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Optimization of the thin-Layer Drying of Brewers' Spent Grain to obtain a safe and Functional Food Ingredient

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INTRODUCTION & AIM

Brewers' Spent Grain (BSG) is the most abundant by-product of beer production; it is rich in fiber, protein, lignin and bioactive substances. However, this product has environmental and health risks due to its high initial moisture content and susceptibility to microbial contamination.

The objective of the work was to design a thin layer drying process of BSG that was coupled to the lethality evaluation of a pathogenic microorganism (***Bacillus cereus* spores**) in order to optimize the industrial treatment to provide a safe and functional ingredient.

Drying should be done immediately at a high temperature to avoid foodborne disease. The gradual cooling of the BSG causes a high risk of ***Bacillus cereus*** proliferation and toxin production.

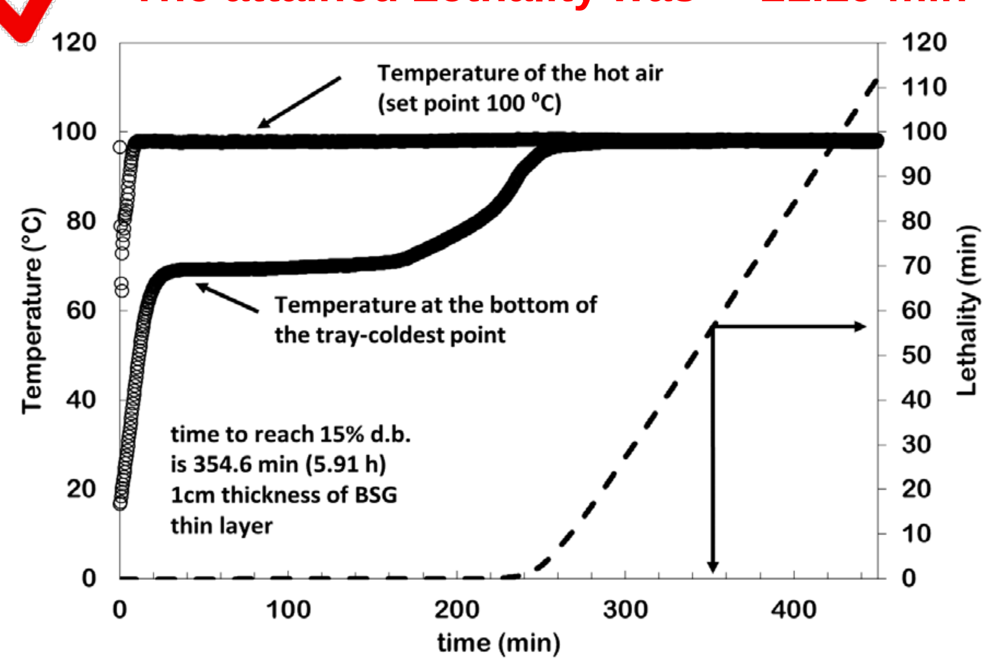
MATERIALS AND METHODS

Drying experiments were conducted using BSG with a high initial water content of 76.46 %, wet basis, varying the air temperatures (75–120 °C), and thin-layer thicknesses (0.75–1.3 cm). Mathematical modeling based on water vapor diffusion and Arrhenius kinetics enabled prediction of effective moisture diffusivity and drying times. The safety criterion was a minimum of 2-log reduction of ***B. cereus* spores**, based on thermal death time (F) calculations using literature values for D- and z-parameters. Simultaneous measurement of thermal histories, at the interphase between the bottom of the product layer and the hot surface of the dryer, allowed precise estimation of microbial lethality.

