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RESEARCH ARTICLE

SCRUTINIZING THE OPPORTUNITIES, CHALLENGES AND SUSTAINABILITY OF BREWERS' SPENT GRAIN AS A FEED SOURCE FOR DAIRY CATTLE

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ABSTRACT

The current contribution of all agro-industrial by-products is merely 5% of the total livestock feed consumption. The brewers' spent grain (BSG), being a chief by-product from barley beer brewing has been acknowledged as a high-quality source of animal feed because of its richness in nutritional composition, being generated in bulk, low cost and being environmentally friendly. Inclusion of 25 - 30 % (DM basis) of BSG in dairy cattle feed rations can improve palatability, digestibility and dry matter intake (DMI) which in turn influence the dairy performances such as milk yield, milk composition and body weight. However, being bulky with substantial moisture content, there is a risk of mycotoxins contamination and additional transportation costs whilst limited knowledge by farmers regarding its utilization and nonexistence and/or weak regulations and standards being other impediments. To minimize the severity of the mentioned threats, several preservatives and quality control measures can be undertaken including feeding of fresh BSG, maintaining proper field and storage conditions, ensiling, the use of mycotoxin binders as well as the application of several drying and pressing techniques. This paper explores the nutritional aspects and the potential of BSG with emphasis on the performance of dairy cattle while also elaborating practical challenges related to the utilization of BSG and suggests useful quality control measures that can ensure its sustainability as dairy feed.

KEYWORDS

Brewers' spent grain (BSG); Feed supplementation; Dairy performance; Regulations; Mycotoxins contamination.

1. INTRODUCTION

The global livestock feed consumption is approximately 6.0 billion tons of dry matter (DM) annually, with the majority of the consumed materials being grass (46%), crop residues (19%) and grains (13%) (FAO, 2015; MacLeod et al., 2018). The contribution of all by-products including bran, molasses, beetroot pulp, and brewer's spent grain share only a 5% fraction (FAO, 2015). Among the major sources of agro-industrial by-products are brewers' spent grains (BSG), which the major constituents (85%) of all by-products from beer production with others being spent hops and spent yeasts (Lynch et al., 2016; Mussatto et al., 2006; Reis et al., 2014). The BSG is a lignocellulosic material that is rich in fiber content, crude protein, minerals, amino acids and lipids (Levic et al., 2010; Lynch et al., 2016; Mirzaei-Aghsaghali and Maheri-Sis, 2008). On an average dry weight basis, it consists of 70% fiber, 20% protein and nearly 10% lipids (Mussatto and Roberto, 2006). Approximately 20 kg of BSG is generated for every 100 litres of beer produced and with the current global production of 190 billion litres of beer per year, this corresponds to the production of 36 billion tons of brewers' spent grain (BSG) annually (FAO, 2015). With the current trend that designates an ongoing increase in beer consumption, this means more BSG will be available and also indicates more efforts should be made to maximize the most of its potential especially for developing countries where BSG less is utilized (Aliyu and Bala, 2011; Mirzaei-Aghsaghali and Maheri-Sis, 2008).

Traditionally, the BSG has quite a wide range of application ranging from a potential animal feed, food and nutrition industry, as a fertilizer source for agricultural production, environmental amelioration, pharmaceuticals, biofuels, and bioethanol production (Bolwig et al., 2019; Tišma et al., 2018). As animal feed resource, it is acknowledged to be affluent in protein content arraying between 20 - 30% CP (on DM basis), a good source of cattle's dietary fiber especially cellulose, arabinoxylan and lignin and but with little starch which is removed during the mashing stage of brewing (Kanauchi et al., 2001; Mussatto and Roberto, 2006; Russ et al., 2005). Moreover, it has abundant crucial mineral elements (e.g. Ca, Co, Cu, Fe, Mg, Mn, P, K, and Na), several vitamins and as well as both essential and non-essential amino acids (e.g. biotin, riboflavin, thiamine and choline) (Essien and Udotong, 2008; Kerby and Vriesekoop, 2017). Apart from being a nutritious feed resource for animals, the BSG is also readily available, produced in high volume and relatively inexpensive (Aliyu and Bala, 2011).

Having a considerable CP level, which is regularly a limiting macromolecule for dairy productivity, numerous studies have reported the influence of BSG in improving palatability, digestibility and dry matter

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intake (DMI) that in turn influence the milk yield, milk components, and body live weight (Belibasakis and Tsirgogianni, 1996; Firkins et al., 2002; Mirzaei-Aghsaghali and Maheri-Sis, 2008). Despite the regarded contribution of BSG, there is still a huge gap for its utilization in livestock feeding regimes globally. As reported by the BSG has been gaining more attention recently in some regions such as Europe and America (Nigam, 2017). However, for other regions such as Africa, literature indicate utilization of this resource as animal feed is less than 10%, with the majority of the rest end up in landfills with a high risk of environmental pollution (Aliyu and Bala, 2011). Therefore, the present paper briefly converses the BSG as a potential feed source by describing its production, the composition and its contribution in improving dairy cattle's performance. Additionally, this article meticulously elaborates on the challenges for utilization and sustainability of BSG while also proposing different and convenient preservation techniques that would ensure that this valuable feed resource contributes towards improved dairy production.

