Incorporating Dried Distillers Grains with Solubles in Sheep Supplementation Programs

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Summary

In the U.S., dried distillers grains with solubles (DDGS) is a highly available coproduct of ethanol and brewery industries utilized in ruminant diets that, due to the comparable nutritional quality, is capable of substituting (partially or totally) traditional sources of protein and energy with a possibility of reducing feed costs. With the use of this product, there is the potential to increase reproductive efficiency, survivability, growth performance, and meat production and quality when a well-designed supplementation program is implemented and monitored. However, the literature has scarce papers evaluating the effects of DDGS in sheep nutrition, notably in supplementation programs. The lack of DDGS utilization in sheep diets may be related to some challenges, such as nutritional composition variability, handling, storage, and feeding issues. In addition to addressing these challenges, an overview of the statistics and concepts applied to the ethanol and sheep industry will be presented here, as well as the criteria involved in the incorporation of DDGS into sheep supplementation programs. These latter factors include the interaction between pasture and supplement type, along with feeding and herd characteristics.

Key Words: Costs, Energy, Meat, Protein, Reproduction
Introduction

Dried distillers grains (DDGS) with solubles, which are a coproduct of the bioethanol and alcoholic beverage industries, have become a commodity for the animal feed sector in recent years. Particularly in the U.S., almost all ethanol production uses corn as a feedstock. In this regard, national ethanol production increased from 1.4 billion gallons in 1998 to 9.3 and 16.1 billion gallons in 2008 and 2018, respectively (USDA, 2019a), corresponding a 12-fold increase over those 20 years as a result of specific policies (EPA, 2019; EIA, 2019).

The dry milled ethanol production process, present in 91% of the approximately 210 biorefineries across the U.S., generates DDGS as a coproduct. Recent data (RFA, 2019) indicated the production of 37.3 million metric tons of DDGS from ethanol plants, of which one-third are exported, plus 1.0 million tons from beverage distillers. The USDA forecast for the next 10 years (USDA, 2019b) projected an increase of ethanol production. Thus, the availability of DDGS for the feed industry seems to be secure in the next decade.

Sheep flocks reached a peak of 55 million animals in 1884 (Connor et al., 1921). Since then, the numbers have declined, and the profile has been changing toward small-scale operations (USDA, 2019c). Currently, all sheep and lamb inventories total 5.2 million head (i.e., 52nd place in the world rank, proportionally 0.44% of the 1.2 billion head), with 3.0 million ewes (FAO, 2017; USDA, 2019d). Although the sheep industry accounts for less than 1% of U.S. livestock industry receipts, sheep operations are important to the economies of several states, mainly in the southern plains, mountain, and Pacific regions (USDA, 2019c). Even though the number of animals has declined in recent decades, lamb and mutton meat imports have increased, accounting for more than half of the U.S. supply (75% from Australia and 24% from New Zealand), and wool imports surpass exports. This clearly illustrates the potential and necessity of organization and improvements within the national sheep industry (USDA, 2019c; USDA, 2020).

Efficient and low-cost nutritional programs are important to reduce the effects of seasonality and offer to the market a suite of competitive and desirable sheep products. In this context, DDGS has been utilized in ruminant diets to replace partially or totally protein supplements and energy feeds. However, there are limited studies evaluating the effects of feeding sheep DDGS compared with other species, notably the utilization of this product in supplementation programs. The lack of DDGS inclusion in sheep diets may be restrained by a series of challenges that will be discussed in this paper. In addition, this article presents opportunities and how to incorporate DDGS into sheep supplementation programs.

Nutritional and Feeding Value of Dried Distillers Grains with Solubles

Despite the many advantages of using DDGS in sheep nutrition, there is a series of challenges, starting with the variability in chemical composition. Most ethanol in the U.S. comes from corn; however, sorghum, wheat, pearl millet, barley, and others also can be used as a source of starch for fermentation, which makes a considerable difference in the final DDGS chemical composition (Liu, 2012; Pedersen et al., 2014). Focusing on corn, the differences in varieties, geographic location, growth conditions (soil type, fertilizers, weather, etc.), degree of maturity, and harvesting methods are examples of factors that can affect the chemical composition of the grain and consequently DDGS composition (Kajikawa et al., 2012; USGC, 2018).

Additionally, differences in processing technologies among biorefineries influence the chemical composition, ruminal degradation, and nutritive value of DDGS (Jie et al., 2013; De Boever et al., 2014; Lee et al., 2016). Furthermore, new engineering technologies have been implemented that can affect DDGS composition, including 1) corn fiber separation for cellulosic ethanol production, 2) enhanced corn oil extraction methods, and 3) production of high protein (>40%) coproducts (USGC, 2018).

The removal of extra corn oil, for instance, affects the nutritional profile of DDGS, primarily by reducing the crude fat content, normally reducing the energy and increasing protein contents. As a result, the DDGS composition and nutritive value differ not only among plants but also among years of production from the same plant or even among batches (Belyea et al., 2010).

