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Invited Review: Rise of craft breweries in the southeastern USA increases supplement availability for beef cattle*

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ABSTRACT

Purpose: The purpose of this invited review was to discuss the current state of craft beer production and the generation, nutritional variability, and importance of wet brewers grains (WBG) as a livestock feed. This article also takes an in-depth look at logistical challenges of using WBG as a feed resource and how local communities are mitigating those challenges.

Sources: Information provided came from the combination of published scientific resources and through experiences based on outreach services and real-world applications of using WBG as a byproduct feed for beef cattle.

Synthesis: Wet brewers grains are often a cheap or no-cost feed for beef cattle producers located near craft breweries. The high concentrations of CP and digestible fiber make it a byproduct of interest for many beef cattle production systems. Moisture content is the greatest limitation, and additives for improved fermentation may be needed during storage of this high-moisture feed.

Conclusions and Applications: The rise of craft breweries has increased the availability of WBG, which is an affordable feedstuff for beef cattle producers located near a brewery. Although there is variability in WBG between brews and craft breweries, successful incorporation of this byproduct into diets has occurred in all sectors of the beef industry. The on-farm handling and storage of WBG should be considered, and the addition of a feed additive may help to prevent spoilage and extend WBG shelf life. In local communities, logistical challenges may be somewhat averted when several smaller beef cattle producers work together on a WBG contract.

Key words: wet brewers grain, beef, craft brewery, byproduct feed

INTRODUCTION

The craft brewing industry in the United States has seen major growth in the last 2 decades (Tremblay and Tremblay, 2005; Woolverton and Parcell, 2008; Baginski and Bell, 2011; McLaughlin et al., 2014; Howard, 2017) and in 2021 was a $26.8 billion industry with sales of 24,489,945 beer barrels (**BBLS**), with one BBLS containing 117.35 L of beer (Brewers Association, 2021). According to data by the Brewers Association (2021) online database, the $100.2 billion US beer market is dominated by domestic beer, owning 65.9% of the total market share. However, the market share held by the craft brewing industry has grown from 5.68% in 2011 to 13.1% as of 2021. The other 21.0% share belongs to the imported beer market. The increase in market share and the rise of craft breweries across the nation can be attributed to the consumer demand for more bold and flavorful beers that have been brewed locally (McLaughlin et al., 2014). Most of this growth has come in the form of microbreweries, taprooms, and brewpubs with the aid of a few regional craft breweries opening as well (Brewers Association, 2021). The Brewers Association (2022) defines a craft brewery as being a small, independent brewer. More specifically, it defines a craft brewery as (1) a small producer that produces less than 6 million BBLS a year; (2) an independent brewer, meaning that 25% or more of the brewery itself cannot be owned or controlled by a beverage alcohol industry member that is not a craft brewer; and (3) a brewer, having a Tax and Trade Bureau Brewer's Notice and making beer. Further designations between craft breweries can be made and include regional craft breweries, microbreweries, taprooms, and brewpubs, with the main distinction being the level of beer production per year and the way in which

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the product is marketed. Regional craft breweries produce between 15,000 and 6,000,000 BBLS per year, whereas microbreweries must produce less than 15,000 BBLS per year and sell at least 75% of their brews offsite. Taprooms sell at least 25% of their beer on site and offer some food service, whereas brewpubs sell at least 25% of their brews on site and offer significant amounts of restaurant-style food service (McLaughlin et al., 2014; Brewers Association, 2022). Another noteworthy component of the craft brewery sector is a contract brewing company, which is a business or brewery that hires another brewery to brew its beer and may also take on the additional responsibilities of marketing, sales, and distribution of the beer.

Many have suggested that the rise in craft breweries is the result of the concept of neolocalism—the deliberate creation of a sense of community or regional lore created by residents (Shortridge, 1996; Murray and O'Neill, 2012). In this sense, the concept of craft beer has become a part of local communities, and craft breweries, taprooms, and brewpubs have become a gathering place for locals and a way for visitors to move away from the homogeneity of large, national domestic beer and immerse themselves in the taste and culture of local areas. This taste of craft beer is often described in the marketplace with adjectives such as flavorful, twists, hometown, independent, individualistic, historic, innovative, interesting, distinct, unique, small, traditional, and bold. As a result of this move to locally produced craft beer, certain states and geographical areas throughout the country have seen such a drastic rise in craft beer production that they have become a destination for craft beer connoisseurs. According to the Brewers Association (2020a), California, Pennsylvania, Texas, New York, and Florida's craft brewing industry led the United States in economic impact, ranging from $7.6 to $3.1 billion in 2020. Hotspot areas have also risen throughout the United States, with one such area being Asheville, North Carolina. Asheville has built a vibrant tourism industry around craft beer (Baginski and Bell, 2011) and is known for its many breweries, brewery tours, beer festivals, and overall beer culture.

