New Application of Brewers Spent Grain for Food

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Contents

Summary

Brewers Spent Grain (BSG) is a side stream from beer production which is currently largely valorised for animal feed. Alternatively, it could also serve as a food ingredient; with an eye on nutritional value (relatively high content of dietary fibre and protein) it is considered a healthy food ingredients for western diets. Indigo / MaGie Creations is a start-up and intends to initiate the production of a food ingredient (first intended application: bread) from BSG. It creates additional value for the products in which this is added and it will reduce the food waste in Brewery and reduce use of grain for produce bread. With financial support of a Voucher from the Ministry of Agriculture, Nature and Food Quality a project was started to select the possible ways of collecting the BSG, to select a drying technology, to investigate the food safety of the process of collecting and drying, to analyse if the process is economically feasible and carry out an analysis on sustainability.

After the technological options and effects on microbiological and economic feasibility and sustainability effects have been investigated for the use of BSG as an application as an ingredient in food, it is concluded that it is quite possible under certain conditions. Those are collection on a food-safe method, transport and process it either warm above 60°C of chill it rapidly before transport, remove water via a press, dry with a paddle or flash dryer and milling after drying to achieve an ingredient which can be used easily.
In sustainability analysis it was found that replacing wheat flour by dried BSG does contribute to net GHG emission reduction in food production, although the net saving is small compared to the total emissions. It also contributes to reduction of land use: using 1 kg BSG as food ingredient, replacing 1kg wholemeal flour, will free up 2 m2 farm land.

1 Introduction

Brewers Spent Grain, BSG, is a side stream from beer production which is currently largely valorised for animal feed. Alternatively, it could also serve as a food ingredient; with an eye on nutritional value (relatively high content of dietary fibre and protein) it is considered a healthy food ingredients for western diets.

Indigo / MaGie Creations intends to set up the processing and commercialisation of brewers spent grain (BSG) as a shelf-stable food ingredient. This plan (supported by 'The Hague's agenda for a circular economy') is described in a report 'Circulair Den Haag - Haags Bierbostel'. In line with this plan, Indigo / MaGie Creations intends to dry fresh BSG to a shelf-stable food ingredient.

Data on macro-nutritional composition and total microbial count for a wet and dry sample are available.

Wageningen Food & Biobased Research (WFBR) has plenty expertise on food processing technologies and their impact on the product, food processing side streams (like BSG), supply chain development, techno-economic assessment and sustainability analysis. These expertises are combined to explain effects of technology choices on technical, microbiological and economic feasibility and sustainability impact.

- Expert background knowledge and limited experiments were oriented on the following issues: choice of drying technology including:
    - dryer technology selection, supported by a drying test at a supplier
    - dryer dimensioning in relation to capacity, based on economic analysis
    - recommendations on dryer type (taking into consideration material properties and sustainability) and estimate of drying energetic efficiency
    - qualitative explanation of influence on product quality and/or nutritional value, with respect to stability and applicability in food
- microbial hazards and safety
- preservation of functionality and applicability of dried BSG (no physical determinations of functionality)
- scheme of the intended processing chain
- estimate of processing costs (OPEX and CAPEX) as function of processing volume, and including the distance between beer factory and BSG dryer
- estimate of GHG emission per kg dry material + comparison with replacement product in a typical application.

This report presents considerations on dryer selection Chapter 2; after that in Chapter 3 results of experimental work with a dryer and dried products are presented. Reflections on microbiological hazards are given in Chapter 4; techno-economic and greenhouse gas emissions analyses are presented in Chapters 5 and 6 respectively. Finally the findings are summarized in Chapter 7.

2 Drying

Drying processes and thus drying equipment is available in a wide variety. Depending on the qualities of the product to dry and the demands on the dried product, a selection must be made. Because BSG tends to stick and cluster, a first selection was made for a paddle dryer; other options will be discussed in chapter 4. It is good to realise that any dryer will be part of a process line that starts at extracting the BSG from the beer production process.
Because drying implies the evaporation of water, considerable energy uses are necessary for drying. Mechanical water removing, for instance by pressing or centrifuging the BSG, consumes far less energy and is therefore recommended as a process preceding the drying. BSG as it comes from the beer production is very wet and pressing to a much lower fluid/water content is well possible.

2.1 Overview of dryers

Drying processes and thus drying equipment is available in a wide variety. Depending on the qualities of the product to dry and the demands on the dried product, a selection must be made. Because BSG tends to stick and cluster, a first selection was made for a paddle dryer; other options will be discussed in chapter 4. It is good to realise that any dryer will be part of a process line that starts at extracting the BSG from the beer production process.
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2.1.1 The Andritz paddle dryer

In advance a paddle dryer is selected as being appropriate for drying of BSG. Andritz Gouda offers experiments at a pilot dryer; see the report of the experiments in Appendix 1. In advance there was doubt about the maximum temperature the BSG could tolerate before deterioration of the quality occurs, for instance browning or the formation of off tastes. From literature an upper limit of 60°C is known. Although the driving force for the drying comes from 3 bar(g) steam, 140°C, and the measured product temperature rises up to 100°C, no visual or sensory deterioration of the quality could be ascertained. Testing of this product by skilled cooks will give a final judgement on the quality and applicability.
After drying the BSG still has the original sizes; it contains the hulls of grains / barley. These large 'fibres' tend to stick between teeth and are therefore less favourable for application in human food. The dried BSG is therefore milled in a laboratory grinder, type IKA, with sieves with 2 and 0.5mm outgoing diameter. These milled BSG samples are applied for testing applications.