Thus, it is recommended to complete a chemical analysis of DDGS prior to use, because the actual values often differ from standard references (e.g., NRC) (Liu, 2012). Table 1 presents DDGS chemical composition data from corn ethanol plants.

The chemical composition of DDGS makes it a peculiar feed. It carries the potential to be included in animal diets to replace traditional sources of protein (e.g., soybean meal, cotton seed meal) and energy (e.g., corn, sorghum) due to the crude protein (CP) content (from 27 to 33%) and energy concentration (89.7% of total digestible nutrients, TDN; Nuez-Oortín and Yu, 2009), equivalent to 130% of the energy value of corn (Klopfenstein, 1996), as well as lower relative costs (Alshdaifat and Obeidat, 2019). The DDGS contains less CP and digestible protein but a higher TDN than cotton seed meal (Hoffman and Baker, 2011). Compared to sorghum grain, DDGS has lower nonfiber carbohydrates and higher fat, NDF, ADF, and CP contents (Trujillo et al., 2016).

For small ruminant production systems, the potential exists for DDGS to replace traditional and, most of the time, more expensive feeds (McEachern et al., 2009; Whitney and Braden, 2010). Furthermore, DDGS contains high levels of bypass protein (from 43 to 63% of total protein; Pecka-Kiełb et al., 2017) and sulfur (0.55%), both of which have been shown to enhance growth and animal fiber production (Castro-Pérez et al., 2013). Additionally, DDGS utilization reduces acidosis, a frequent issue in high-grain diets (Klopfenstein, 1996), by virtue of the proportion of NDF (40.5%). However, DDGS is deficient in lysine, which is the first limiting amino acid; therefore, it is necessary to combine DDGS with some feed rich in lysine, such as soybean meal (SBM, Todorov et al., 2013).

No papers were found comparing dry lot with grazing situation in terms of lysine deficiency in sheep. There are works showing response to lysine supple-
The high-fat content of DDGS (14.3%) works well for supplementation programs, where DDGS enters a relatively low proportion of the total diet, and fat increases the energy value of the ration and increases feed efficiency (i.e., gain:feed). On the other hand, DDGS can be an issue when used in larger proportions, for instance, in fattening feedlot diets. A fat content over 8% can depress ruminal fiber digestion, reduce intake, and suppress performance, mainly when forage is the primary source of nutrients (Palmquist, 1994; Pezzanite et al., 2010). The phosphorus (P) content in DDGS is high (0.78%). This characteristic can be an economic advantage, considering this element is the third most expensive nutrient in a diet, although P presence in excreta has been an environmental concern due to its pollutant potential (Liu, 2011). The calcium (Ca) content of DDGS varies considerably. In a given supplementation strategy, the mineral concentration of the supplement after mixing DDGS with other ingredients should be considered for the mineral formulation to meet the nutritional requirements of a specific flock and maintain an adequate balance among the minerals, notably the Ca:P ratio.

Dried distillers grains with solubles is known for its substantial sulfur (S) concentration. Sulfuric acids are commonly used in the dry-grind ethanol process to keep pH levels conducive to yeast cells that, in addition to natural corn and yeast sulfur concentrations, result in a byproduct that may contain considerable levels of this mineral. This can lead to concerns regarding pH, limitations in feed intake, and animal health (i.e., polioencephalomalacia) (Uwituze et al., 2011; Morrow et al., 2013; Drewnoski et al., 2014). In some parts of the U.S. such as rangelands in the West, drinking water also can be a major source of sulfur, increasing the risk of the aforementioned problems. Thus, caution is recommended. Water tests determining S level can help the nutritionist to calculate how much DDGS could be used as supplement. Increased water consumption when animals are fed diets with high levels of S (Neville et al., 2011) can aggravate the concern if the water contains considerable levels of S.

For ruminants consuming high-concentrate diets, the maximum tolerable level of S is 0.3%, according to the NRC (2005). However, works using DDGS in feedlot lamb diets with levels of S up to 0.8% have not reported any related problems (Neville et al., 2010; Neville et al., 2011; Morrow et al., 2013). In fact, the proportion of concentrate in supplementation programs normally is lower than in finishing feedlot rations, notably for ewes.

Lambs fed diets with more than 0.6% of S are at risk of developing polioencephalomalacia (Morrow et al., 2013). To prevent this disease in sheep, some research groups have suggested the administration of thiamine when 25 to 50% DDGS is included in the diet (Pezzanite et al., 2010); however, Neville et al. (2010) stated that thiamine did not appear to be necessary when DDGS is less than 60% of the diet.