Craft Brewing in North Carolina

In 2020 North Carolina was ranked ninth in the United States for number of craft breweries and eighth in number of BBLS produced, with 359 breweries producing 912,589 BBLS (Brewers Association, 2020b). The craft brewing industry also had a $2.8 billion economic impact on the state, which ranked ninth overall in the United States. The industry also plays a crucial role in local economies by providing $547 million in labor income and employing 13,177 full-time employees who averaged an annual salary of $46,306 in 2020 (Brewers Association, 2020a). Making the top 10 list for almost every internet search for "best city for craft beer," Asheville is the most recognizable craft beer destination in North Carolina, but other metropolitan areas of Charlotte and Raleigh-Durham have also contributed to the rise of the craft brewing industry in the state. Like most craft beer destinations across the Southeast, the North Carolina craft beer industry has largely settled in metropolitan areas where there is a population of beer drinkers to consume the product on site. Baginski and Bell (2011) first recognized this phenomenon in their analysis of the state of craft brewing in the Southeast and suggested that rural areas are much more likely to be "dry" counties than their metropolitan counterparts. Additionally, authors used a stepwise regression procedure to determine that, besides population density, location of craft breweries in operation was also influenced by the cost of living, the furnishing of healthcare, and tolerance to diversity within an area. Because what Baginski and Bell (2011) term as "hierarchical diffusion," or the expansion of craft brewing from metropolitan to more rural settings, has been slow to occur in the Southeast, the movement of the brewery waste product wet brewers grain (**WBG**) has posed logistical challenges for both the brewery and for the livestock producers wishing to use it. This conundrum is evident in North Carolina, where Troxler and Smith (2021) do not report the number of beef and dairy cattle in 2 of the 3 counties making up the Raleigh-Durham and Charlotte areas to protect the identities of such few farmers who are present in those areas. Therefore, byproducts from the brewing industry in this region must be hauled greater distances to be used by livestock in more agricultural-dense areas.

Overview of the Brewing Process

The craft brewing process produces several byproducts that are used in beef cattle rations including brewers dried yeast, malted hulls, sprouts and cleanings, and WBG, also sometimes referred to as wet spent grains. Of all the byproducts produced during the beer making process, WBG constitutes 85% of the total waste products available for upcycling by the ruminant animal (Xiros and Christakopoulos, 2012; Mussatto, 2014). Wet brewers grain is produced after an energy source, primarily barley in craft beer production, goes through a 3-step malting process. The grain is first steeped in 5 to 18°C water for approximately 2 d (Mussatto et al., 2006) for moisture to penetrate the micropylar region (Briggs et al., 1981) because the seed coat, pericarp, and husk, or the 3 most outside layers comprising the grain coverings (Kunze, 2019), are somewhat waterproof. Once moisture content inside the grain reaches approximately 42 to 48%, the grain coverings start to soften and the germination process begins (Briggs et al., 1981; Mussatto et al., 2006). The barley is then either left in the steeping tanks or moved to a germination vessel, where both temperature and humidity can be precisely controlled to promote modification of the endosperm and to prevent losses due to excessive growth of barley seed during this process (Briggs et al., 1981). After 6 to 7 d of germination (Mussatto et al., 2006), the barley seed is then dried, sometimes referred to as kilning, before proceeding to the next steps of the beer making process. Because drying of the malted seed creates a shelf-stable product, the malting process can take place in house or can be done by a third-party vendor and purchased by a craft brewery.

The malted grain is then milled via a wet or dry process to increase surface area (Willaert, 2007) and may be mixed with additional grain adjuncts such as corn or rice (Westendorf and Wohlt, 2002). The milled grains then go through the mashing process, where the grains are once again mixed with water, and through the manipulation of both temperature and pH, enzymatic activity of the mash is optimized and starch is turned into fermentable sugars (Willaert, 2007; Mussatto, 2014). This process of mashing may differ between craft breweries and among beers and is part of what gives each beer its unique flavor. Once the mashing process has been completed, the wort is separated by filtration. The wort is the liquid portion that is then further processed and fermented for beer production. Meanwhile, the disposed WBG are largely used as animal feedstuffs, although other applications for industrial (Aliyu and Bala, 2011; Xiros and Christakopoulos, 2012) and human food (McCarthy et al., 2013) use have been studied.

Wet brewers grain primarily consists of the endosperm, pericarp, seed coat, and the husk of the barley seed (Mussatto et al., 2006; Willaert, 2007; Mussatto, 2014) with some insoluble fractions of other added adjuncts (Xiros and Christakopoulos, 2012) and resulting in about 20 kg of WBG produced per 100 L of beer produced (Reinold, 1997). Based on conversion factors outlined by Reinold (1997) and production statistics from Brewers Association (2020b), we estimate that in North Carolina alone, craft breweries produce roughly 21,418 t of WBG annually. Globally, estimates of WBG byproduct continue to increase. Xiros and Christakopoulos (2012) took 2008 and 2009 worldwide beer production statistics and calculated waste production to be at 34 million wet tonnes. Two years later, Mussatto (2014) estimated that worldwide production of WBG to be around 38.6 million tonnes, and in 2016 global WBG production was estimated to be 39 million tonnes (Lynch et al., 2016). The chemical composition of WBG in combination with their vast availability as a cheap or no-cost feed alternative has driven their popularity among livestock producers.

