic matter High water consumption High energy consumption Caustic wastes from cleaning Solid wastes handling High noise level
OTHER OPERATIONS	High water consumption High energy consumption Chemical and special waste handling Ammonia Solid wastes handling High noise level

Source: "Stefani & Co" Brewery, Tirana, Albania

Table 2. Solid Wastes Generated from "Stefani & Co" Brewery

STAGE	TYPE OF SOLID WASTE	GENERATION AMOUNT
BREWHOUSE	Spent grain (80% moisture) + Trub. Malt Dust Trub	16 kg/hl beer 0.12 kg / hl beer 0.004 kg / hl beer
FERMENTATION/CONDITIONING	Surplus yeast (90% moisture)	2 kg / hl beer
FILTRATION	Kieselguhr (70% moisture) PVPP (regenerable)	0.4 kg/hl beer
PACKAGING LINES / AUXILIARY MATERIAL	Glass (70 % recyclable) Plastic Paper Cans + Crowns Cardboard Wood	0,2 kg/hl beer 0,3 kg/hl beer 0,11 kg/hl beer 0,019 kg/hl beer 0,098 kg/hl beer 0,022 kg/hl beer
TOTAL	(kg/hl beer)	19,273

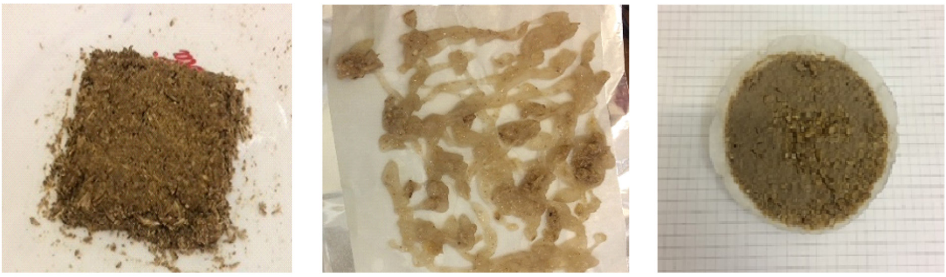
Source: "Stefani & Co" Brewery, Tirana, Albania

2.3. Pretreatment/Stabilization Methods

We intend to combine some different processing methods to extend BSG's life. In this paper, we have used three different pretreatment/stabilization procedures.

1. Applying pressing technology combined with thin layer drying technique.
2. Alginate treatment of BSG. After this procedure to prolong preservation time we can also use lactic acid treatment (alternative).
3. Vacuum filtration of BSG with cold and hot water.

For each sample, we have monitored drying kinetics based on remaining water content and BSGs.



BSG thin layer drying technique | Alginate Stabilisation method | Vacume filtration technique

Figure 1. Photo of BSG treated with different stabilization techniques

Source: Chemical Engineering Laboratory, FSHN, Tirana, Albania, 2023

Figure 2. Final moisture content measurements (3 g samples) made for each technique applied

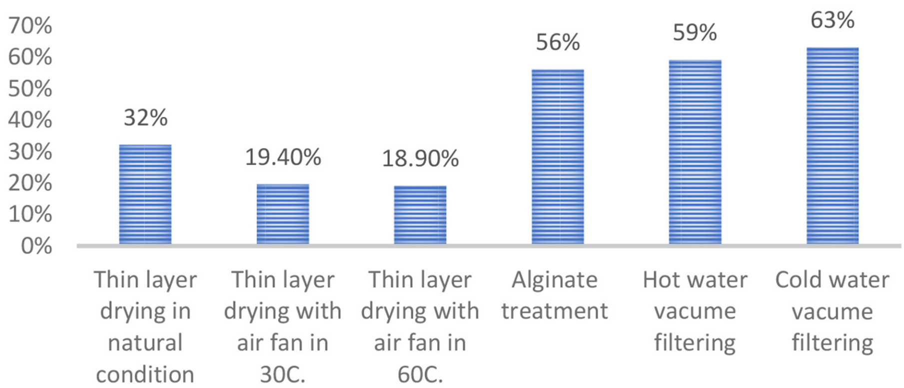
Source: Chemical Engineering Laboratory, FSHN, Tirana, Albania, 2023

BSG water content is a variation of brewhouse procedures, and the type of work produced in the brewhouse, BSG is around 80 - 85 %. Dry BSG content has around 60-63% hemicellulose, cellulose and lignin, protein content is around 22-25%, lipids 8-9%, phenolic compounds 1.7-2%, ash 2.5% (Stefani & Co brewery).