The nutritive characteristics (i.e., high energy, CP, P, and S) and low acquisition cost make DDGS attractive for feeding sheep on rangelands and pastures. However, DDGS, like any feed source, may contain mycotoxins depending on, among other factors, the levels in the original grain feedstock, because there is very little degradation of mycotoxins during ethanol production (Liu, 2011). Mycotoxins, which are secondary metabolites produced by fungi (i.e., molds), are very stable molecules. The ingestion, skin contact, or inhalation of these fungal metabolites can cause illness or even death by mycotoxicosis (Gallo et al., 2015). Although ruminants are less susceptible than nonruminant species, mycotoxins can affect sheep health in many ways (Mostrom and Jacobsen, 2011). Indeed, an assessment of the prevalence and levels of mycotoxins in DDGS in the U.S. generally found concentrations below the FDA regulations, which can fall well

<table>
<thead>
<tr>
<th>Component</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>CV (%)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (%)</td>
<td>90.9</td>
<td>88.9</td>
<td>92.2</td>
<td>2.4</td>
<td>1, 5, 7, 9, 10</td>
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<tr>
<td>CP (%)</td>
<td>35.3</td>
<td>26.9</td>
<td>33.1</td>
<td>5.6</td>
<td>1, 2, 3, 5, 6, 7, 8, 9, 10</td>
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<tr>
<td>Fat (%)</td>
<td>14.3</td>
<td>10.8</td>
<td>13.7</td>
<td>7.2</td>
<td>2, 3, 5, 6, 7, 8, 10</td>
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<tr>
<td>NDF (%)</td>
<td>40.5</td>
<td>26.6</td>
<td>58.9</td>
<td>23.5</td>
<td>1, 2, 3, 6, 7, 8, 9, 10</td>
</tr>
<tr>
<td>ADF (%)</td>
<td>14.8</td>
<td>7.00</td>
<td>23.7</td>
<td>30.4</td>
<td>1, 3, 5, 6, 7, 8, 9, 10</td>
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<tr>
<td>Ash (%)</td>
<td>4.63</td>
<td>2.00</td>
<td>6.70</td>
<td>31.9</td>
<td>1, 2, 3, 6, 8, 10</td>
</tr>
<tr>
<td>Starch (%)</td>
<td>5.23</td>
<td>5.10</td>
<td>5.50</td>
<td>3.6</td>
<td>2, 5, 10</td>
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<tr>
<td>P (%)</td>
<td>0.78</td>
<td>0.68</td>
<td>0.90</td>
<td>10.4</td>
<td>3, 4, 8, 10</td>
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<tr>
<td>Ca (%)</td>
<td>0.11</td>
<td>0.03</td>
<td>0.29</td>
<td>102.2</td>
<td>3, 4, 10</td>
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<tr>
<td>S (%)</td>
<td>0.55</td>
<td>0.33</td>
<td>0.84</td>
<td>39.4</td>
<td>5, 6</td>
</tr>
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1 Cromwell et al. (1993).
2 Lodge et al. (1997).
3 Spiehs et al. (2002).
4 Belyea et al. (2004).
5 Belyea et al. (2010).
6 Kajikawa et al. (2011).
7 Belyea et al. (2004).
8 Olukosi and Adebiyi (2013).
9 Gauthier et al. (2019).
10 Ranathunga et al. (2019).
below any harmful concentration when DDGS is blended with other ingredients to mix the total ration (Zhang et al., 2009).

Color can vary in DDGS from light to dark and yellowish to reddish (Figure 1). The variations in grain and methods used among ethanol plants, plus the complex interactions of many factors during the process within a plant, lead to great variations in the color score (Jie et al., 2013). Both particle size and color had little correlation with the composition of DDGS (Liu, 2008). Lightness or darkness also did not seem to be related to chemical composition, except for ADF and ADIN, in which darkness is associated with increased concentrations of these constituents (Cromwell et al., 1993).

**Opportunities**

**Reducing Feeding Costs**

The increase in feed costs has challenged profit margins in all livestock systems (Johnson, 2016). Thus, it is imperative to search for alternatives to offset feeding costs without sacrificing the performance and quality of the final products (Tjardes, 2002). Dried distillers grains with solubles has gained popularity as feedstuffs for animal nutrition because of availability, nutritive value, and costs. More than a source of energy, DDGS has a considerable density of protein, that is the most expensive fraction of a diet (Sahin et al., 2013). Given the substitutability of DDGS for corn and SBM, DDGS prices are significantly related to these feedstuffs (Langemeier, 2020). In the past, DDGS used to be approximately 70 to 90% of the price of corn (Griffin et al., 2012). However, recent studies (Langemeier, 2020; Dennis and Erickson, 2021) showed prices of DDGS more expensive than corn 70% of the time in the last 5 years. Conversely, DDGS prices have always been below SBM. From 2007 to 2020, on average, SBM prices were 129% higher than DDGS (Langemeier, 2020). The costs of grazing forages also have increased. Therefore, supplementing DDGS in grazing situations may be profitable through increased market weight and decreased feeding costs (Morris et al., 2006; Griffin et al., 2012).