2.1.2 Alternative dryers

Test at pilot scale showed that the (Andritz) paddle dryer satisfies. Other suppliers also deliver paddle dryers. Alternative dryers should be considered especially with respect to the economy of the BSG reuse.
An alternative that is expected to satisfy as well is the flash dryer, the so called DMR offered by Hosokawa; see Figure 1 for its working principle. The incoming product is torn apart an partly milled by a rotating milling plate at the bottom of the drying chamber and the final dried product is selected before exhaust by a classifier. Test have not been performed but proper operation is expected, although no defined diameter is expected of the dried BSG from this process, thus a separate milling step may be necessary.

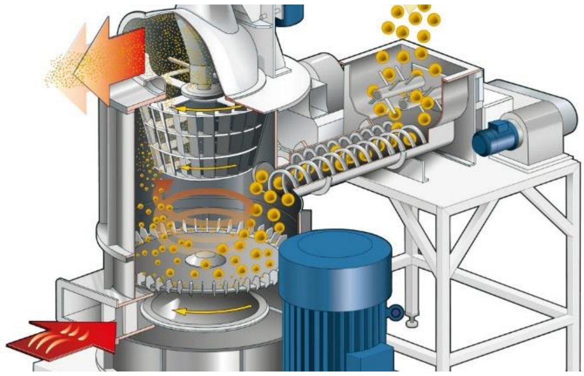

Figure 1. Hosakawa DMR dryer working principle

For any alternative dryer lump formation, that can occur with BSG and will hinder drying, should always be considered.
In Table 1 an overview of dryer types, their expected fitness for BSG drying and an indicative cost estimate.

Table 1. Overview of dryer types

Type of dryer	**Efficiency**	**Energy use per kg water evaporation**	**general**	**Suitability for BSG drying**	**Costs / economy**
	(%)	(kJ/kg)			(indication)
Paddle dryer	50 - 80	4800 - 3000			expensive
Belt dryer	40 - 60	6000 - 4000	Simple, robust	Risk of lump formation	cheap
Tunnel dryer	35 - 40	6950 - 6000	Simple, robust	High risk of lump formation	-
Fluid bed dryer	40 - 80	4000 - 3000		Risk of lump formation	moderate
Room dryer	40 - 60	6000 - 4000	Simple, robust	Risk of lump formation	Batch wise, much handling
Infra red dryer	30 - 60	8000 - 4000		1-sided drying. Risk of burning	moderate
Dielectric dryer	60 [1]	4000			expensive
Super Heated Steam dryer	> 100% with energy reuse	1500 - 3500	Limited availability and experience	possible	expensive

For the final dryer selection the throughput, operating hours and operator demand is very crucial.

2.2 Drying as part of a process line

Figure 2 shows a schematic BSG process line including drying.

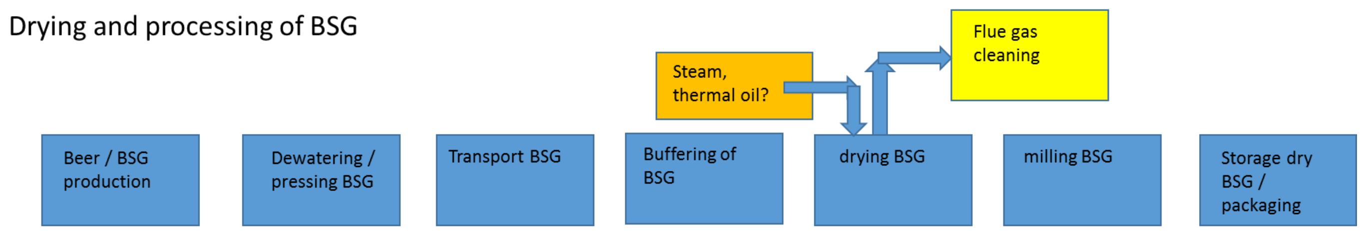

Figure 2. Processing line diagram for production of dried BSG powder from fresh BSG

Because of the perishability of BSG a direct coupling between the wort kettle at the brewery, where the BSG comes from, and the drying process line is strongly recommended. Because the BSG comes available periodically, a short in-between storage before entering the continuous drying process line will be necessary. As a mechanical dewatering is recommended, this can be installed before the storage making the stored BSG less heavy, voluminous and less perishable.
Laboratory tests on fresh BSG showed that pressing can reduce the moisture content from 75 to 43 to 31%, depending on the pressure and pressing time. For industrial equipment the exact pressing efficiency must be determined.