INCLUSION IN BEEF CATTLE DIETS

Nutritional Content and Variability

Wet brewers grains are a nutrient-dense feedstuff commonly used in beef cattle diets due to their high concentrations of protein, fat, and digestible fiber. The adoption of WBG by many producers is stimulated by interest in nutritional content, more specifically, the perceived notion that WBG is a cheap, or sometimes free, source of high-quality protein. Thomas et al. (2010) reported that the high concentration of CP found in WBG comes from the germ of barley, with protein becoming more concentrated as other components, such as sugars and starches, are malted during the production of beer. Table 1 reports nutrient concentrations of WBG analyzed by Dairy One (Ithaca, NY) in cumulated crop years from 2004 to 2022. In this survey of 3,554 samples, mean CP content was reported as 28.60% of DM and ranged from 23.85 to 33.35% (Dairy One, 2022). Additionally, mean RDP was reported as 36.09% of CP in 2,069 of the previously described samples. These estimates are consistent with those previously described in the literature, which estimated RUP as high as 65% (Merchen et al., 1979; Thomas et al., 2010). When observing a single facility producing WBG, Westendorf et al. (2014) reported a greater mean and slightly less variable CP concentrations of WBG from an Anheuser-Busch facility in New Jersey as compared with samples reported by Dairy One (2022). The CP content in grain sampled for 2 consecutive days for 48 consecutive weeks averaged 33.6%, had a SD of 2.0, and ranged from 29.6 to 37.4% of DM. Similarly, grain samples had a mean RDP of 28.8%, a SD of 2.5, and ranged from 24.5 to 35.3% of DM. This discrepancy in both nutritional content and magnitude of variability in nutritional concentrations is likely explained by the inconsistency in the origin of samples sent to the Dairy One Laboratory. The database may include samples from large-batch corporate breweries as well as many smaller microbreweries, which can encompass a variety of brew types, grain blends, and regional influences. Nutritional differences in WBG may be attributed to grain species, inclusion levels, grain variety used, stage of maturity at harvest, hops variety, or other additives such as fruit (Santos et al., 2003). Differences in the brewing process between brew types can also contribute to variability and is mainly influenced by both the temperature at which the wort is boiled and the stirring speed, and, collectively, can lead to burning of the mash or increased protein oxidation (Briggs et al., 2004).

There is concern surrounding the moisture content of WBG. Reported DM in WBG ranges from 16.32 to 30.60%, with the mean being 23.46% (Dairy One, 2022). This characteristic can make WBG difficult to use, creating challenges in transportation, storage, and feeding. Schingoethe et al. (1988b) reported that high-moisture-content feeds can decrease feed intake, with every 10% increase in moisture leading to a DMI decrease of 0.2 kg/100 kg of BW. Lahr et al. (1983) reported similar findings, indicating that lactating dairy cows consuming treatment diets of 78% DM consumed 1.8 kg of DM/d more than those fed a 64% DM diet, where dietary ingredients remained constant and diets only differed in DM. Similar research has explored this phenomenon using pressed brewers grains (**PBG**). Pressed brewers grains are WBG that have been mechanically pressed to reduce moisture content. Davis et al. (1983) described findings from 2 trials feeding 4 dietary inclusion levels of PBG (0, 20, 30,

Table 1. Wet brewers grain nutritional analysis from crop years 2004 to 2022 performed by Dairy One in Ithaca, New York

Item	Unit of measure	Average	Range		SD	N
			Low	High		
DM	%	23.46	16.32	30.60	7.14	6,867
CP	% of DM	28.60	23.85	33.35	4.75	3,554
Degradable protein	% of CP	36.09	29.79	42.39	6.30	2,069
ADF	% of DM	24.41	20.68	28.14	3.73	3,270
NDF	% of DM	49.19	42.65	55.73	6.54	3,268
Crude fiber	% of DM	12.10	8.67	15.53	3.43	41
Starch	% of DM	5.59	0.09	11.09	5.50	2,224
Crude fat	% of DM	9.78	8.23	11.34	1.56	2,526
Ash	% of DM	4.49	3.78	5.19	0.71	2,386
TDN	% of DM	74.24	70.77	77.71	3.47	3,284
NE_l	Mcal/kg	1.81	1.70	1.90	0.09	3,284
NE_m	Mcal/kg	1.81	1.68	1.94	0.13	3,284
NE_g	Mcal/kg	1.17	1.06	1.28	0.11	3,284
Calcium	% of DM	0.34	0.21	0.47	0.13	2,742
Phosphorus	% of DM	0.69	0.57	0.80	0.11	2,760
Magnesium	% of DM	0.23	0.19	0.27	0.04	2,739
Potassium	% of DM	0.15	0.00	0.32	0.17	2,754
Sodium	% of DM	0.03	0.00	0.11	0.08	960
Sulfur	% of DM	0.33	0.33	0.39	0.07	2,500
Iron	mg/kg	244.14	34.17	454.10	209.97	948
Zinc	mg/kg	91.06	68.02	114.11	23.05	948
Copper	mg/kg	13.96	2.78	25.14	11.18	950
Manganese	mg/kg	52.48	33.47	71.49	19.01	949
Molybdenum	mg/kg	2.21	1.26	3.15	0.95	949
Cobalt	mg/kg	0.74	0.00	1.65	0.91	16
Selenium	mg/kg	0.67	0.54	0.80	0.13	6