2. AN OVERVIEW OF BEER BREWING FROM BARLEY

With its total annual production of 190 billion litres, beer is the fifth most consumed beverage in the world apart from tea, carbonates, milk as well as coffee (FAO, 2015). Barley is globally the most commonly used ingredient in beer production with other components being adjuncts, hops, yeasts and water (Lynch et al., 2016). In the brewing process, the first phase known as malting involves the conversion of starch stored in barley grains into fermentable sugars (Kerby & Vriesekoop, 2017). The grains upon careful selection, cleaning, and grading are being soaked in water at low temperature (8 - 15^0 C) for 48 consecutive hours (Kerby & Vriesekoop, 2017; Varmam & Sutherland, 1994). Suitable conditions for germination such as humid air and elevated temperature (15 - 21^0 C) are subsequently provided for the next 7 days where the malting phase ends with malted barley, an important constituent in brewing (Kerby & Vriesekoop, 2017). The germination process breaks down barley's endosperm that is having high molecular weight into simple sugars. By drying up to 5% moisture content, the germination ceases since most of the enzymatic activities become inactive (Papageorgiou & Skendi, 2018). The quality of malted barley can be influenced by various conditions such as field conditions that barley is grown, genetic factors, handling as well as malting conditions especially the efficiency of germination process (Papageorgiou & Skendi, 2018; Rosentrater & Evers, 2017).

The second phase is known as mashing which involves malted barley being milled and heated in hot water (70 - 74^0 C) whereby a mixture of milled malt and hot water (mash) is left standing until the fermented sugars (mainly maltose and maltotriose) dissolve to form wort (Kerby & Vriesekoop, 2017; Varmam & Sutherland, 1994). At times, depending on the quality, colour or flavour of beer to be produced, several other cereal types, also known as adjuncts may be added (optional) into malted barley for wort elaboration and these may include oat, corn, rye, rice or wheat (Lynch et al., 2016). In this case, the resulting BSG produced will differ in chemical composition and this may eventually influence the animal when BSG is used as feed (Levic et al., 2010; Lynch et al., 2016). There is then a filtration process where liquid rich in sugar (wort) proceeds with subsequently brewing stages to produce beer while the rejected solid materials are known as brewers' spent grain and will be freed out as by-products (Ishiwaki, 1999; Levic et al., 2010; Lynch et al., 2016). From wort up to the production of beer, there are a series of procedures including sterilization, fermentation, heating with additional of other materials such as yeast, hops, and water (Ishiwaki, 1999). These brewing procedures involve the production of other by-products called spent hops and spent yeast with the two comprise approximately a total of 15% of all wastes from brewing (Mirzaei-Aghsaghali & Maheri-Sis, 2008; Mussatto & Roberto, 2006).

2.1 Spent Yeast

To facilitate the fermentation process in brewing, yeast cells, (*Saccharomyces cerevisiae*) which are single-celled organisms are incorporated with their responsibility of converting simple sugars (e.g. glucose and maltose) into ethanol and carbon dioxide (CO_2) (James et al., 2003). Being living cells they can undergo cell multiplication numerous times to create a mass of yeast cells compared to the levels presented initially. Huige, (2006) estimated the average spent yeast from big brewing companies to be 0.6 - 0.8 lb/bbl (UK pounds per beer barrel) of the final beer being produced. Spend yeast has been widely used in flavor addition in the human diet because of its nutritional benefits such as richness in minerals, abundant essential amino acids and B-complex vitamins (Kerby & Vriesekoop, 2017).

2.2 Spent Hops

Hops are flowers of a hop plant (*Humulus lupulus)* used in brewing as flavoring and stability agents (Zanoli & Zavatti, 2008). Spent hops are the least in volume by-product in beer brewing that is often removed in the wort production phase before the fermentation process commences. Unlike the BSG, the spent hops can be added or removed at different points in beer manufacturing (Ishiwaki, 1999; Kerby & Vriesekoop, 2017). Huige, (2006) estimated that about 85% of the hops added will eventually be removed as the by-product. Most of the studies done in European countries, especially in the UK, have indicated major means of spent hops disposal is for fertilizer or production of compost (Huige, 2006). This is because, with its bitterness in the taste, the hops are nearly impossible to be included with other feed rations or mixed with BSG as the strongly bitter taste may reduce feed quality and acceptability by livestock (Huige, 2006; Kerby & Vriesekoop, 2017). Moreover, spent hops are relatively more fibrous than BSG and the energy than can be derived by livestock is 50% less as that of spent grain (Kerby & Vriesekoop, 2017). There are however several promising experiments that have been done in producing insect repellents that come from oil extracted from spent hops (Maia & Moore, 2011).

3. CHEMICAL COMPOSITION OF BSG

3.1 Fiber Content

Principally, the BSG constitutes of three layers namely husk, pericarp and seed coat which predominantly help in protecting the barley grain (Lynch et al., 2016). While little starchy endosperm content might be present, the majority of BSG content is hence made of structured carbohydrates (cellulose, hemicelluloses, and lignin) that arise from the husk-pericarp-seed coat which can range between 60 - 70% of total DM of BSG (Aliyu & Bala, 2011; Lynch et al., 2016; Russ et al., 2005). The summarized nutrient levels (Table 1) from macro and micro brewing commercial companies globally indicate the richness of BSG in terms of the fiber content of up to 70%. As a major source of energy together with richness in crude protein, BSG is proving to be a potential for application as a feed source for livestock.