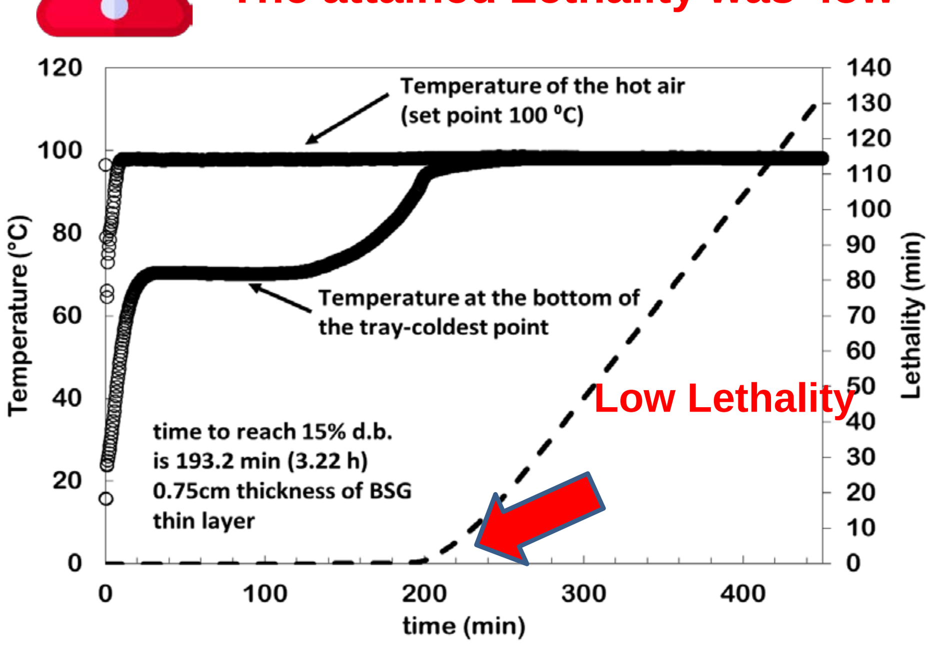
The process ensured compliance with the Argentine Food Code requirement of ≤13% final moisture (wet basis) in the product and a maximum of 10^3 CFU/g of *B. cereus*. Under optimal conditions (such as a treatment time of 5.9 h for 1 cm layer thickness at 100 °C) both, drying targets and microbial lethality were achieved. In terms of total phenolic content (TPC) and antioxidant activity (AC) the highest values were obtained at 120 °C; TPC 19.8 mg GAE/g dry matter, and AC using DPPH and ABTS were 20.9 and 17.6 mmol trolox/g dry matter, respectively.

Lethality > 21.19 min which achieves a minimum 2 log microbial reduction is achieved when the thickness values are 1-1.3 cm BSG ; these conditions require longer thermal treatment times.

The attained Lethality was > 21.19 min



The attained Lethality was low



RESULTS & DISCUSSION

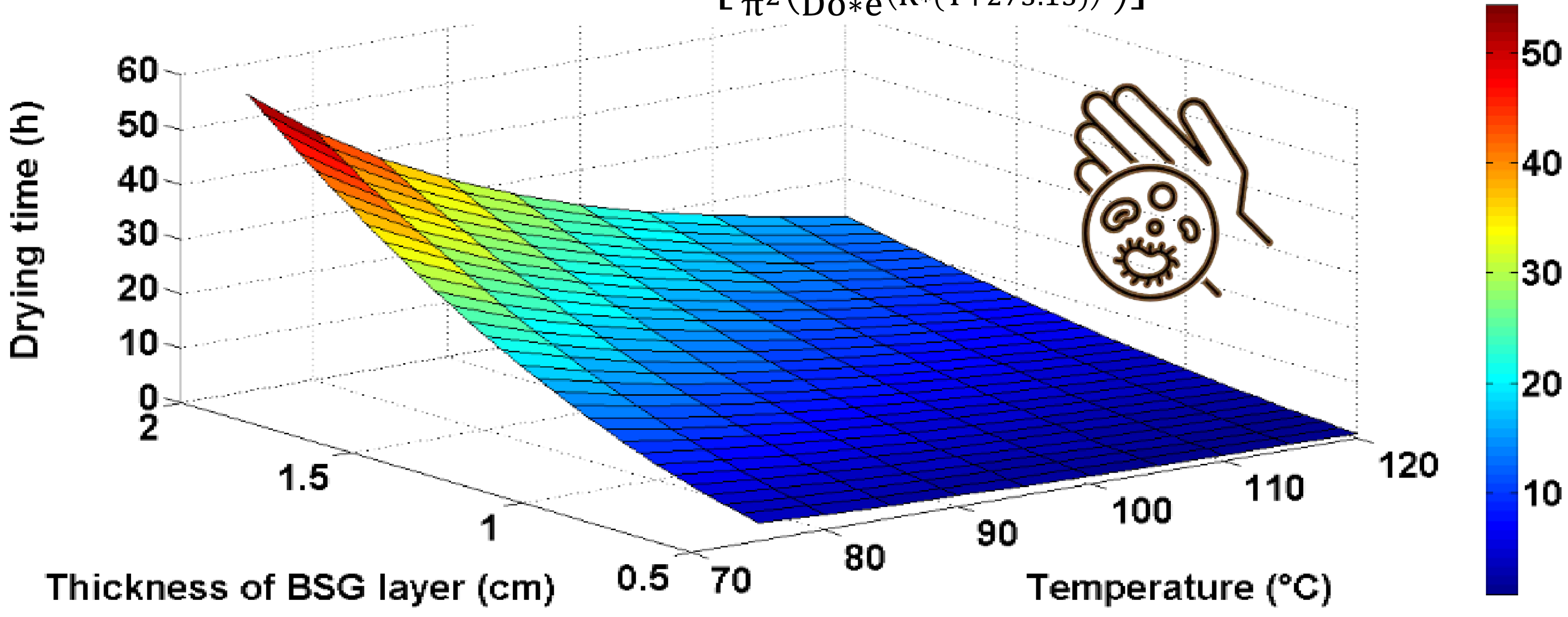
The drying curves of BSG in a thin layer at different conditions were experimentally obtained and mathematically modeled by the analytical solution of Fick's law; the effective diffusion coefficients of water (D_{eff}) at each temperature (Table 1), the activation energy of the process and pre exponential factor (Do) were calculated, Ea=34.773 KJ/(K mol) (standard error= 4.41) and Do=3.86 x10^{-4} m^2/s (standard error=5.57 x10^{-4}), with R^2=0.95.