and 40% DM) in a TMR to lactating Holstein cows, with PBG in this trial containing 30% DM. Dry matter intake was decreased in the diets containing 30 and 40% PBG as compared with the control (17.1, 14.8, and 19.7 kg/d in trial one, respectively), as was milk production (24.4, 22.2, and 25.6 kg/d, respectively). The inverse relationship between DMI and dietary moisture content likely results from increased rumen fill when high-moisture feeds are consumed. Feeding WBG in conjunction with feedstuffs containing greater DM concentrations or using WBG to limit dust in TMR may be a practical approach for use of this high-moisture byproduct.

Wet brewers grain is a nutritionally viable feed resource for beef cattle (Westendorf and Wohlt, 2002). The variability in nutritive value of WBG between breweries, and within brew types at each microbrewery, can pose challenges. Lynn et al. (2009) recorded such variability among 142 samples of WBG from 3 microbreweries over a 12-mo period. Reported NDF values varied by over 30% (29.4–65%, average 46.1%), and ADF values varied by 18.8% (13.6–32.4%, average 22.3%). These mean values are comparable to those reported by the Dairy One Feed Composition Library (Dairy One, 2022). Variation in fiber has also been noted in commercial brewers grains. Westendorf et al. (2014) reported NDF values from a large domestic brewery ranging from 44.3 to 52.1% (average 48.5%) and ADF ranging from 18.1 to 25.5% (average 20.9%). Historically, increased NDF has been associated with decreased DMI. Belyea et al. (1993) estimated that forage NDF intake is maximized at 1 to 1.2% of BW for dairy cows, which equates to less total DMI as NDF content increases. Alternatively, Arelovich et al. (2008) reviewed and analyzed total dietary NDF and subsequent DMI from 11 experiments. Their findings indicate that DMI increased with total dietary NDF in feedlot diets but noted that maximum total NDF in these diets was approximately 35%. Wet brewers grains are recommended only as supplements or ingredients in a balanced ration (Thomas et al., 2010), which would likely allow for total dietary NDF to be adjusted to this level.

Wet brewers grains contain crude fat concentrations that range from 8.23 to 11.34%, with an average of 9.78% (Dairy One, 2022). The high concentration of fat in WBG can be beneficial to help increase the caloric density of diets, but increased consumption of fats may also have negative associative effects of reduced digestibility and DMI. In ruminants, acceptable dietary fat concentration varies depending on the stage of production and diet composition, with recommendations for high-forage diets to limit inclusion to 2 to 4% of DM and high-concentrate rations to 6% of DM (Hess et al., 2008). Schingoethe et al. (1988a) reported that dietary fat can reach 5 to 6% in lactating dairy cows without affecting DMI or fiber digestibility. More recently, Plascencia et al. (2022) reported findings on fat supplementation in growing Holstein calves. Treatment diets included either 0 or 3.5% yellow grease as a partial replacement for steam-flaked corn. Calves consuming the 0% yellow grease had reduced performance when compared with calves consuming the 3.5% yellow grease, having decreased G:F (0.26 and 0.28, respectively) and daily gain (1.25 and 1.31 kg/d, respectively). Despite the positive results fat supplementation can have on increasing the energy density of the diet, Plascencia et al. (2022) recommended supplemental fat not exceed 3.5% of total diet DM for growing calves because no adverse effects on DMI were found.

Last, the brewing process leaves behind high concentrations of digestible fiber that allows WBG to be a complimentary supplement for forage-based diets. The fiber content of WBG is a product of the malting and mashing processes, which converts starch to sugar using heat and enzymatic activity. Resulting fermentable sugars remain in the wort, whereas grain residues (containing cellulose and hemicellulose) are separated from the wort and become WBG (Westendorf and Wohlt, 2002). Dairy One (2022) reports average TDN concentrations of 74.24% of DM and average NE_l of 1.81 Mcal/kg and NE_g of 1.17 Mcal/kg. These values are favorable as compared with an average grass hay, which is expected to contain less TDN (58.55% DM) and NE_l and NE_g (1.12 and 0.60 Mcal/kg, respectively) and greater ADF and NDF (38.31 and 61.60% DM, respectively).