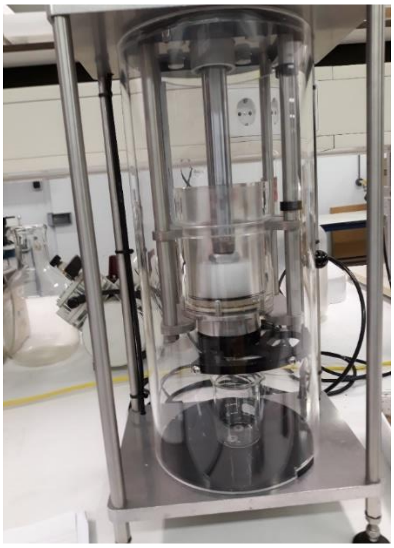

Figure 3 Laboratory pressing equipment

For dewatering/pressing electricity is needed, for drying electricity and a heat source like steam, thermal oil or electricity. These ‘utilities’ must be present.

A drying process will always have an exhaust to vent away the evaporated water to the environment. In principle exhaust gas cleaning is necessary because the exhaust air will contain dust and maybe some volatile smelling elements. The paddle dryer tests showed very little exhaust of dust from this drying process. A simple bag filter or wet scrubber is certainly appropriate (can also be used for the exhaust of the grinder).

3 Experiments with a paddle dryer

Pilot test trials have been executed with the ANDRITZ Gouda Paddle Dryer 10 (GPD 10) with brewers spent grain. The aim was to achieve a more sustainable way to use the spent grain by making it suitable for human consumption. The BSG was supplied on the day preceding the tests and in this case the BSG originates from the Gulpener brewery located in Gulpen The Netherlands. The product was collected in plastic drums, transported in a refrigerated truck and kept refrigerated until the start of the test.

3.1 Objective

The objective of the tests was to reduce the residual moisture content from approximately 75% to 6-2%, preferably with the product temperature below the 70ºC.

3.2 Results

In the test, the product is being fed into the dryer continuously, while monitoring the temperature profile along the dryer length. This indicates the heating up curve of the product. A continuous mode test typically consists of three residence times, the first is used to fill the GPD using a calculated feed rate based on initial information like moisture content, bulk density and other product specific properties. The second residence time is used to stabilize the process in the GPD. The third residence time is used to confirm the process parameters and sample taking.

During the tests, the following data were collected:

- feed product parameters (moisture content, temperature, bulk density)
- end product parameters (residual moisture content, temperatures, appearance and colour, bulk density)
- process parameters (heating medium temperature / pressure, holdup inside the dryer)
- capacity of the product

The product has no plastic phase. There is slight encrustation visible in the beginning of the GPD but this is refreshed by new product. The product build-up does not pass 30% of the trough length. After 50 minutes, the dryer started to discharge the product and the product temperature at the outlet was 100°C and the product bed level is not stable. After 60 minutes the product bed is level and stable. After 180 minutes the test is stopped and samples are taken for moisture analysis. After deliberation with the customer is was decided to run the GPD with the same settings and produce additional sample material for the customer.
The customer tasted the dried product and approved the taste. There was some discoloration of the product.
The collection of surplus material came to an abrupt stop due to a foreign object blocking the GPD after 260 minutes.
Inspection of the paddles showed that there was slight encrustation visible in the first part of the GPD but this needed hardly any force to be removed.

3.3 Conclusion

Testing with the ANDRITZ Gouda Paddle dryer has proved that the product, Brewers spent grain, as tested at the ANDRITZ Gouda pilot plant located in Waddinxveen, provided by the customer is suitable for drying with the GPD technology.
The product provided by the customer can be dried with little to no taste degradation.

The results with different spent grain samples can vary because these results are largely subject to variance in sugar content in the product.
The slight encrustation is refreshed by new product and is easily removed.
Using the data collected during the test the K-value is 188.7 W/m2.K.
Temperatures exceeding 150ºC have not been tested. If higher temperatures will result in increasing encrustation of the shafts and product taste degradation will have to be tested to conclude on.

4 Microbiological assessment

In this paragraph, we describe the microbiological hazards of brewers spent grain (BSG), which is processed as soon as possible after release into a dehydrated product suitable for human consumption. We also describe which critical points during the production process are present. We assume the following aspects:
• Implementation of good manufacturing practices (GMP) and presence of HACCP
• Use of ingredients suitable for human food
• Heating of the final finished product for consumption (for example, the dehydrated beer grains are processed into bread that is still baked). Expert-judgement on preservation of functionality and applicability of dried BSG (no physical determinations of functionality)

Microbiological hazards of BSG spore-formers of pathogenic micro-organisms that survive the beer brewing process. Specifically, these include fungi and bacteria that can form spores, such as Fusarium spp., Aspergillus spp., Penicillium spp., Alternaria, Bacillus spp. (including *Bacillus cereus*) and Clostridium spp. (including *Clostridium botulinum* and *Clostridium perfringens*).

Intended process: the BSG coming from the brewer's chain will have a temperature of 80°C or higher and will be dehydrated as soon as possible.

By keeping the temperature of the brewing above 63°C, pathogenic spores will not germinate and grow and thermophilic lactic acid bacteria cannot acidify the product. At temperatures of 63-70°C, the non-pathogenic spores of *Geobacillus stearothermophilus* and *Desulfotomaculum nigrificans* may germinate and grow and possibly spoil the product. At slightly less high temperatures (57-62°C), growth of Bacillus species (such as *Bacillus amyloliquefaciens* and *Bacillus coagulans*), *Thermoanaerobacterium thermosaccharolyticum* and thermophilic fungi can occur. At temperatures below 57°C, growth of even more microorganisms, including pathogenic spore-formers [such as *B. cereus* (see Figure 4 below), *C. botulinum*, *C. perfringens* (see Figure 5) and toxin-producing fungi] may occur.