The feasibility of a supplementation program depends on both the cost of additional average daily gain (ADG) and the value of the additional ADG. However, the net return varies with DDGS cost and BW (Jenkins et al., 2009). Furthermore, the economic analysis of a supplementation program must measure the additional return and break-even on supplemental feed cost (Tjardes, 2002; Gadberry et al., 2010).

The use of DDGS likely will reduce feed costs, but the unitary cost (e.g., $US per pound) is relative to the amount produced, which is related to animal performance. For instance, if DDGS in the diet improved growth performance and the animal could be fed for fewer days, it would result in decreased costs. Even if higher inclusions of DDGS decreased feeding values but still resulted in comparable or better performance than a corn-based diet, it may be economically advantageous because of decreased input costs (Erickson et al., 2012).

As the literature evaluating DDGS for sheep supplementation is very scarce, many of our assumptions had to be taken from beef cattle. We found that DDGS has become a viable resource for supplementing growing cattle consuming forage-based diets. In the supplementation model based on pastures or hay (i.e., winter roughage supplementation), the introduction of DDGS has been economically viable, with a greater net return, probably because its inclusion in the diet increased performance and reduced the forage demand due to the higher content of nutrients in the DDGS compared to roughages such as forage or hay (Morris et al. 2006, Klopfenstein et al. 2008; Griffin et al. 2012).

The most prominent source of regional variation in DDGS utilization is the spatial dependence in its price relative to competing for feed ration inputs. Feed prices reflect supply and demand conditions and other region-specific factors unique to a market. Least-cost rations are formulated with the most cost-effective combination of inputs while meeting minimum nutritional requirements. The DDGS price and nutrient content determine its feeding value within least-cost ration formulas, and the volume of DDGS utilized in the diet is contingent upon its value concerning competing feed inputs (Johnson, 2016). When compared to commercial pellets, cubes, blocks, and tubs, the differential in favor of mixing a supplement on-farm with DDGS or to use it as a unique concentrate supplement might be economically attractive, despite the intensification in labor and extra feeding trough management. As DDGS prices fluctuate at the time of the purchase, extension agents and producers should evaluate local markets to compare its price with feedstuffs such as corn, sorghum grain, SBM, and CSM.

To obtain an accurate DDGS cost, one should not only consider the feed cost but also the final delivery cost, computing any additional costs associated with freight or storage. Hence, the size of the load and the distance of the supplier have an enormous influence on the final cost. Hauling small loads will increase the cost of the operation per ton of DDGS delivered. Shipping 24-ton loads per truck for short distances (up to 250 miles) is more common and cost-effective (Dooley and Martens, 2008).

In this context, for an owner of a

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**Figure 1. Color variation of dried distillers grain with solubles.**

Quadros, D.G. San Angelo, TX, 2019.  
Quadros, D.G. Champaign-Urbana, IL, 2014.
small sheep operation to reduce the costs of storage and mixing, one clever solution is to gather a group of neighbors, form a cooperative, and share a commodity barn and mixer. Mixing feed on site can result in substantial financial savings because it allows the use of mixtures with cheaper and regional ingredients, such as low-quality roughages as a source of fiber (e.g., hay, crop wastes), DDGS, minerals, and, depending on the category, grains to increase energy, and other protein feeds such as cotton seed meal.

Increasing Reproductive Efficiency and Lamb Production

It is known that nutrition before breeding and during gestation has a significant effect on the fertility of ewes and the development and survival rates of the resulting lambs (Robinson et al., 2006). The practice of increasing nutrient intake before and during breeding (“flushing”) can increase conception rates by increasing the number of eggs and the embryo survival rate (Shad et al., 2011). The utilization of DDGS in “flushing” supplementation can improve ovulation and fertility due to the high amounts of easily fermentable carbohydrates (energy) that provide fast access to glucose for follicular development as well as bypass protein, leaving large amounts of amino acids available to produce protein-based hormones such as growth hormone and insulin-like growth factor 1 (IGF-1) (Erdogan et al. 2018). In addition, the risk of acidosis in utilizing short-term feeding schemes with DDGS is lower than with other traditional sources of energy, such as corn and sorghum, due to the greater NDF content (Buckner et al., 2008). In rams, the inclusion of DDGS in their diets did not negatively impact reproductive traits (Crane et al., 2018).

Maternal nutritional regimens during different periods of gestation affect fetal development (Ford et al., 2007). Supplementation is expected to have a significant impact on enhancing fetal growth and survivability. For instance, high percentages of cereals increase rumen propionic acid, which is transformed into glucose in the liver and stimulates insulin secretion, which may increase the availability of nutrients required by the uterus for gestation (Harnon 1992; Radunz et al., 2011). Supplementation with DDGS can not only benefit the fetus but also have a strong positive effect on ewe BW and body condition score (BCS) (Van Emon et al., 2014; Torreão et al. 2014). In addition, gestational feed costs may be significantly reduced for ewes fed DDGS (Radunz et al., 2011). It is worth a reminder that an inappropriate dietary regimen, along with the presence of two or more fetuses, may cause toxemia of pregnancy and other metabolic disorders (Sigurðsson, 1991; Van Saun, 2000).