3.2 Crude Protein

Regardless of origin and conditions of the BSG produced, the majority of globally reviewed studies indicate significant levels of the protein that on average range from 20 - 30% CP (Robertson et al., 2010; Santos et al., 2003), as summarized in Table 1. Usually, the CP composition in BSG is higher compared to barley grains since there is digestion of starch fraction by amylase enzymes from what was present in the initial grain i.e. hydrolysis of starch during the germination process, in malting phase (Mussatto et al., 2006; Westendorf & Wohlt, 2002). Some recent findings have reported relatively higher CP content and this might be attributed to the genetic improvement of barley varieties (Westendorf & Wohlt, 2002).

3.3 Mineral Content

The BSG is also affluent with mineral elements. Among the common mineral elements that have been thoroughly studied include; calcium (0.2 - 0.6%), potassium (0.16 - 2.0%), phosphorus (0.4 - 0.6%), sodium (0.03 - 0.1%) and sulphur (0.27 - 0.33%). Besides, others such as zinc, manganese, iron, and copper have been observed in lower levels (Table 2). Apart from its convenience as livestock feed, the mineral content in BSG also valuable in agricultural productivity as it is useful in the production of compost as a fertilizer (Mussatto et al., 2006).

3.4 Amino acids

The essential amino acids present nearly 30 % of the total protein content in BSG with studies indicate some amino acids such as lysine can be as much as 14 - 15% (Levic et al., 2010; Waters et al., 2012) as seen in table 3. It is also common in Europe that some industrially produced amino acids including lysine and threonine being added together with BSG rations to improve the formulated diet (Nigam, 2017). There are however some reported cases of non-essential amino acids being abundant beyond actual demand by animals (Arvanitoyannis & Tserkezou, 2008). With glutamine and proline, the excess amino acids consumed release the non-utilizable nitrogen by which when this is excreted via urine can create environmental pollution especially with pigs (Arvanitoyannis & Tserkezou, 2008).

Table 1: The chemical composition of BSG (as % DM) from currently available literature

Cellulose	Hemicellulose	Lignin	Crude Protein	Ash	Starch	Lipids	Phenolics	Literature Sources
-	-	-	25.8 - 25.9	4.1 - 4.6	5.7 - 7.8	6.7 - 7.0	-	(Rosentrater & Evers, 2017)
21.7	19.2	19.4	24.7	4.2	-	-	-	(Meneses et al., 2013)
26.0	22.2	-	22.1	1.1	-	-	-	(Waters et al., 2012)
-	22 - 29	13 - 17	20 - 24	-	2 - 8	-	0.7 - 0.9	(Robertson et al., 2010)
31 - 33	-	20 - 22	15 - 17	-	10 - 12	6 - 8	1.0 - 1.5	(Kanagachandran & Jayaratne, 2006)
12	40	11.5	14.2	3.3	2.7	13	2.0	(Xiros et al., 2009)
0.3	22.5	-	26.7	3.3	1.0	-	-	(Celus et al., 2007)
16.8	28.4	27.8	15.2	4.6	-	-	-	(Mussatto & Roberto, 2006)
23 -25	30 - 35	7 - 8	19 - 23	4 - 5.5	-	9 - 12	-	(Russ et al., 2005)
25.3	41.9	16.9	-	4.6	-	-	-	(Silva et al., 2004)
21.9	29.6	21.7	24.6	1.2	-	-	-	(Carvalheiro et al., 2004)
-	-	16	31	4.0	-	3.0 -3.6	1.7 - 2.0	(Santos et al., 2003)
25.4	21.8	11.9	24	2.4	-	10.6	-	(Kanauchi et al., 2001)
13.32	31.79	4.88	25.94	3.65	-	6.08	-	(Arosemena et al., 1995)

3.5 Vitamins

The most common types of vitamins and their quantities (in ppm) as according to Mussatto et al., (2006) are biotin (0.1), choline (1800), folic acid (0.2), niacin (44), pantothenic acid (8.5), riboflavin (1.5), thiamine (0.7) and pyridoxine (0.7). Even though the vitamins are needed in relatively small quantity, they are presumed to be important in regulating body functions and promoting resistance against diseases (Jenkins & Hidiroglou, 1972).

3.6 Lipids

The majority of the studied BSG have indicated that lipid represents between 3 to 10% of DM content with a few cases of it constitutes up to 18% of DM (Table 1). A study done by Nigam, (2017) observed the predominant types of lipids in BSG being triglycerides (67% of total extract), with the other being a series of free fatty acids (18%) while also lower levels of monoglycerides (1.6%) and diglycerides (7.7%) were also quantified. Lipid content has brought considerable attention from the food industry especially in baked and flour products and its inclusion of up to 10% has been considered acceptable for human foodstuffs such as snacks, bread, and biscuits (Ainsworth et al., 2007; Nigam, 2017).