Critical points: The temperature of the BSG. Temperatures below 63°C, but above 57°C are likely to be maintained for several hours. It is strongly advised not to let the temperature drop below 57°C due to possible growth of pathogenic micro-organisms. Temperatures of the grains below 57°C can therefore also be tolerated for a maximum of 2 hours, provided the BSG has been no longer than a few hours at temperatures between 63°C and 57°C. Monitoring the temperature until the brew is dehydrated is essential.

To obtain a completely microbiologically stable dehydrated product at room temperature, the water activity (a_w) should be 0.50 or less (to prevent the growth of xerophilic fungi). During storage, the product must be prevented from absorbing moisture.

Note: if the dehydrated product does not undergo further heat treatment, contamination by micro-organisms (such as pathogenic viruses, Salmonella spp. and Listeria monocytogenes) must be prevented.

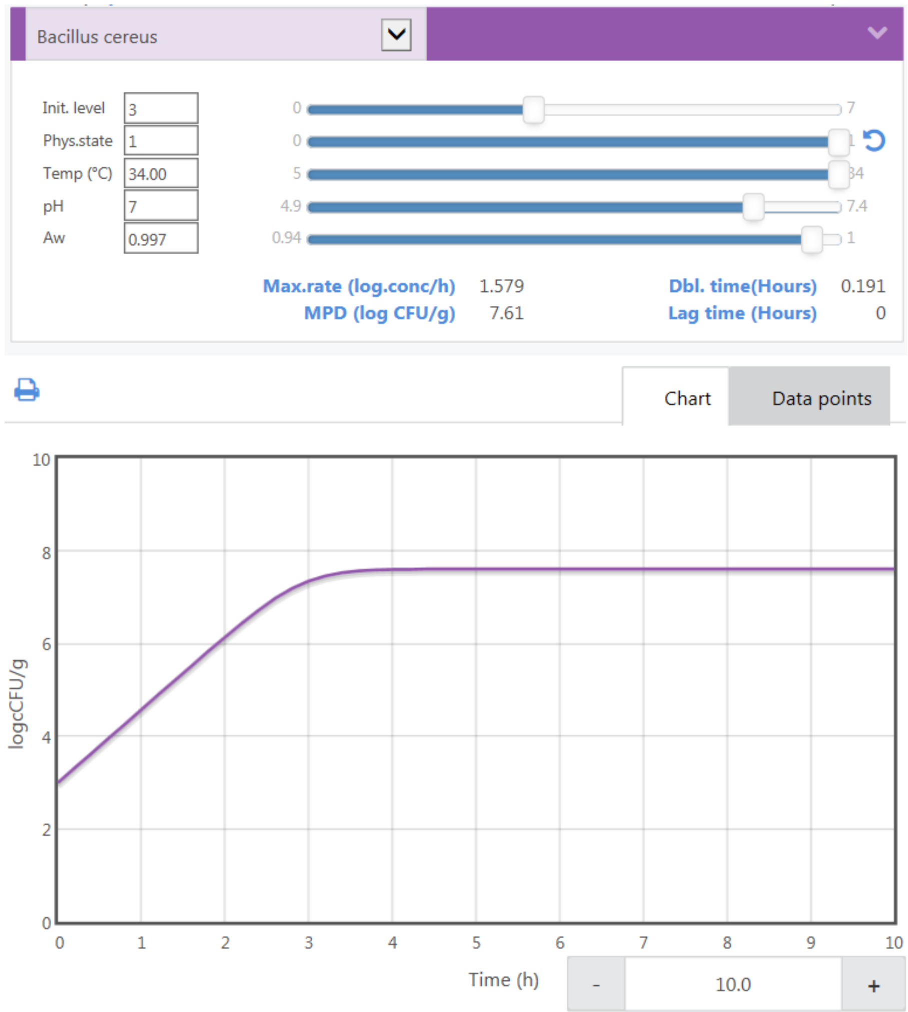

Figure 4. Predicted growth of Bacillus cereus at 34°C (optimum growth temperature and maximum temperature use for modelling) in liquid medium, enriched with nutrients Source: ComBase (modulated on 10 juli 2019)