In sheep flocks grazing in rangelands, maternal undernutrition is common and has been associated with low BW, low vigor, and high mortality in neonatal lambs, mainly in twin or triplet births (Mellor and Stafford, 2004; Ford et al., 2007). Concentrate supplementation enhances lamb strength and locomotor ability, avoiding a delay in consuming colostrum, which could increase the morbidity and mortality of lambs, especially in extensive systems (Pedernera et al., 2018). Moreover, providing ewes with a high-energy supplement during the final stage of pregnancy greatly increases the amount and viscosity of colostrum, which increases lamb survivability, particularly in those bearing twin lambs, in response to the circulating concentrations of hormones and metabolites that influence the provision of glucose and lactose synthesis (Banchero et al., 2004).

Undeniably, milk is essential for lamb survival and growth (Gentil, 2010). Ewes consuming DDGS in their diets increased milk production due to the greater digestibility when DDGS replaced parts of barley grain and SBM in a conventional ration (Alshdaifat and Obeidat, 2019). Additionally, ewe milk yield has a positive effect on the lamb growth rate (Morgan et al., 2007).

Utilization of DDGS in creep-feeding supplements, which can increase weaning weights, thus helping the lambs attain feedlot weights faster, as well as in diets for drylot lambs on the ranch, are seen as opportunities for producers. In these situations, DDGS can replace (partially or totally) traditional and more expensive feed ingredients such as corn, sorghum, SBM, and cotton seed meal, reducing feeding costs without compromising growth performance and feed efficiency (Huls et al., 2006; Todorov et al., 2013; Crane et al., 2018; Hodges et al., 2020). Consequently, DDGS is indicated for growing and fattening lamb diets, constituting an economical and palatable protein and energy feed ingredient (Sahin et al., 2013).

Gastrointestinal nematode infections negatively impact the health and performance of infected animals and the economic results of sheep production systems, notably on rangelands and pastures (Mavrot et al., 2015). Nutrition can affect the ability of the animal to contain, overcome, and cope with the consequences of parasitism (Coop and Kyriazakis, 2001). Supplementation with dietary protein can enhance the expression of acquired resistance and increase resilience to the pathogenic effects of major nematode parasites of the abomasum (e.g., Haemonchus contortus and Teladorsagia circumcincta) and small intestine (Trichostrongylus colubriformis) in young and mature sheep (Van Houtert et al., 1995; Steel et al. 2003; Turner et al., 2016). Protein-supplemented animals produced higher plasma levels of parasite-specific immunoglobulin A (IgA), which is the major immunologic mechanism of inhibiting worm development and regulating worm numbers (Stear et al. 1995; Strain and Stear 2001; Steel et al. 2003). Supplementation of grazing lambs with DDGS increased growth performance and reduced anthelmintic applications and the risk of anemia due to internal parasites (Felix et al., 2012).

Challenges

Handling and Storage

Compared to other feedstuffs, DDGS has some intrinsic physical and chemical properties that affect handling and storage, such as the propensity for poor flowability (i.e., the relative movement of bulk of particles), bridging (Figure 2), and caking (when macroparticles are incapable of independent translations) (Ganesan et al., 2008a; USBG, 2018). Particle agglomeration and caking during transportation results in increasing costs related to break the bridges, worker safety issues, vehicle damage, and economic losses (Bhadra et al., 2017).

Many factors affect the physical properties of DDGS: moisture content (which also influences microbial growth
and consequently feed safety); humidity (the hygroscopic properties of DDGS can lead to bridging, caking, and reduced flowability during transport and storage); temperature (the most drastic is freezing of the moisture to form ice bridges); pressure (the bulk may be subjected to compaction due to vibration); and solubles and fat contents (Ganesan et al., 2007; Ganesan et al., 2008a; Clementso and Ileleji, 2010; USGC, 2018). Regarding the fat content, the extraction of corn oil from DDGS has become a common practice in the corn ethanol industry. Low-oil DDGS had a lower average particle size and a narrower particle size distribution than regular DDGS, which indicates a higher probability of compaction but more uniformity of handling (Bhadra et al., 2017). Additionally, particle size and particle size distribution play significant roles in flowability and other properties, such as bulk density, angle of repose (angle between the horizontal and the slope of a heap of granular material dropped from some elevation), and compressibility (Ganesan et al., 2008a). Because of variability, the bulk density of DDGS ranges from 365 to 590 kg/m³ (Bhadra et al. 2009; Clementso and Ileleji, 2010; USGC, 2018).