Growing Diets

Studies using WBG in growing diets have often compared the product alone or in combinations with other feedstuffs. Crickenberger and Johnson (1982) studied WBG inclusion in 3 wintering diets for beef heifers. Dietary treatments included corn silage with no supplement (**CSNS**); corn silage + WBG (**CSWBG**); and a diet consisting of WBG, ground corn, and tall fescue hay (**WBGCH**). At 6.7% dietary inclusion of CP, the CSNS diet did not meet CP requirements for the growing beef heifers, which resulted in less gain/DM (0.11) than the CSWBG and WBGCH treatments (0.16 and 0.16, respectively). Final weight and ADG were greatest for heifers on CSWBG diets, which was attributed to these heifers having almost double the mean daily CP intake as those on the CSNS treatment (0.68 and 0.32 kg, respectively) and indicating that WBG can function as an adequate protein source in growing beef heifer diets.

In a similar study, Moriel et al. (2015a) reported findings comparing WBG, ground corn (**CN**), and a 50:50 mixture of the 2 (**CNWBG**) as supplement to tall fescue hay on heifer growth performance. Reported DMI varied for treatments throughout the experiment, with the most notable difference being during wk 6, when both CN and CNWBG groups recorded greater DMI than WBG heifers. As previously discussed, both the fat and moisture content of WBG can result in depressed DMI (Lahr et al., 1983; Schingoethe et al., 1988a). In this specific study, dietary DM ranged from 86% (CN) to 33% (WBG), with CNWBG being intermediate (68%). The authors also referenced fat content of treatments as a plausible explanation of DMI differences, which were 5.96, 3.38, and 1.18% for WBG, CN, and CNWBG, respectively. In forage-based diets, it is not recommended for dietary fat to exceed 2 to 4% of DM (Hess et al., 2008), as it can decrease intake due to changes in ruminal fermentation. Overall ADG was reported to be similar in WBG and CNWBG groups, at 0.98 and 1.04 kg/d, respectively, with CN heifers gaining the least (0.70 kg/d). Finally, G:F was greater in WBG and CNWBG heifers (0.23 and 0.22, respectively) than the CN treatment (0.16). Thus, it was concluded that decreased DMI of the WBG treatment did not affect performance, likely due to the increased protein content of WBG, which has been previously described in the literature (Lynn et al., 2009; Thomas et al., 2010; Westendorf et al., 2014).

Mature Cattle Diets

Literature on inclusion of WBG in mature beef cattle diets is limited but indicates WBG to be a viable supplement. Moriel et al. (2016a) explored WBG supplementation frequency for late gestation beef cows offered *ad libitum* ground tall fescue hay and reported no differences in BCS or BW at calving between groups supplemented 3 times weekly versus those supplemented daily, which was attributed to similar intakes for hay, CP, and TDN. In addition, no effects of decreased supplementation frequency on subsequent calf performance was reported. The conclusion that WBG supplementation can sustain pregnant cows is supported by Thomas et al. (2017), who compared WBG supplementation to dried distillers grain supplementation in round bale silage systems. Authors indicated no effect of supplementation strategy on cow BW or BCS throughout the experimental period, further confirming the value of WBG as a supplement in cow diets.

Presently, there is great interest in the role diet has in ruminant methane production. Duthie et al. (2015) compared methane (CH_4) emissions between TMR containing barley straw and either 22.6% WBG or 30.1% grass silage. Although differences in BCS and DMI were not reported, it was determined that cows offered TMR with WBG had decreased methane emissions as compared with cows offered TMR with grass silage (13.5 and 16.4 g/kg of DMI, respectively). Authors explained this difference due to the increased dietary lipid in the WBG diet as compared with the grass silage diet, as dietary lipid has been known to affect ruminal fermentation, shift microbial populations, and alter VFA production (Beauchemin and

McGinn, 2006). There is not enough data in the literature to conclude that WBG can decrease greenhouse gas emissions in ruminant livestock; further research is necessary to determine the value of WBG for this purpose.

Finishing Diets

Considerable interest exists in the feedlot sector in the use of readily available byproduct feeds as a source of energy and protein for finishing cattle. Feedlot nutritionists want the flexibility to substitute byproduct feedstuffs based on availability and price without compromising feedlot performance, carcass characteristics, and beef flavor and cutability, which has been known to be influenced by finishing diet (Larraín et al., 2009; Arnett et al., 2012). As early as the 1970s, studies were conducted to determine the viability of dried brewers grains as a corn replacement in finishing rations. Preston et al. (1973) reported these findings, noting that dried brewers grains included in finishing rations at rates up to 50% had similar feeding value to corn. Dried brewers grains were included in the diet at either 25 or 50%, with the control ration being 80% corn, 10% urea, and 10% mineral supplement. Because the control diet lacked roughage, ruminal effects and liver abscess occurrence were compared between the treatment diets. Steers receiving experimental diets experienced no physical indicators of negative effects on rumen health and no liver abscesses, indicating that dried brewers grains can provide a level of roughage replacement in diets, which is consistently reported due to the digestible fiber content of WBG (Lynn et al., 2009; Thomas et al., 2010; Westendorf et al., 2014).