Table 2: The reported values of common mineral elements present in BSG

P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	S (%)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Literature Sources
0.57 -0.58	1.6 - 2.9	-	-	-	-	83 - 89	130 - 138	-	14 -19	(Rosentrater & Evers, 2017)
0.6	0.6	0.36	0.19	0.13	0.29	82	154.9	40.9	11.4	(Meneses et al., 2013)
0.46	-	0.22	0.24	-	-	-	-	-	-	(Waters et al., 2012)
-	-	0.35	1.958	0.039	-	-	-	-	-	(Mussatto & Roberto, 2006)
0.68	0.16	0.35	0.23	0.04	0.33	97	207	50.3	8.34	(Westendorf & Wohlt, 2002)
0.64	0.31	0.23	0.26	0.035	0.27	88.4 - 93.9	123.4 - 138.4	48.7 - 49.4	10.6 - 17.4	(DePeters et al., 2000)
0.44	0.11	0.27	0.28	0.03	-	-	148	50	24	(Arosemena et al., 1995)
0.51	0.79	0.65	-	-	-	-	-	-	-	(Cozzi & Polan, 1994)
0.4	3.4	0.40	0.48	-	-	-	-	-	-	(Mbagwu & Ekwealor, 1990)

Table 3: The common amino acids present in BSG expressed as a percentage of total protein

Classification of Amino Acids		(Waters et al., 2012)	(Cozzi & Polan, 1994)	(DePeters et al., 2000)	(Rosentrater & Evers, 2017)	(Robertson et al., 2010)	(Levic et al., 2010)
Essential Amino Acids	Lysine	14.31	3.8	2.55 - 4.0	3.1	4.4	15
	Leucine	6.12	7.9	7.99 - 8.18	-	7.8	3.31
	Phenylalanine	4.64	5.7	5.75 - 5.90	-	6.0	2.03
	Isoleucine	3.31	-	-	-	4.7	2.35
	Threonine	0.71	3.1	3.57 - 3.82	-	4.1	1.49
	Tryptophan	0.14	-	1.22 - 1.25	-	1.5	5.9
	Methionine	-	1.2	2.05 - 2.18	1.5	2.0	7.8
	Valine	-	5.4	5.75 - 5.81	-	5.7	2.16
Non-essential Amino Acids	Histidine	26.27	2.1	2.19 - 2.25	-	2.5	6.9
	Glutamine	16.59	-	-	-	19.5	-
	Arginine	4.51	6.2	4.87 - 6.04	-	5.8	1.80
	Alanine	4.12	-	-	-	4.9	-
	Tyrosine	2.57	-	-	-	4.3	1.7
	Asparagine	4.81	-	-	-	7.0	-

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4. INFLUENCE OF BSG ON HEALTH AND PERFORMANCE OF DAIRY CATTLE

Whether it is for live weight gain or increased animal products, this will mainly depend on the supply of amino acids as well as energy-yielding substrates from animal feed (Poppi & McLennan, 1995). BSG can be supplemented alone or combined with other inexpensive nitrogen sources such as urea and be able to supply all the essential amino acids needed by animals (Mould et al., 1983). Feeding of either wet or dry BSG to dairy animals has reported influencing the rate of DMI, body live weight, milk yield, and milk components and overall animal health (Belibasakis et al., 1996; Firkins et al., 2002).

4.1 The prebiotic potential of BSG

The prebiotics are selectively fermented feed, usually non-digestible carbohydrates (NDC), that can induce the growth and activities of gastrointestinal microbiota hence improve the health and performance of the host animal (Kelly, 2009; Lao et al., 2020; Samal & Behura, 2015). For a feed material to be considered prebiotic it should not be absorbed or hydrolyzed by upper parts of GIT of an animal, able to maintain good GIT conditions and stimulate the growth and activities of beneficial microbes (Samal & Behura, 2015). Arabinoxylans are NDC and are predominant in cereals such as barley, maize, rye, and wheat play a key role in the growth of beneficial microbes in the gut. Even though most of the arabinoxylans are being extracted during the beer-brewing process, up to 30 - 40% remain in the BSG (Izydorczyk & Dexter, 2008; Mussatto et al., 2006). Research studies have reported that fermented arabinoxylans can stimulate the growth of some beneficial microbe groups especially *Bifidobacterium*, *Lactobacillus* and *Eubacterium* but also to a small extent some species from the *Bacteroides* and *Clostridium* genera. These bacteria groups are responsible for the production of short-chain fatty acids such as propionate, butyrate, and acetate which are associated with reduced pH in GIT. The acidic condition is favorable for several metabolic activities to a host animal such as suppressing the pathogenic activities of organisms such as *Salmonella*, proteolytic Bacteroides, clostridia and *Escherichia coli* (Reis et al., 2014). Other benefits to a host animal include modulation of gut microflora, increased immunity, improved adsorption of calcium and magnesium and improvement of intestinal development. However, the effectiveness of BSG as a source of the prebiotic source differs from factors such as animal diet, age, stress and response rate of the microbiota. For instance, the prebiotics has been observed to be more effective in young animals in which their digestive system is still in development as compared to adult animals (Lao et al., 2020; Uyeno et al.,2015).

4.2 Body live weight

Nissanka et al., (2010) conducted a study using weaned Friesian heifers to determine the influence of the total mixed ration constituted of BSG, Kikuyu grass *(Pennisetum clandestinum)*, commercial pellets and minerals on the weight gain. With the conventional feeding used as a control for the experiment while the treatment diet was a total mixed ration the results showed daily weight gain was significant for the treatment group (0.55 kg/day) compared to the control group (0.33 kg/day). The conclusion from this study indicated BSG being advantageous when fed in a mixed ration as compared when it is provided separately as in conventional feeding. Senthilkumar et al., (2010) also observed significant changes in dairy cows body weight when three diets, diet 1 (rice straw, experimental concentrate and 25% BSG fed separately), diet 2 (rice straw, experimental concentrate, and 25% BSG mixed altogether) and diet 3 (rice straw and experimental concentrate only) were used in a feeding experiment. Diets with BSG inclusion shown improved weight gain as compared to a diet with no BSG.