Table 1. Effective diffusivity of water vapor at different temperatures considering Mr<0.6. SE is the standard error obtained for each parameter with the regression.

Temperature (°C)	D_{eff} (m^2/s)	SE (m^2/s)	R^2	RSS
120	8.56 x10^{-9}	7.61 x10^{-10}	0.801	4.84
105	6.40 x10^{-9}	5.30 x10^{-10}	0.798	11.13
90	4.36 x10^{-9}	5.39 x10^{-10}	0.709	7.91
75	2.13 x10^{-9}	2.61 x10^{-10}	0.639	1.86

This information enabled the determination of drying times as a function of the layer thickness and air-drying temperature to reach the maximum residual moisture content that assures product stability.

$$\mathrm{tdp\ (h)} = \mathrm{Ln}\left(\frac{8}{\pi^2\ \mathrm{Mr}}\right) * \left[\frac{4*(\mathrm{L}*0.01)^2}{\pi^2\left(\mathrm{Do}*e^{\left(\frac{-\mathrm{Ea}*1000}{\mathrm{R}*(\mathrm{T}+273.15)}\right)}\right)}\right] * \left(\frac{1}{60}\right)^2$$



where tdp is the drying process in hours, L is the BSG thin layer thickness in cm, Ea is in KJ/mol, R=8.31 J/K mol, D_0 in (m^2/s) and T in °C.

F required to reach 2 log cycles microbial reduction of *B. cereus* spores is 21.19 min (z=12.44ºC , Juneja et al., 2020).

Table 2. Accumulated lethality (min) of the drying process when the BSG thin-layer reaches a final moisture content of 13% (w.b.) for different i) external drying air temperatures, ii) thickness of the BSG layer, iii) z values found in literature for *Bacillus cereus* spores. Values of lethality that have gray background indicate that a minimum of 2D-log reduction was achieved during the drying process at the given conditions.

Thickness (cm)	Drying air temperature T (°C)	Accumulated Lethality (min) when 13% (w.b.) is reached.			Drying time to reach 13% (w.b.) (h)
		Z=7.63 °C	Z=8.53°C	Z=12.44°C	
	75	0	0	0.12	7.65
	90	2.37	3.47	9.84	4.57
	100	0.27	0.27	2.13	3.22
0.75	105	1.15	1.53	3.61	2.85
	100	**53.03**	**57.63**	**73.53**	5.91
1	120	**931.57**	**636.36**	**242.78**	3.27
	100	**110.46**	**119.60**	**149.36**	10.00
1.3	120	**14,696.98**	**8,468.60**	**1,987.41**	5.50

CONCLUSION

The proposed method provides a scientifically validated drying process for BSG promoting its use as a functional ingredient. It represents a sustainable approach aligned with circular economy goals.

References

Juneja, VK, Osoria, M, Hwang CA, Mishra, A, Taylor TM (2020) Thermal inactivation of *Bacillus cereus* spores during cooking of rice to ensure later safety of boudin. LWT Food Science and Technology, 122, 108955. https://doi.org/10.1016/j.lwt.2019.108955.