More recently, studies have explored the performance implications of using WBG in complete finishing diets. Available data indicate no negative effect on overall ADG between control diets and rations containing WBG up to 30% total ration DM, with the majority of inclusion rates being much lower (Ojowi et al., 1997; Parmenter et al., 2018a; Parmenter et al., 2018b; Belon et al., 2019). Homm et al. (2008) studied the corn replacement value of WBG in feedlot heifers. Wet brewers grains were included at 4 levels in treatment diets (0, 15, 30, and 45% of total DM) as a replacement for high-moisture corn. The TMR also included corn silage and a supplement mix consisting of soybean meal, ground corn, urea, limestone, Rumensin 80 (Elanco Animal Health), Tylan 40 (Elanco Animal Health), and minerals. A quadratic response was reported for final BW, ADG, and DMI, with the 15 and 30% WBG treatments being greater than the 0 and 45% treatments. Increasing moisture content in diets has been shown to decrease DMI due to increased fill (Lahr et al., 1983; Schingoethe et al., 1988a), which is consistent with these findings, as the dietary DM of the 15, 30, and 45% WBG treatments were 50.28, 43.14, and 37.72%, respectively. West et al. (1994) reported no DMI differences between 0, 15, and 30% WBG rations (13.6, 13.1, and 13.0 kg/d, respectively) in lactating dairy cows during hot, humid weather in Georgia. Although these data are conflicting, it may be explained by environmental differences, as it is likely that feedlot heifers in Illinois in the Homm et al. (2008) study would not have experienced the same heat stress and respiration rates as those reported by West et al. (1994).

Inclusion rates of less than 10% WBG have also been studied. Ojowi et al. (1997) compared finishing diets of 5.7% WBG [also containing 88.5% concentrate mix (96.8% barley) and 5.8% straw)] and 4.7% wet distillers grain (also containing 86.6% concentrate mix and 8.7% straw) to a control diet of 93% concentrate mix and 7% straw. Whereas similar values were reported for final BW, DMI, and feed conversion, ADG was less for the WBG treatment than the control (1.25 and 1.40 kg, respectively). However, authors contributed this difference to compensatory gain among the control group due to poor performance during the previous growing period of the study. As a result, there were no differences overall in ADG among treatments for the growing and finishing studies combined. Alternatively, Parmenter et al. (2018b) also described findings concerning WBG in finishing diets for steers and heifers. Treatments consisted of a control of corn silage, whole shelled corn, and dried distillers grains (12.90, 65.20, and 18.80% total dietary DM, respectively), and a WBG diet consisting of corn silage, whole shelled corn, dried distillers grains, and WBG (14.80, 61.40, 13.40, and 7.2% of total dietary DM, respectively). Average daily gain, total gain, and G:F did not differ between treatments, but a diet-by-sex interaction was reported for DMI. Steers consuming the control diet had greater DMI than control heifers (18.3 and 18.0 kg/d, respectively), but WBG steers had decreased DMI compared to WBG heifers (17.2 and 17.4 kg/d, respectively). Otherwise, no dietary differences were reported for performance parameters, including ADG and G:F, further proving viability of WBG inclusion in finishing diets, possibly as an alternative for dried distillers grains or shelled corn.

As with all byproducts included in or used as a grain alternative in finishing rations, the effects of diet on carcass merit and consumer satisfaction are of concern. Presently, literature reports little to no effect on palatability and carcass characteristics from inclusion of WBG in finishing diets. Shand et al. (1998) reported no chemical differences in longissimus muscle samples from cattle finished in the previously described research by Ojowi et al. (1997), which included a control ration, a ration containing WBG, and a ration containing wet distillers grain. There were also no differences in cooking losses or sensory attributes of firmness, tenderness, overall juiciness, and flavor desirability among the 3 dietary treatments. Few studies have recorded specific results concerning Warner-Bratzler shear force, or tenderness, values resulting from WBG in finishing diets, but available results indicate that WBG has no effect on meat tenderness (Shand et al., 1998; Parmenter et al., 2018b). Belon et al. (2019) described similar findings in carcass data, reporting no effect of 30% WBG inclusion in finishing diets on several parameters, including DP, 12th-rib fat thickness, marbling score, or YG, which is consistent with other literature (Ojowi et al., 1997; Homm et al., 2008; Parmenter et al., 2018a). Although available data are limited, there are indications that WBG can be included in finishing diets at up to 35% of total DM without affecting stability of meat stored at 4°C for up to 75 d (Stefanello et al., 2019).