Similar feeding experiment by Trach, (2003) with the inclusion of 10% BSG or 10% molasses from sugarcane on rice straws (untreated, treated with 3% lime plus 2% urea) observed the effect of BSG on dairy weight gain. The study showed persistent results of BSG being effective in improving cows' daily weight of up to 130 g/day higher as compared to sugarcane molasses supplement. Besides, another experiment was done with the lactating Jersey cows by West et al., (1994) with assigned 0, 15 and 30% BSG diets but also with 30% BSG that have liquid brewers' spent yeast. The study findings indicated in the expense BSG, animals were able to maintain their body weight while also improve milk productivity and this brought a conclusion that milk yield was not at the expense of body tissue stores. There are however some inconsistencies reported such as the study by Valentine & Wickes, (1982). This experiment that involved Friesian cows provided 70% of their ME requirement as forage hay with supplementation of 2.4, 4.8, 7.2 kg of BSG or 3.9 kg of rolled barley observed no differences in live weight gain among the treatments.

4.3 Influence on milk yield and its composition

Several studies have observed the positive results of supplementing BSG on milk yield even though few studies also reported inconsistent findings. Belibasakis & Tsirgogianni, (1996) experimented with multiparous Friesian cows in a crossover design with a control diet constitutes 45% maize silage and treatment diet contained spent grain as a substitute for maize silage, soybean meal, and wheat bran. As compared to control diet, cows received BSG demonstrated significant improvement of milk yield (24.8 versus 21.7 kg), milk fat percentage (4.08 versus 3.82%) and total solids content (12.89 versus 12.44). Other attributes such as milk protein content were not different for control and treatment diets. Another study conducted by Valentine & Wickes, (1982) with Friesian cows fed on pasture hay together with BSG at different levels (2.4, 4.8 and 7.2 kg DM) or rolled barley given at 3.8 kg DM.

The milk yield, milk protein, and solids not fat were higher at 4.8 kg (15.6 lt, 0.49 kg and 1.36 kg respectively) and 7.2 kg DM spent grain (16.4 lt, 0.54 kg and 1.45 kg respectively) as compared to cows fed 3.8 kg rolled barley. Other milk components such as milk fat did not differ significantly for both BSG and rolled barley supplementation. Also, a different feeding experiment which highlighted the potential of spent grain was done by Senthilkumar et al., (2010) with three diets; diet 1 (rice straw, experimental concentrate and 25% BSG fed separately), diet 2 (rice straw, experimental concentrate and 25% BSG mixed) and diet 3 (rice straw and experimental concentrate only). The cows responded in terms of milk yield the highest in diet 1 where feed materials are provided separately, followed by diet 2 with mixed feed materials and lastly diet 3.

Both fat-corrected milk, as well as milk fat, were not different while milk protein observed to be higher in diet 1 (fed separately) than diet 2 (mixed feed) and diet 3 (no spent grain). Besides, Polan et al., (1985) experimented with multiparous Holstein cows with four different feed types which were basal diet (12% CP), dry spent grain (14.5% CP), freshly spent grain (16% CP) and soybean meal (17.5% CP). The results from this study indicated that cows receive basal diets were inferior in terms of milk yield levels, milk protein, milk fat, and total solids. This study also observed milk protein for cows received fresh BSG and soybean meal to be higher compared to that of dry BSG while other milk components did not vary significantly.

There are however inconsistent results with the actual potential of the BSG. Murdock et al., (1981) used Holstein cows where they were assigned different feed treatments based on CP content and feed source. With the 15 and 30% of fresh BSG provided to replace concentrates, both the milk yield and milk components were not different for the cows from early to mid-lactation (140 days since calving). Both supplementation of BSG and soybean meal achieved similar results. Comparable responses were reported by West et al., (1994) where Jersey cows that were involved with supplementation of fresh BSG at 0, 15 and 30% DM in which milk yield, as well as fat-corrected milk, were not different.

Other studies observed a reduction in milk yield and some milk components when dairy cows were fed BSG. Significant milk reduction was observed by Davis et al., (1983) whereby spent grain was a substitute feed material for soybean meal and corn silage. With the pressed spent grain assigned at 0, 20, 30 and 40% DM, the milk yield was reduced significantly at 20, 30 and 40% (25.0, 24.4 and 22.2 kg/day, respectively) as compared to 25.6 kg/day for control feed contained soybean meal. With this study, the milk fat content was significantly higher for BSG diets compared to control while the milk protein was lower for the diets containing 40% BSG compared to other treatments.

4.4 Influence on Dry Matter Intake (DMI)

Physiologically, the palatability and hence DMI is expected to change with the feed moisture content since the animal will be able to consume considerably more when feed is moderately wet compared to dry feeds (Albright, 1993; Baumont, 1996). This will, however, depend on numerous factors including variation in feeding behavior among animals, the nutritive value of feed, sensory properties of feed (e.g. odor, taste), physical characteristics of feed (e.g. particle size, digestibility, dry matter) and environmental factors (Baumont, 1996; Sclafani, 1995). The currently available literature present contrasting findings in DMI levels when BSG is included in dairy cows feed rations.