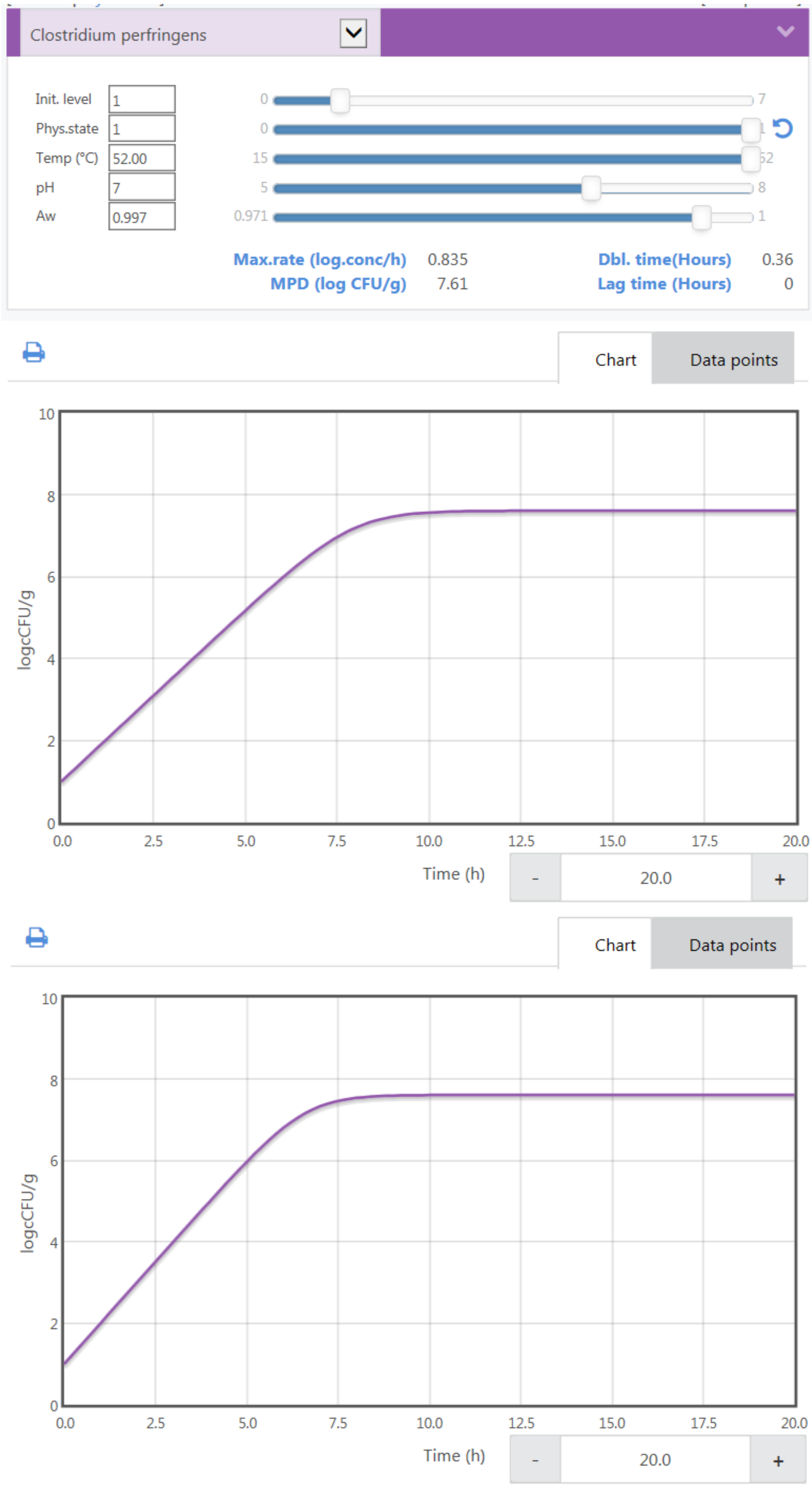

Figure 5. Predicted growth of Clostridium perfringens at 52°C (maximum temperature to model, upper graph) and 45°C (optimum growht temperature, lower graph) in liquid medium, enriched with nutrients. Source: ComBase (modulated on 10 juli 2019)

5 Techno-economic analyses

To estimate the production costs of using BSG for food application the operational expenditure (OPEX) and capital expenditure (CAPEX, aka fixed capital) were determined based on the results of the experiments carried out with the paddle mixer and estimations of purchase and selling the BSG. The approach is shown in Figure 6.

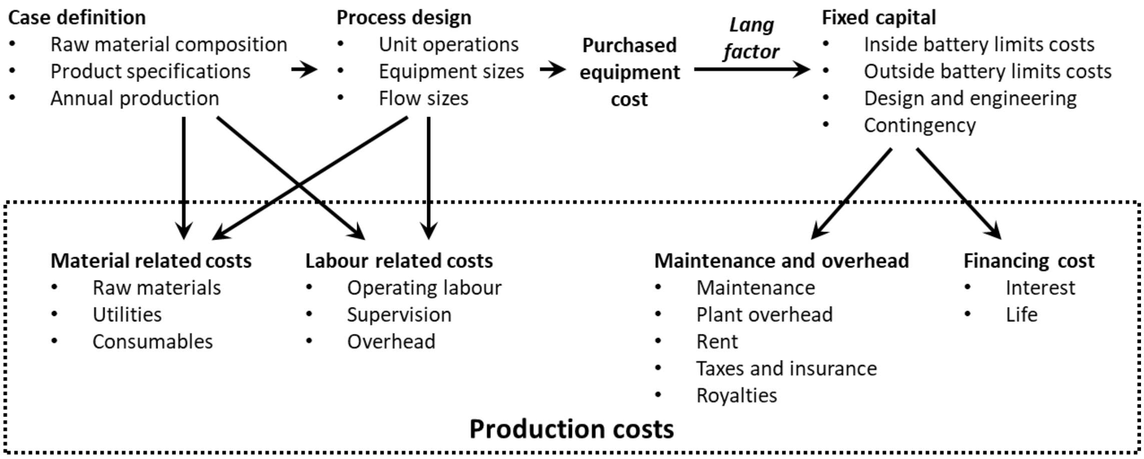

Figure 6 Approach of estimating the production costs

Two different scenarios are analysed: one without a press, and one with a press to remove a part of the moisture which is present in the BSG. The press increases the dry weight from 22% to 36%, approximately half of the moisture is removed by the press. The press increases the purchased equipment and CAPEX.