LOGISTICAL CHALLENGES

Despite positive nutritional characteristics, the high moisture content of WBG continues to be one of the most limiting factors for its use on beef cattle farms. Transportation, storage, and feedout challenges can often lead to short-term adoption as a nutritional supplement by many small- to medium-sized beef cattle operations. In most scenarios, the economics of hauling wet feed long distances from production source to end user is not financially viable. Wet feed is not only heavy, which requires special transportation equipment large enough to handle the added weight, but seepage from unsealed equipment is generally viewed upon negatively by the public.

Seasonality of craft beer production poses yet another challenge for the adoption of WBG in beef cattle diets. In general, beer consumption increases during the summer months (Allen and Stevenson, 1975) and during major holidays, such as the July 4th holiday and Labor Day (Woolverton and Parcell, 2008). With increased demand comes the increased production of beer and availability of WBG. Unfortunately, this does not lend itself advantageously to most beef cattle production systems. During the summer months when byproduct supply of WBG is plentiful, most cow/calf producers have their animals turned out on pasture and assume forage quality and quantity is adequate enough to meet both their intake and production goals. Therefore, many cow/calf producers operate on a low input system and do not supplement their cowherds during this time of year. In contrast, more intensive production systems, such as pasture-raised freezer beef, stocker, or background operators may supplement their cattle during this time of year to increase gains above that of what pasture alone can produce. However, another issue arises in that the greatest supply of WBG comes during a time of year when spoilage is likely to occur very rapidly if storage and feed out is not managed.

The combination of high humidity and high temperature climates, such as those found in the Southeast, is not conducive to the storage of WBG in an open environment. Typically, WBG stored in an uncovered pile during the hot summer months quickly deteriorates compared with WBG stored during the winter months, with the main driving factor of this difference being temperature (Nofsinger et al., 1983). Wang et al. (2014) evaluated surface spoilage ratings of WBG stored at 4 temperatures and found that surface spoilage started to occur and increased rapidly in WBG stored at temperatures of 35°C and 25°C after only 12 and 36 h of storage, respectively. Meanwhile WBG stored at 15°C did not have visible spoilage until hour 72, whereas WBG stored at 5°C showed no signs of surface spoilage throughout the same time period. Similarly, Nofsinger et al. (1983) looked at microbial counts of wet distillers grain stored with no preserving agent at 30°C for up to 10 d of storage and reported not only visible surface spoilage after 3 d of storage, but, even more worrisome, pH of the grains elevated from 4.1 on d 0 to 7.3 within the first 24 h. This surface spoilage from the growth of molds and yeast is primarily concerning due to the production of mycotoxins, which when fed, can have serious effects on animal health and production (Kemboi et al., 2020). In addition, as WBG storage conditions start to deteriorate and microorganism counts flourish, losses of DM and nutrients become of concern. In the work by Nofsinger et al. (1983), authors reported DM losses to range from 7.1 to 11.2% in WBG stored at 30°C. Likewise, Wang et al. (2014) reported a linear increase in DM loss with increasing storage temperatures, with the greatest DM loss of 27.8% occurring when WBG was stored at 35°C. In addition, CP, NDF, and water-soluble carbohydrates decreased linearly and quadratically as storage temperatures rose.

In aerobic conditions, high-moisture feedstuffs can easily spoil in warm climates, resulting in reduced feed intake and overall performance by ruminant animals. The most effective method of preserving WBG is to dry the product through the use of industrial dryers (Aliyu and Bala, 2011); however, this method is energy intensive and commercial dryers are not always available in areas where craft breweries are located. In an attempt to reduce spoilage and increase shelf life for on-farm storage, researchers have tried to store WBG with numerous additives or under various covered conditions. In a case study, Marston et al. (2009) attempted to preserve WBG with a commercially available lactic acid–producing bacterial preservative and found numerical reductions in yeast, mold, and *Clostridia* counts with increasing rates of preservative. In the same study, researchers also studied the effect of covering the WBG with a tarp and found variable results in its effectiveness. In a similar study, Moriel et al. (2015b) stored WBG with no additive, in a mixture with 15% of DM soyhulls, in a mixture with 30% of DM soyhulls, or with propionic acid and found that covering the WBG with plastic decreased loss of DM in all treatments except in WBG stored with propionic acid, where coverage had no effect. Furthermore, of the 4 storage treatments, the ability of propionic acid to act as an active fungicide resulted in the lowest total DM loss and lowest pH in the stored WBG on d 63 of storage. Further investigation into the use of propionic acid–based preservatives led Moriel et al. (2016b) to look into the best method of product application for this preservative. Authors found that a commercially available propionic acid–based product either mixed into or top-dressed on WBG decreased total DM losses on d 28 of storage compared with WBG with no additive, indicating that farmers may be able to use a form of propionic acid–based preservative application that is based on convenience.