Table 3. Summarized experimental results taken after different stabilization methods applied

Stabilization method used	Final moisture content (Initial moisture content 82%)	BSG life
Thin layer drying in natural condition	32%	Around 3 weeks
Thin layer drying with air fan in 30^{0}C.	19.4%	No deterioration noticed after 2 months
Thin layer drying with air fan in 60^{0}C.	18.9%	No deterioration noticed after 2 months
Alginate treatment	56%	Around 2 weeks. The polymer creates a barrier pollution. Repeated lactic acid washing increases BSG life up to 7 weeks.
Hot water vacuum filtering	59%	3 weeks
Cold water vacuum filtering	63%	10 days

Source: Own research



Graph 1. BSG moisture contents after different pretreated techniques applied. Initial moisture content 82%

Source: Chemical Engineering Laboratory, FSHN, Tirana, Albania, 2023

2.4. Study of Thin Layer Drying Kinetics

The drying kinetics for BSG were conducted on aluminum foil trays where a drying fan device was used to remove the moisture. In regular intervals of time was measured by a digital balance sample weight loss. The thickness of the sample on each tray was around 1 cm and the air speed was around 1 m/s. The drying kinetics measured was the function of airflow velocities and temperatures applied (T = 30^{0}C and T = 60^{0}C).

Moisture ratio (MR) was found using the Fick's diffusion equation. As we can see from equation 1, the moisture ratio is a function of effective diffusivity (D_{eff}) (m^2/s), the characteristic dimension of the "thin layer" product (A), and the drying time (t). The linear form of this equation, (eq 2) allows us to find effective diffusivity and activation energy parameters. Effective diffusivity is a fundamental parameter in drying processes.

$$MR = \frac{8}{\pi^2} exp - \frac{\pi^2 D_{eff} t}{A^2} \quad (1)$$

Were, $A = \frac{mass}{density \times surface} = \frac{0.5}{589 \times 0.21} 0.004042\, m$

$$\ln MR = \ln\frac{8}{\pi} - \frac{\pi^2 D_{eff}}{A^2}t \quad (2)$$

The effect of temperature on moisture ratio was found based on the Arrhenius equation. The activation energy (E_a.) which is in our case the minimum energy needed to start the drying process is related to the Arrhenius equation with the effective diffusivity and temperature (eq 3).

$$D_{eff} = Kexp - \frac{E_A}{RT} \quad (3)$$

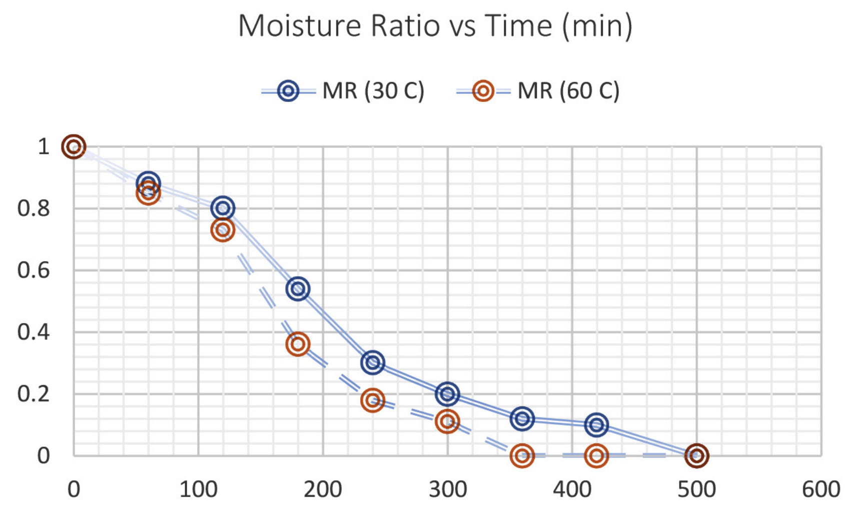
where:

K is a pre-exponential factor (m^2/s).

E_a is the activation energy of moisture diffusion (kJ/kmol).