The estimated production costs are used to calculate the economic indicators: average cash flow, simple pay-back period, net present value (NPV), and internal rate of return (IRR). An interest rate of 2.1%,a tax rate of 35%, and the MACRS 5 years depreciation method are used in the calculation of the economic indicators. The used raw material costs are € 30/ton BSG and the product price is estimated on € 0.85/kg dried spent grain. All assumptions of the techno-economic analyses are given in Annex 1. An overview of the techno-economic evaluation is given in Table 2. The economic indicators are after tax and based on a 10 year period.

Table 2. Overview of TEA

		without press	with press
Spent Grain	(kg/h)	3850	6311
	(ton/y)	30800	50492
	(%DW)	22%	22%
Pressed Spent Grain	(kg/h)		3850
	(ton/y)		30800
	(%DW)		36%
Dried Spent Grain	(kg/h)	892	1462
	(ton/y)	7133	11693
	(%DW)	95%	95%
Purchased equipment costs	(k€)	1996	2328
Capital expenditure	(k€)	7982	9313
Main product revenue	(k€/y)	6063	9939
Raw material costs	(k€/y)	924	1515
Utility costs	(k€/y)	881	733
Labour reated costs	(k€/y)	446	446
Maintenance and overhead	(k€/y)	798	931
Cash COP	(k€/y)	3049	3625
Average cash flow	(k€/yr)	2344	4651
Simple pay-back period	(y)	3.4	2.0
Net present value	(k€)	13139	32541
Internal rate of return	(%)	30%	56%

Because of the relatively large revenue (i.e. high product price), both scenarios are profitable. The scenario with press is significantly more profitable compared to the scenario without press, because of the larger production capacity.

6 Sustainability analysis

In sustainability we compare the option of using BSG in bread to the reference situation (application for feed). The following effects should be adequately taken into consideration:

- When diverting BSG from animal feed to food application, the animal feed demand must be filled in through an alternative biomass. Since feeding value of BSG is largely based on the protein content, in the analysis we choose an obvious protein source for that: soy bean meal.
- The BSG derived food ingredient replaces wheat flour in the food application.
- No transport from the brewery to the dryer.
- Drying energy use: 1.3kg steam per kg water removed.
- Press energy use is small compared to the steam use, and therefore neglected.

GHG emissions analysis

Parameters used in the calculations:

- GHG emissions attributed to 1 kg soy bean meal: in literature values varying from 0.4 kg (Mogensen, 2011), 0.5 kg (Zgola *et al.*, 2016), 0.7kg (Cerri *et al.*, 2017; Dalgaard et al., 2008) are found (all excluding post-harvest transport; differences due to region of sourcing, and whether or not to include land-use-change effects in consideration). Transport to Europe may add up to 0.4 kg CO2-eq. per kg soy bean meal. We choose a typical value: 0.9 kg CO2-eq. per kg soybean meal (agricultural production + ocean transport).
- Replacement ratio in feed (based on protein content): 2:1 (soybean meal: 0.47kg protein/kg; BSG: 0.285 kg protein/kg, based on CVB Veevoedertabel)
- GHG emissions attributed to 1 kg wheat flour: 0.77 kg CO2-eq. per kg flour (see Appendix).
- GHG emissions steam generation 0.166 kg CO2 eq. per kg steam.

Net result of upgrading 1kg BSG to food (dry product basis):

- requires 0.5kg soybean meal in feed: +0.45 kg CO2-eq.
- requires evaporation of about 1kg water: +0.22 kg CO2-eq.
- prevents use of 1kg wheat flour: -0.77 kg CO2-eq.

Result: net reduction of 0.10 kg CO2-eq per kg BSG food ingredient.

It is concluded that replacing wheat flour by dried BSG does also contribute to net GHG emission reduction in food production, although the net saving is small compared to the total emissions.

Analysis of effect on land use

Analysing impact on land use is more fuzzy than GHG emission effects calculation. This is due to the fact that replacement products (see above) are derived from different continents: when transferring usage as feed to bread ingredient, wheat which is mostly derived from Europe would be replaced by soy from another continent. There's one country that we import both products from in substantial volumes: the USA. Therefore we use production yields from USA, based on FAOSTAT (http://www.fao.org/faostat/en/#data/QC, average for 2016 and 2017):

- soybeans: 3.4 ton per hectare, that is 0.34 kg per m^2.
- wheat: 3.3 ton per hectare, that is 0.33 kg per m^2.

Like in full LCA we use a price-allocation to indicate land use to soybean meal (the beans are separated in oil and meal). Rules of thumb: the total oil value is equal to the value of the meal; 1 kg bean gives 0.73kg meal (https://odells.typepad.com/blog/an-explanation-of-the-soybean-crush.html).