To overcome some of the handling and storage challenges of DDGS, anti-caking and flowability agents have been researched, and adapted-design feeders have been developed. Flow conditioners and anticaking agents (e.g., calcium carbonate, zeolite) have been used as additives at low concentrations (up to 2%) to keep steady or increase the flow rate (Ganesan et al., 2008a), although some works (Ganesan et al., 2008b; Johnston et al., 2009) have found no advantage to use them for preventing flowability and caking issues. Pelleting is another approach that a few ethanol plants have attempted to improve bulk density and flowability; however, the additional costs related to infrastructure and equipment requirements, additional storage space, and labor have constrained this practice (USGC, 2018).

The material and design of storage bins and feeders also can interfere with DDGS flowability (Hilbrands et al., 2016). Furthermore, the storage bin ought to be designed for optimal feed flow to avoid bridging and caking issues. As a dry feed, DDGS requires relatively minimal storage facilities. Delivery, storage, and loading areas should be protected from wind or moisture. In practice, storage areas (old sheds or high-ground sites walled off with large hay bales) can be surfaced with hardened clay, gravel, blacktop, or cement and covered with tin sheets and/or heavy tarps. Caution should be taken when storing dry coproducts in upright bins due to settling and bridging. On the farm, the bulk storage of DDGS can be made in 22.7kg (50-lb) sacks, 2-ton bags, or commodity barns (Figure 3).

Feeding

Supplement is subjected to animal sorting. Sheep are known by their sorting capacity (more than cattle and less than goats or deer), which, together with other physiological adaptions, is very important for species adaptation in different environments, including harsh conditions (Preston and Leng, 1987; Van Soest, 1994). When in a heterogeneously mixed-species pasture (e.g., rangelands), they can exercise diet selection by choosing the most nutritive plants and parts of the plants by using unique foraging styles, learned perception, and prehensile capabilities (McFarland et al., 1992; Bartolomé et al., 1998; Pittarello et al., 2017). The ability to select certain portions of plants is extended to mixed rations to some degree, which may result in an unbalanced intake of nutrients (not consuming enough or overconsumption), reduction of the nutritive value of the ration, alteration of rumen fermentation, increased risks of rumen disorders (e.g., acidosis), and ultimately affects digestion efficiency and production (Miller-Cushon and DeVries, 2017; Sari et al., 2018). Processing (e.g., grinding) and mixing feed ingredients are common practices attempting to prevent sorting by animals and ensure that daily nutritional requirements will be satisfied (Zinn, 2004).

Another practical concern related to supplementation, notably in rangelands, is nontarget species consumption, including wildlife (e.g., hogs, birds, deer, bison, and raccoons) and other livestock species (e.g., cattle and goats). Livestock and wildlife may compete for feed resources (Ranglack et al., 2015; Schieltz and Rubenstein, 2016). Before choosing the supplementation management option, sheep raisers and managers should be aware of the potentially signif-

Figure 2. Dried distillers grain with solubles (DDGS) “bridging up” in a commodity shed.
significant loss of supplemental feed by non-target animals (Lambert Jr. and Demarais, 2001). Feed consumption by other species will increase costs, reduce feed supply, and compromise the supplement plan and feasibility.

An additional challenge that can affect the predictability of sheep supplementation results is weather, i.e., wind, rain, and snow. Strong winds are typical in the U.S. central plains. Part of the roughage and other light ingredients can simply be blown by the wind. Rain can increase the moisture content, change the consistency, and reduce the intake of a given feed. The type and placement of feed troughs also can interact with rain influence. For instance, if the feeder is in a location favorable to water accumulation, the site easily can turn into a muddy area, and the normal trampling effects on soil density surrounding the feeder will increase the possibility of water accumulation and mud that can reduce supplement consumption and be a concern to animal health and welfare.

The effectiveness of a supplementation program can be affected by the individual intake variation, which is increased by excessive trough space, limited supplement allowance, self-fed supplements, feed and feed delivery equipment neophobia, and individual feeding of supplements (Bowman and Sowell, 1997).

Self-feeders can reduce labor. Intake limiters can be utilized to regulate the consumption. Sodium chloride (salt, NaCl) is commonly used as a limiter of supplement intake. Nel (1985) recommended the inclusion of salt in 25% of the supplement to restrict the intake by sheep. Other options of intake limiters used for ruminant production are ammonium chloride, ammonium sulfate, calcium hydroxide, urea, animal fat, among others (Schauer et al., 2004; Sugg, 2013). However, works testing intake limiters for sheep are scarce. If amount of DDGS or a mixed supplement effectively consumed cannot be controlled by intake limiters, self-feeders will be more suitable for finishing diets where maximum feed intake is required to get sheep to a marketable weight.

Automated feeding systems have been developed to reduce labor, control the amount supplement, and optimize flexibility. However, there is still lacking validation works testing them in the field.