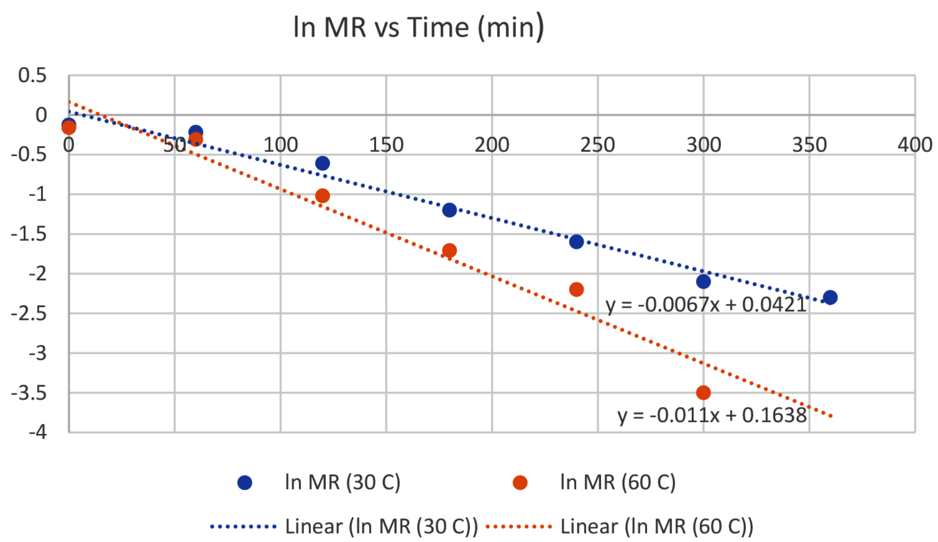
T is the absolute temperature of the air (K); R is the universal gas constant (8.314 kJ/(kmol K)).

Linear form of eq 3, allows us to determine pre-exponential factor and activation energy.



Graph 2. Moisture Ratio versus time for two different temperatures applied during thin layer drying procedures.

Source: Chemical Engineering Laboratory, FSHN, Tirana, Albania, 2023

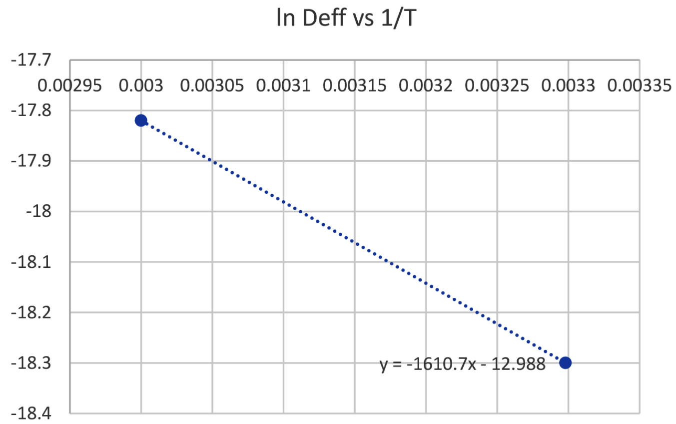


Graph 3. Linearization equations to calculate Effective Diffusion

Source: Chemical Engineering Laboratory, FSHN, Tirana, Albania, 2023

From linear equations in Graph 3, the slope is used to calculate effective diffusion.

$$D_{eff\ in\ 30C} = 1.1 \times 10^{-8} m^2 s^{-1}$$
$$D_{eff\ in\ 60C} = 1.81 \times 10^{-8} m^2 s^{-1} \quad (4)$$



Graph 4. Activation Energy calculation through the Arrhenius linear model
Source: Chemical Engineering Laboratory, FSHN, Tirana, Albania, 2023

Even though we have used only two different air temperatures it is obvious that effective diffusivity values are greater for higher temperatures. From the linear equation in Graph 4, we can calculate Activation Energy; E_a = 13.363 *kJ/mol.*

3. FUTURE RESEARCH DIRECTIONS

Our future research work will be focused on exploring and proposing innovative technologies in utilizing BSG in the production of value-added compounds (xylitol, lactic acid), microorganisms' cultivation, or simply as raw material for extraction of compounds such as sugars, proteins, acids and antioxidants.

We intend to make the identification of microorganisms associated with BSG useful for further fermentation approaches.

Further research will consist of the valorization of spent grains for the extraction of bio compounds and/or the use as integrators/ingredients of food products with nutritional added value.

We intend to explore and set up also new BSG fermentation process and characterization of BSG fermented products and propose the reuse of these products in the food/feed industries.

4. CONCLUSION

BSG stabilization techniques can be employed as a function of their future destination. The vacuum filtering technique can lower moisture content by up to 60%. If we need a longer BSG life it is good to use the hot water vacuuming technique. The alginate treatment method is remarkably interesting if we are interested in using BSGs as food additives for humans and animals too. Acid washing can be applied to extend BSG's life. Drying techniques ensure a long BSG life and could be a solution for further use as a biofuel.

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