Calculation of land use change due to extracting 1 kg BSG from feed:

- Replacement product: soybean meal, volume: 0.5 kg (see above).
- Meal to beans ratio is 0.73:1.00. Thus for 0.5kg meal 0.5/0.73 = 0.68 kg soybeans are needed.
- Only half of soybean value is allocated to the meal; the other half is allocated to oil. Thus, half of 0.68, that is 0.34 kg, soybeans are allocated to the feed demand.
- 0.34kg soybean is produced on $1m^2$.

Thus, when 1kg BSG is used as bread ingredient instead of traditional use in feed, 1 m^2 land extra is needed for the replacing soybean meal.

Calculation of land use change due to preventing wheat in bread related to 1 kg BSG:

- Replacement product: wholemeal wheat flour, volume: 1kg (see above).
- wholemeal flour:wheat ratio is 1:1
- 1 kg wheat is produced on 3 m^2.

Thus, when 1 kg BSG is used as bread ingredient instead of traditional use in feed, 3m^2 less land is needed for the growing the traditional ingredient wheat.

Net result: use of 1 kg BSG as food ingredient, replacing 1 kg wholemeal flour, will free up 2 m^2 farm land.

Effect on nitrogen emissions to air

The Dutch government and agricultural sector aims to reduce nitrogen emissions from livestock through reducing nitrogen (mainly in proteins) content of feed. It is expected that especially protein-rich feed ingredients will be reduced; BSG only has moderate protein content, so we do not foresee a change in market attitude. It could become more attractive from this perspective, but this is still unclear.

7 Conclusions

In previous chapters technology options and effects on microbiological and economic feasibility and sustainability impact were presented. An integrated summary of the findings and recommendations:

- Compositional/microbial analyses of a few fresh samples has shown that these fresh products are food-safe, and when they sufficiently soon are treated through an adequate preservation treatment will result in a food-grade product.

- Storage (possibly in transport) for fresh material: Microbial growth reaches a maximum around 40°C. Hence, occurrence of such temperatures should be minimised. This can be achieved by either direct further processing, rapid cooling to low temperature regime or keeping high product temperature (preferably above 60°C). (In the current animal feed chains, the product's pH is reduced - through auto-fermentation or acidification - to make it stable at ambient temperatures; this option is not preferred for food application because it may affect product perception).

- Pre-processing: Through pressing, a significant amount of water can be removed from the product (typically 50%). This step is relatively inexpensive, though may still be relevant because of required investments; energy use is low compared to the alternative of evaporating the water.
  Disadvantage: the removed water fraction will contain some solids. This is a loss of material, and disposal as waste water will give to some additional costs.

- Drying: In the selection process of adequate drying process, specifically stickiness and lumping behaviour of the material is largely limiting the set of suitable technologies. Paddle and flash driers are considered suitable. From these, a paddle dryer was selected because of anticipated cost-benefit ratio.
  At temperatures above 60°C possibly the product is vulnerable to browning reactions and off-flavour development. However, in pilot tests, where temperatures up to 100°C occurred, these effects were not detected in the final produce.

- Milling: After flash drying the milling degree can be adapted to the final customer's preference. The paddle-dried product can be milled to any desired powder size (in contrary to flash drying that results in less defined or controllable particle sizes).

- In the spatial design of the processing chain principles of food safety, economies of scale and efficiency should be taken into consideration. This leads to the following recommendations:
  - Minimise the time between production and processing of the BSG.
  - However, with an eye on the common brewing process practice, fresh BSG will be generated batch-wise. Adequate storage conditions (see above) is recommended. Depending on the volumes and efficiency of transport, this storage may be either at the brewery or drying factory.
  - Economies of scale are small for pressing; with an eye on transport efficiency we recommend to consider applying this step at the beer brewery (thus prior to transport).
  - Drying processes are generally more sensitive to economies of scale; hence we recommend drying at one centralised location.
  - Transporting (either or not pre-processed) BSG to the central drying factory will have a significant effect on total cost price. Thus, notwithstanding previous points, it would be relevant to choose a beer factory that could fulfil all BSG input needs, so that the transportation step can be skipped.

- Sustainability: effects of replacing wheat by BSG in bread were analysed:
  - Replacing wheat flour by dried BSG does contribute to net GHG emission reduction in food production, although the net saving is small compared to the total emissions.

- Using 1kg BSG as food ingredient, replacing 1kg wholemeal flour, will free up 2m^2 farm land.

Estimates of volumes

Production of BSG in The Netherlands is estimated at 500 kton per year; thus the biggest breweries are estimated to produce at least 100 kton/year.
When aiming for 7 ton per year dry BSG product, only about 30kton BSG (wet basis) is needed, which certainly can be supplied by one medium to large-scale brewery.

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GHG analysis

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Annex 1 Techno-economic analyses

1.1 Scenario without press

1.1.1 Production costs

Operating hours	8000	h/yr
Spent Grain	3850	kg/h
	30800	ton/y
	22%	DW
Dried Spent Grain	892	kg/h
	7133	ton/y
	95%	DW

Raw material costs		
Brewers Spent Grain	30	€/ton
Utility costs		
Electricity	0.08	€/kWh
Steam	25	€/ton st.