**Sheep Supplementation**

In rangelands, native shrubs mixed with grasses may provide adequate nutrient levels for grazing sheep production, except for copper, which is deficient in most months of the year, especially during fall and winter (Ramirez, 2003). However, forage may be insufficient to meet the nutrient requirements of ewes during late gestation and early lactation, therefore concentrate supplementation at a rate of 1% of BW is recommended to enhance the BCS of ewes and birth weight, survivability, and growth rate of lambs (Chaturvedi et al., 2003). Supple-
Additional feeding can increase tenderness (Resconi et al., 2009) of typical lamb aroma and producing desirable odors and flavors (strange, rancid, and acid), generating a higher intensity of the meat, which was related to its effect on lowering the intensity of undertasty (Karim et al., 2007). Additionally, the inclusion of concentrate in lambs only (Ocak et al., 2006).

Lambs commence to consume some forage in the pasture after the first couple of weeks and can be weaned onto solid food at an early age (Michalk and Saville, 1979). According to these authors, offering an exclusive differentiated supplementation for lambs (creep feeding) may be used to increase lamb growth and reduce the competition of young lambs with their mothers since ewes will increase their liveweight at the expense of lamb growth. In addition, preweaning nutrition and gains might have a significant influence on postweaning performance and finishing liveweight (Bhatt et al., 2009).

Independent of the breed, supplementation is a key strategy for finishing lambs grazing on semiarid rangelands because the concentrate level is reflected in better growth performance and feed efficiency (Santra et al., 2002). Supplemented lambs had higher carcass yield, dressing percentage, and loin eye area than those managed on extensive rangelands only (Karim et al., 2007). Additionally, the inclusion of concentrate in the lamb diet improved the sensory quality of the meat, which was related to its effect on lowering the intensity of undesirable odors and flavors (strange, rancid, and acid), generating a higher intensity of typical lamb aroma and producing higher tenderness (Resconi et al., 2009). In addition, supplemental feeding can alleviate grazing pressure and consequently maintain long-term grassland productivity, avoiding overgrazing and desertification (Böising et al., 2014).

To implement a well-planned supplementation program in rangelands or established pastures, the first consideration is forage availability. If the forage is insufficient to attend the demand or it is unavailable (which becomes more of a dry lot scenario), hay, silage, baleage, or agricultural wastes should be provided.

Then, to recommend the proportion of DDGS and other ingredients in the feed mixture and the amount offered, the breed, size (weight), purpose (wool, meat), category of the herd (ewes, rams, lambs, weaners, wethers, hoggets, muttons), physiological state (pregnancy, lactation, flushing), and objective must be determined, because the animals will vary in terms of their nutritional requirements.

Interaction of Pasture Supplement

The interaction between the forage available (i.e., rangeland, grasslands, grass-legume mixed pasture, silage, hay, byproducts) and the supplement should be considered when a supplementation program is planned.

Rangelands are very significant in the American sheep production context. Rangeland is a land on which indigenous vegetation (predominately grasses, grass-like plants, forbs, or shrubs) is managed as a natural ecosystem (Mitchell, 2000). All rangelands present extreme spatial and temporal variability. Spatial variability occurs at scales ranging from the plant part to the regional level, while temporal variability ranges from a few seconds to a few years, resulting in a mosaic of patches characterized by fluctuations in forage quality and availability (O’Reagain and Schwartz, 1995; O’Reagain and McMeniman, 2002). Above-ground net primary production (ANPP) varies among years in response to interannual precipitation variability in mesic and semiarid rangelands, while in desert rangelands, ANPP does not respond as much to precipitation pulses because plant growth is limited by inherently low leaf area and plant density (Polley et al., 2013). Conversely, animals raised in rangelands require a relatively constant intake of nutrients to satisfy the requirements of metabolism, growth, and reproduction (O’Reagain and Schwartz, 1995). Thus, seasonal deficiencies in nutrients (protein and/or energy) are frequent in both arid and high elevation rangelands (DelCurto et al., 2000), and supplementation is required to mitigate nutrient deficiencies and the effects of plant secondary metabolites (PSM) toxicity (Kawas et al. 2010).

When low-quality roughages are not limited in quantity, protein is generally the most beneficial supplemental nutrient (DelCurto et al., 2000). Forage CP levels below 7%, typical in the dry season (Table 2), result in decreased forage intake due to decreased ruminal microbial activity, which reduces digestibility and the rate at which the particles pass throughout the rumen (passage rate) (Popp and McLennan, 1995).

Therefore, for sheep consuming dry pastures, the first limiting nutrient is usually rumen-degradable protein (RDP), especially in summer rainfall regions. Once RDP deficiencies are corrected, energy and possibly undegraded dietary protein (UDP) usually become the next limiting nutrients (O’Reagain and McMeniman, 2002). In contrast to protein supplements, energy supplements may decrease both the intake and digestibility of high-fiber low-quality forage; however, when the availability of

Table 2. Crude protein (CP) and dry matter digestibility (DMD) of North American rangelands in wet and dry seasons.