Consistent results were reported by Trach, (2003) when supplementing rice straws with either 10% of BSG or 10% sugarcane molasses. This study found the organic matter intake was 1.98% and 1.84% of live weight for supplemented and non-supplemented cows respectively. Moreover, Miyazawa et al., (2007) observed comparable findings with the incorporation of BSG in the diet that consists of alfalfa hay, corn silage, and grain mixture and this makes BSG a potentially effective feed to replace expensive feed sources such as soybean meal. Similar results were reported by West et al., (1994) in hot and humid areas where the BSG of up to 30% DM of total feed can be included without affecting the DMI while also being economical to a farmer.

Some studies, on the other hand, reported no differences in DMI with the inclusion of spent grain in dairy cows diets. Senthilkumar et al., (2010) when using three different diets of which cows were fed as a mixed ratio (BSG, rice straw, and experimental concentrate), separately feeding (BSG, rice straw, and experimental concentrate) and diet with no BSG (only rice straw and experimental concentrate) observed no differences in DMI among three diet groups. Also Dhiman et al., (2003) observed that feeding of either dry or wet BSG had no influence of Friesian-Holstein dairy breeds in DMI (25.6 kg/day for dry and 25.1 kg/day for wet BSG).

There were also contrasting findings on the DMI levels with an inclusion of the BSG. Davis et al., (1983) experimented with dairy cows by replacing soybean meal and ground corn with BSG at 0, 10, 20, 30 and 40% of the total feed ration. The study observed a significant reduction of DMI as reported being 18.2, 17.1 and 14.8 kg/day at 20, 30 and 40% levels of BSG as compared to control diet which constitutes corn silage (19.7 kg/day). Similar responses were reported by Davis et al., (1983) observed a significant decrease of DMI especially above 30% of BSG and hence suggested the supplementation of 25 - 30% BSG as favorable for improved yield and milk components without depressing the daily intake.

The differences in responses of BSG contained feeds by dairy cows can be attributed by one or a combination of factors include proportion and moisture of BSG supplemented, types and nature of feed sources, feed rations, variations in potential of dairy breeds, physiological state of animals, climatic conditions and overall husbandry practices a farmer employ. For instance, fresh BSG which has high moisture content tends to decrease DMI, especially when included with feed sources such as silage and fresh forage. Schingoethe et al., (1988) pointed out that for every 10% increase in feed moisture content, there is a decrease of DMI by 0.2 % of cow's live weight.

5. CHALLENGES RELATED TO UTILIZATION AND SUSTAINABILITY OF BSG

5.1 BSG handling

The freshly spent grain from brewing is bulky with water content being as high as 70% (Levic et al., 2010; Mussatto et al., 2006). This results in difficulties in handling and its transportation may result in additional production costs to a farmer (Thomas & Rahman, 2006). This will, however, depend on the distance to the brewing source, the scale of farm production (small, medium or large), the economic return of supplementation and existing BSG's preservation methods a farm employs (Ben-Hamed et al., 2011). Mussatto et al., (2013) estimated the significant transportation costs that averagely about 16 US dollars per ton (USD/t) with wet BSG transported at only a distance of 5 miles (equivalent to 8 km). In most cases, the rate at which feed materials are collected is lower compared to quantities being produced by a brewing company which leads to increased disposal with the risk of environmental contamination.

5.2 The impediment to non-ruminant animals

The suitability of spent grain as the feed source for non-ruminant animals is constrained with its high fiber content which can on average be up to 70% on a DM basis (Ben-Hamed et al., 2011; Kerby & Vriesekoop, 2017). Rumen, which is among the four stomach chambers of ruminants (others being omasum, abomasum, and reticulum) possess millions of bacteria, protozoa and other microbes that produce enzymes which assist in digesting the structured carbohydrates (cellulose, hemicelluloses, and lignin) (Doreau & Ferlay, 1994). The digestion results in the production of sugars and fatty acids which a host animal can directly consume (Doreau & Ferlay, 1994; Montagne et al., 2003). Monogastric animals such as pigs, horses, and rabbits only acquire a single chamber, a true stomach with no such high capability (Montagne et al., 2003). The application and efficient utilization of spent grain as animal feed will hence be more beneficial to farmers with ruminants such as cattle, goats, and sheep.

5.3 Inadequate knowledge by farmers

Proper education to farmers regarding mycotoxins contamination of feed is hardly being implemented in most of the developing countries especially in Africa (Misihairabgwi et al., 2017). Survey study that was done in sub-Saharan countries of Zambia, Malawi and South Africa indicated there is a lack of knowledge regarding mycotoxin contamination and that farmers are not fully aware of the implications of these contaminants to human and animal health (Mboya & Kolanisi, 2014). For instance, a research study in Zambia by Mukanga et al., (2011) observed only 7% of the smallholder farmers were fully cognizant that mycotoxins were produced from molded cereals. Interestingly, the spoiled cereals were either burnt, thrown away, being fed to livestock or also sold to local beer brewers.

Moreover, a study that was done in Malawi in assessing the knowledge, attitude and practices on fungal development on foods indicated significant of the respondents had minimal understanding of the link between mycotoxin produced from fungal colonization and implication to health (Matumba et al., 2015). There is, therefore, a deliberate need for awareness creation to smallholder farmers and consumers on the health risks that can arise from directly or indirectly consumption of the contaminated food. The mycotoxin control programs, surveillance systems and awareness creation programs should be included in districts, national and regional development agendas so as necessary knowledge to be disseminated. The government bodies should work together with non-governmental organizations, private institutions, and mass media to ensure that the sustainability of these interventions is successful.