Operating labour	100%
Supervision	25%
Direct salary overhead	63%
General plant overhead	122%
Labour related costs	309%

Shift positions	1	
Operators per shift position	4.8	
Operating labour costs	18	€/(operator·h)
	30	k€/(operator·y)
Labour related costs	446	k€/y

Lang factor (grass roots)	4.0	FC/PEC
Plant related costs	10%	of FC/y
Financing costs	10%	of FC/y

Budget Quotation Andritz		
Paddle dryer (GPD 17W300)		
Purchased equipment costs (PEC)	1663	k€
Specific steam consumption	1.3	kg/kg w.r.
Electrical power installed	175	kW

Other assumptions		
PEC buffer vessel, press, and grinder	20%	of dryer

PEC	2.0	M€
Fixed capital	8.0	M€

Processing costs		
Raw material	924	k€/y
Steam	769	k€/y
Electricity	112	k€/y
Labour related	446	k€/y
Plant related	798	k€/y
Financing	798	k€/y
Total	3847	k€/y
Raw material	0.13	€/kg product
Steam	0.11	€/kg product
Electricity	0.02	€/kg product
Labour related	0.06	€/kg product
Plant related	0.11	€/kg product
Financing	0.11	€/kg product
Total	0.54	€/kg product

1.1.1.1 Internal rate of return and net present value

k€/yr Project year	0	1	2	3	4	5	6	7	8	9	10
Capital expenditure	7982										
Revenue		6063	6063	6063	6063	6063	6063	6063	6063	6063	6063
Cash cost of production		3049	3049	3049	3049	3049	3049	3049	3049	3049	3049
Gross profit		3014	3014	3014	3014	3014	3014	3014	3014	3014	3014
Depreciation charge		1596	2554	1533	920	920	460	0	0	0	0
Taxable income		1417	459	1481	2094	2094	2554	3014	3014	3014	3014
Taxes paid		0	496	161	518	733	733	894	1055	1055	1055
Cash Flow	-7982	3014	2518	2853	2495	2281	2281	2120	1959	1959	1959
Discount factor	100%	98%	96%	94%	92%	90%	88%	86%	85%	83%	81%
Present value of cash flow	-7982	2952	2415	2681	2296	2056	2013	1833	1659	1625	1591
Net present value (k€)	-7982	-5031	-2615	65	2362	4417	6431	8264	9922	11547	13139

1.2 Scenario with press

1.2.1 Production costs

Operating hours	8000	h/yr
Spent Grain	6311	kg/h
	50492	ton/y
	22%	DW
	3850	kg/h
	30800	ton/y
	36%	DW
Dried Spent Grain	1462	kg/h
	11693	ton/y
	95%	DW

Raw material costs		
Brewers Spent Grain	30	€/ton
Utility costs		
Electricity	0.08	€/kWh
Steam	25	€/ton st.

Operating labour	100%
Supervision	25%
Direct salary overhead	63%
General plant overhead	122%
Labour related costs	309%

Shift positions	1	
Operators per shift position	4.8	
Operating labour costs	18	€/(operator·h)
	30	k€/(operator·y)
Labour related costs	446	k€/y

Lang factor (grass roots)	4.0	FC/PEC
Plant related costs	10%	of FC/y
Financing costs	10%	of FC/y

Budget Quotation Andritz		
Paddle dryer (GPD 17W300)		
Purchased equipment costs (PEC)	1663	k€
Specific steam consumption	1.3	kg/kg w.r.
Electrical power installed	175	kW

Other assumptions		
PEC buffer vessel, press, and grinder	40%	of dryer

PEC	2.3	M€
Fixed capital	9.3	M€

Processing costs		
Raw material	1515	k€/y
Steam	621	k€/y
Electricity	112	k€/y
Labour related	446	k€/y
Plant related	931	k€/y
Financing	931	k€/y
Total	4556	k€/y
Raw material	0.13	€/kg product
Steam	0.05	€/kg product
Electricity	0.01	€/kg product
Labour related	0.04	€/kg product
Plant related	0.08	€/kg product
Financing	0.08	€/kg product
Total	0.39	€/kg product

1.2.1.1 Internal rate of return and net present value

k€/yr Project year	0	1	2	3	4	5	6	7	8	9	10
Capital expenditure	9313										
Revenue		9939	9939	9939	9939	9939	9939	9939	9939	9939	9939
Cash cost of production		3625	3625	3625	3625	3625	3625	3625	3625	3625	3625
Gross profit		6314	6314	6314	6314	6314	6314	6314	6314	6314	6314
Depreciation charge		1863	2980	1788	1073	1073	536	0	0	0	0
Taxable income		4452	3334	4526	5242	5242	5778	6314	6314	6314	6314
Taxes paid		0	1558	1167	1584	1835	1835	2022	2210	2210	2210
Cash Flow	-9313	6314	4756	5147	4730	4480	4480	4292	4104	4104	4104
Discount factor	100%	98%	96%	94%	92%	90%	88%	86%	85%	83%	81%
Present value of cash flow	-9313	6185	4563	4836	4353	4038	3955	3711	3476	3404	3334
Net present value (k€)	-9313	-3128	1434	6271	10623	14661	18616	22327	25802	29207	32541

To explore the potential of nature to improve the quality of life

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