Other preservation methods have focused on using dry feedstuffs as a means to create a blended silage with a more desirable moisture content or adding readily fermentable sugars like what is usually found when ensiling grass or legume forages. Nishino et al. (2003) attempted to ensile WBG either by itself or in a TMR with lucerne hay, dried beet pulp, corn, wheat bran, and molasses in a 5:1:1:1:1:1 ratio, respectively. Initially, the WBG ensiled as a TMR had a more complete soluble sugar profile and, after 60 d of ensiling, appeared to have undetectable yeast counts compared with WBG ensiled alone. Results from the fermentative profile at 5, 20, 40, and 60 d after ensiling indicated that WBG ensiled alone worked well for a brief period of time, but to increase shelf life, mixing with other feed ingredients may be necessary. More specifically, it has been suggested that selecting feedstuffs high in water-soluble carbohydrates may improve the fermentation profile of ensiled WBG, but Moriel et al. (2015b) reported impaired fermentation when mixing WBG with soyhulls at a rate of 15 and 30% of DM. Meanwhile, in a 28-d fermentation study, Ferraretto et al. (2018b) found pH and acid profiles that correlate with a good fermentation when WBG was mixed with various rates of dry ground corn, but these profiles were not found when WBG was ensiled alone. In a similar but contradicting experiment, Ferraretto et al. (2018a) analyzed WBG stored with either 25 or 46% dry ground corn over a 28-d period and found no benefit of adding the feedstuff over WBG alone.

Although some of these additives, including commercial silage inoculants, propionic acid, salt (Hatungimana and Erickson, 2019), and mixtures with other various feedstuffs appear to have promising results, their real-world application scaled to an on-farm setting is questionable. For example, the storage work done by Moriel et al. (2015b) was conducted in 19-L buckets, and the work by Ferraretto et al. (2018a) was conducted in 3.78-L laboratory bucket silos, where filtration of oxygen would have been minimal compared with that of WBG stored in piles on concrete or in bunker silos. Furthermore, to our knowledge, the extent of the storage work has mostly focused on the first 28 d of storage (Moriel et al., 2016b; Ferraretto et al., 2018a,b; Hatungimana and Erickson, 2019), with the longest work reporting up to 60 (Nishino et al., 2003), 63 (Moriel et al., 2015b), or 90 d (Schneider et al., 1995) of storage. However, in real-world applications, small- to medium-sized beef operations may receive WBG during the summer when supply is high and store them until they are needed during winter feeding. Case in point, more work is needed to determine how to logistically manage on-farm storage of WBG.

LOCAL INTEGRATION OF WBG IN NORTH CAROLINA

Despite the multitude of logistical challenges, incorporating WBG can be done successfully. Some of the challenges of having a WBG contract with a small- to medium-sized craft brewery is that the grain must be picked up every day, especially when the brewery does not have an onsite storage silo for the grain. In many cases, grains are often dumped into storage totes, barrels, or dump trailers, which are left on site by the producer and are readily accessible by the brewery upon completion of a brew. It is then the farmer's responsibility to empty the containers or dump trailer and leave the brewery with an empty container or trailer ready for the next brew to be dumped into. Sometimes, mechanical breakdowns at the brewery can delay grain pickup, and this may have to be done at unconventional hours.

In western North Carolina, there are 3 farm families that have worked together as a team to mitigate logistical challenges such as these and successfully incorporate WBG into their feeding programs. Some of their biggest accomplishments include the use of 3 dump trailers and a rotating 3-d pickup schedule for each family. The brewery that holds the contract does not have onsite storage and requires a dump trailer to be left at the brewery at all times. After brewing is complete each day, the full trailer must be picked up and an empty trailer dropped off. Each of the 3 families is scheduled to take an empty trailer and pick up a full trailer every third day. This schedule prevents each family from having to drive the 45-km round trip every day and allows them to use all of the grain in a 3-d window to prevent spoilage before getting the next shipment of WBG. Some of the benefits of using WBG expressed by these farmers included increased stocking densities on their farms, especially in an area where urbanization is happening at an increased rate; decreased need for stored forages; ability to sell more hay or open an additional farm enterprise; cows with better BCS; cows weaning heavier calves; adding a high-quality feedstuff into the feeding program; and adding good quality family time when making the trip to get the WBG. Using this team approach, it may be possible for small- to medium-sized beef cattle operations to take advantage of the rise of craft breweries in local areas.

APPLICATIONS

The craft brewing industry has seen major growth in the United States and now holds a 13.1% share of the total US beer market. The increase in demand for bolder flavored and independently produced craft beer has led to a rise in the production of WBG. Wet brewers grains are a byproduct of the brewing industry and are produced from the brewery after the malting and mashing process of beer production. Their nutrient profile, with high concentrations of CP, fat, and digestible fiber, make them a desirable feed for ruminant animals and have often been fed to dry, lactating, growing, and finishing cattle. However, nutrient concentrations in WBG from craft breweries can vary, and the decreased DM concentration can lead to logistical challenges during the hauling, storing, and feeding processes. On-farm storage and shelf life of WBG may be improved by using an additive or by storing under anaerobic conditions. In local communities, logistical challenges may be somewhat averted when several small- to medium-size beef cattle producers work together on a WBG contract.

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