5.4 Weak or nonexistence Regulations and Standards

Unlike some developed regions like Europe and America where there are clear-cut standards on feed quality and safety, currently, there are no regional established regulations in Africa that make individual countries to have their standards (Matumba et al., 2015). By 2003, a worldwide survey that was done by FAO found only 15 African countries had documented mycotoxins regulations (FAO, 2004). In a subsequent study by Matumba et al., (2015), it was proclaimed significantly little or no improvement had been done, with even the existing regulations being poorly enforced with indicators of mycotoxin exposures being the threat to human health. In 2015, the International Agency for Research on Cancer (IARC) in a survey for low and medium-income countries identified some of the countries with no existing regulations and guidelines on mycotoxin control which include Swaziland, Lesotho, Zambia, Botswana and Namibia

(Wild et al., 2015).

The suggested reasons behind weak and nonexistence regulations and standards in most of the developing countries are lack of prevalence data of certain mycotoxins, human capacity and necessary resources to obtain toxicological and exposure data (Matumba et al., 2015; Mboya & Kolanisi, 2014; Wild et al., 2015). In addition to that, research on mycotoxins doesn't appear as a top priority in most of the developing countries with most of the attention being given on issues related to malaria, HIV/AIDS and infant mortality (Wild et al., 2015).

5.5 Mycotoxin contamination of Feed

The contamination starts in the field where there is a continuous interaction between plant and microbial population which might, in turn, influence grain both pre and post-harvest (Keller et al., 2012). Even though most of the microbes rarely survive the malting and mashing procedures of brewing, the secretory factors could persevere and as a result both quality of the beer and spent grain may be affected (Bokulich & Bamforth, 2013). Having high protein and digestible fibre content, they are quite palatable feed source for animals, even though the high levels of moisture and polysaccharide contents make the wet BSG susceptible for spoilage by fungi and bacteria (Lynch et al., 2016; Robertson et al., 2010; Stojceska et al., 2008). Furthermore, the fermenting smell from BSG attracts numerous vector pests such as fruit flies (*Drosophila spp.*) and small mammals including rodents that accommodate various undesirable microorganisms (Thomas & Rahman, 2006).

Fungi are responsible for the development of mycotoxins, the secondary metabolites that have negative impacts on the human, animals, and crops (Hussein & Brasel, 2001). Different genera of fungi including *Aspergillus*, *Penicillium* and *Fusarium* produce numerous groups of these chemicals and toxic substances which are hazardous when ingested from feed or food that is contaminated (Yiannikouris & Jouany, 2002). Some fungi species produce more than one type of mycotoxins while it is also common for certain mycotoxins to be produced by more than one species of fungi (Gonzalez Pereyra et al., 2011). Moreover, not all fungi are toxigenic and as well not all the produced secondary metabolites are toxic.

As reported by Gonzalez Pereyra et al., (2011), the common mycotoxins that have been documented from the brewing industry are aflatoxins (AF), fumonisins (F), ochratoxin-A (OTA), trichothecenes and zearalenone (ZEN). Numerous aspects influence distribution as well as the toxicity of mycotoxins and these include storage and climatic conditions, fungal strain specificity and strain variations (Keller et al., 2012). Different livestock groups have different susceptibility levels to mycotoxins in which ruminants are more resistant as compared to monogastric animals and this is associated with rumen microbiota having a certain ability to degrade the mycotoxins (Hussein & Brasel, 2001).

To a farmer, mycotoxin contamination on livestock feed is of economic importance since there are inevitable additional costs incurred for veterinary treatment, disposal of contaminated feed, reduced productivity as well as the death of the animals (Siegel & Babuscio, 2011; Yiannikouris & Jouany, 2002). Also, mycotoxins are detrimental to humans as extensive exposure results in health deterioration or even death (Hussein & Brasel, 2001). These metabolites appeal to an increased annual investment of millions of dollars worldwide in combating the mycotoxin contaminations (Siegel & Babuscio, 2011).

6. PRESERVATION AND SAFETY CONTROL OF BSG

At the point of its production, the spent gain is considered microbiologically stable with insignificant levels of contamination (Robertson et al., 2010). With time, due to its high moisture and sugar contents, feed materials need to be fed to the animals within a short period or appropriate preservation methods have to be applied to avoid spoilage (Chanie & Fievez, 2017). Stabilization of feed hence involves a wide range of techniques that might include chemical treatment, oven drying, steaming, ensiling and pressing to reduce the moisture level.

6.1 Field and storage condition

The preliminary contamination that occurs while barley is still in the field should carefully be monitored since immeasurable microbe population can arise from the surrounding environment, insects as well as animals (Robertson et al., 2010). Generally, the variation on weather conditions naturally influence the microbial community growth on barley grain and hence the pathogenesis (Bokulich & Bamforth, 2013). To minimize the severity, barley is recommended to be stored preceding brewing to break dormancy (Bokulich & Bamforth, 2013). The grains are also supposed to be stored in conditions where there are low moisture and the low-temperature environment to impede microbes growth (Mussatto, 2009). Several plant breeding programs have recently been working to produce plant varieties which are resistant to fungal contamination (Yiannikouris & Jouany, 2002).

6.2 Detoxification of mycotoxins by Biochar

The biochar or also known as activated carbon or charcoal are compounds generated through the process of pyrolysis of various organic materials and have been useful in agroecosystems such as improvement of soil quality, crop productivity, and carbon sequestration (Toth & Dou, 2016). The effectiveness of activated carbon or biochar in detoxification of mycotoxins by adsorption have been studied. The mechanism behind their binding capability to these toxic metabolites are associated with the surface area, the presence of mesopores (ranging from 2 - 50 nm) and low surface acidity. When charcoal material tends to have high surface acidity and/or micro porosity above 2 nm, the sorption capacity is significantly impeded. When Galvano et al., (1996) added about 2 % in the dairy feed the two types of activated carbon and hydrated sodium calcium aluminosilicate they observed a significant reduction of 41 - 74% of aflatoxin B_1 concentration while also its levels in milk were reduced up to 45%. The study observed that the included activated carbon did not suppress the DMI of cows as well as live weight gain, milk productivity, and milk composition.

Moreover, some commercially activated charcoal has been reported to bind up to 99 % of the potent aflatoxin B_1 in an *in vitro* experiment done by Diaz et al., (2004). The mode of the action of these sorbents was suggested to be complexing of aflatoxin, thereby decreasing intestinal adsorption and reducing the transfer of the metabolite into milk. Key factors on effectiveness in mycotoxin adsorption include chemical and biological characteristics of charcoal material, the duration is taken to feed animals, variations of experimental diets involved, type/breed of animal, concentration level and type of mycotoxin (Toth & Dou, 2016).

6.3 Feeding of fresh BSG

The fresh and wet spent grain from the brewing should be consumed by animals as soon as possible since they are prone to biological degradation (Chanie & Fievez, 2017). Aliyu & Bala, (2011) suggested approximately the first three days as safe for animal consumption as some studies suggest microbial contamination starts from the seventh to the tenth day since spent grain came out the malting process (Stojceska et al., 2008). Farmers located nearby spent grain sources will benefit from the reduced transport costs while distant farmers need to establish an appropriate conservation technique which will be cost-effective and preserve the nutritional status of the feed.

6.4 Ensiling

Storage of feed material in the form of silage either in plastic drums, plastic bags or silo has been widely acknowledged as an effective preservation technique whereby no alteration of the quality or the nutritional value being observed (Küntzel & Sonnenberg, 1997; Thomas & Rahman, 2006). The feed material is filled in containers in the absence of oxygen which facilitates anaerobic fermentation of sugars present in the feed material into lactic, acetic and benzoic acid (Küntzel & Sonnenberg, 1997; Lynch et al., 2016). The lower pH between 3 - 4 prolongs the shelf life and well conserving the nutritional status of the feed by inhibiting the growth of degrading/undesirable microbes (Thomas & Rahman, 2006). In recent years, silage inoculants have been used to facilitate the fermentation process with the most common inoculants groups being lactic acid bacteria from genera of *Lactobacillus* (*L. plantarum* and *L. buchneri*) as well as *Enterococcus* (*E. faecium*) (Lynch et al., 2016). Since the feed material is being ensiled, it usually takes up at least two weeks until it can start being fed to animals (Kazemi et al., 2009). Unlike other techniques which might involve purchasing of expensive facilities, ensiling when done appropriately can be feasible, cost-effective and improve dairy productivity especially to the resource-constrained farmers (Kazemi et al., 2009).

6.5 Oven drying

This technique is used in reducing moisture content in spent grain where the temperature below 60^0 C is often applied (Mussatto et al., 2013). Higher temperatures should be avoided since there is a generation of spent grains with unpleasant flavors while also toasting and/or burning as well as occurrences of odor pollution at extreme temperatures (Mussatto et al., 2006). Superheat steaming is proposed as an alternative method to oven drying since steaming helps in reducing possible environmental pollution from drying the spent grain while also it has an improved drying efficiency, eradicate the threats of fire or possible explosion as well as retains organic matter content (El-Shafey et al., 2004).

6.6 Membrane filter press

This preservation method is done to reduce the water content which means a large quantity of spent grain with reduced moisture content can be transported. With the application of recent technology of membrane press filter in Portugal, El-Shafey et al., (2004) enabled to achieve high drying level of up to 20 - 30 % moisture through a series of procedures including spent grain being filtered, membrane squeezed and vacuum dried. The pressed spent grain through being kept in the open air for approximately two days achieved the moisture levels of 10 % and has been promising in extending the shelf life of up to six months with no lethal bacterial contamination being observed (El-Shafey et al., 2004). In improving the shelf life of pressed spent rain, the inclusion of Potassium sorbate which is a common additive for the preservation of foods and drinks has also been suggested (Küntzel & Sonnenberg, 1997; Mussatto et al., 2006).

7. CONCLUSION

The brewers' spent grain is a valuable agro-industrial by-product in terms of quantity and chemical composition for feeding livestock. The dairy performance can be maintained or even improved when the spent grain is utilized within nutritional and feeding management guidelines. The intensification of research and investment for diverse applications in recent decades has been driven by its inherited environmental and economic reasons. Important benefits and opportunities for improvement have been explored by the current literature. This paper also discussed the potential challenges of utilization as feed material as well as possible preservative methods to be taken to ensure its sustainability. The hazardous mycotoxins with significant impacts on the commercial value of crops, livestock productivity, and human health have been studied. The existing shortcomings related to standards and regulations on feed safety need to be reviewed and researched to conform to the international standards, guidelines, and recommendations. Additionally, more research studies and surveys need to be done to generate data on epidemiology, exposure and health impacts on both animals and human beings.

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