<table>
<thead>
<tr>
<th>Rangeland</th>
<th>Species</th>
<th>Forage type</th>
<th>Wet season CP (%)</th>
<th>Wet season DMD (%)</th>
<th>Dry season CP (%)</th>
<th>Dry season DMD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperate shrubland</td>
<td>Mixed grasses</td>
<td>G</td>
<td>7.0</td>
<td>53.0</td>
<td>5.0</td>
<td>42.0</td>
</tr>
<tr>
<td></td>
<td>Mixed shrubs</td>
<td>S</td>
<td>11.1</td>
<td>55.0</td>
<td>7.0</td>
<td>41.0</td>
</tr>
<tr>
<td>Subtropical shrubland</td>
<td>Mixed grasses</td>
<td>G</td>
<td>8.0</td>
<td>44.0</td>
<td>5.0</td>
<td>31.0</td>
</tr>
<tr>
<td></td>
<td>Forbs</td>
<td>F</td>
<td>19.0</td>
<td>59.0</td>
<td>11.0</td>
<td>53.0</td>
</tr>
</tbody>
</table>

1 G, grass; S, shrub; F, forb

Source: Adapted from O’Reagain and McMeniman (2002).
low-quality forage is limiting, energy supplementation becomes a viable alternative (DelCurto et al. 2000). In some cases, however, there is no effect or even increased utilization of grazed forage with energy supplementation, mainly when lower levels of supplementation are offered (Caton and Dhuyvetter, 1997).

Feed Characteristics and Herd Category

To adjust the proportion of the ingredients in a supplement, the herd category and the physiological stage of the animals should be considered as well as the season of the year. Under extensive grazing conditions, supplementation programs to overcome seasonal nutrient deficiencies usually need to be low in cost and targeted at reproducing or young growing sheep. In summer rainfall regions, spring lambing is the preferred option, and autumn-joined ewes in later stages of pregnancy or lactating, frequently grazing RDP-deficient pastures, should be supplemented. Ewes in late pregnancy and lactating, grazing dry pastures with low protein concentrations, may respond to UDP and RDP supplementation. The utilization of energy supplements to maintain liveweight or support pregnancy and lactation is usually suitable for the beginning of drought conditions (O’Reagain and McMeniman, 2002).

Microbial proteins are synthesized from RDP or nonprotein nitrogen. Microbial protein is adequate for maintenance, slow growth, early pregnancy, and low milk production. Rapid growth, late pregnancy, and high milk yields (early lactation) require dietary protein that escapes ruminal degradation (Abbott, 2018), as shown in Figure 4.

Feeding ewes diets with higher TDN and CP during late gestation affects the performance of lambs at weaning (Torreão et al., 2014). Most likely, a greater concentration of metabolizable protein during the third trimester of gestation supports the improvement of offspring growth performance due to enhanced placental or mammary gland function (Van Emon et al., 2014). The supplementation of ewes during pregnancy results in a higher BCS at weaning, most likely because they can deposit more body fat reserves during lactation. At the end of pregnancy, the nutrient demand increases, as 60% of fetal growth occurs during this period. At this stage, an inappropriate dietary regimen, along with the presence of two or more fetuses, may cause toxemia during pregnancy (Van Saun, 2000).

The energy intake of lactating ewes has important effects on the volume of milk produced, milk energy yield per day, and lamb growth (Wilson et al., 1971). During lactation, nutrition deserves more attention because ewes can be in three distinct phases of nutritional requirements. First, and this usually occurs during the first weeks postpartum, the ewe has a negative energy balance because milk production is increasing and intake has not yet reached its peak; thus, the animal mobilizes body reserves. Second, the energy balance was zero, as milk production declined, and females reached the peak dry matter intake. Finally, in the third phase, when the energy balance is positive, body reserves are replenished (Tedeschi et al., 2010).

When the goal is to obtain early spring lambs, supplemented ewes increased BW during the lactation period, while without supplementation, they lost weight, mainly among the ewes suckling lambs that were not creep-fed (Jordan and Gates, 1961). Increasing lamb performance from birth to weaning results in postweaning feed efficiency and reduces feeding costs when considering the entire production cycle of sheep meat (Galvani et al., 2014). Early creep feeding showed a positive effect on BW gain and facilitated the transition from monogastric to a ruminant, buffering the weight loss of the lambs after the milk production peak of their dams (Abou Ward, 2008; Martínez et al., 2015). In addition, the supplementation of lambs by creep feeding can reduce the dependence on anthelmintic treatment (Melo et al., 2017).

In a supplementation program, it is important to consider the protein-energy relationships because animal performance depends mainly on the supply of amino acids (AAs) and energy-yielding substrates delivered to the tissues (Popp and McLennan, 1995). There is evidence (Archibeque et al., 2008) that DDGS, as a supplement for forage-fed sheep, can improve the absorption of AAs. One step before that, however, is to provide substrates for rumen microbiota growth. Indeed, utilizing DDGS to formulate supplements for sheep is an opportunity to deliver rumen degradable (30–50%) and undegradable (50–70%) protein as well as a considerable concentration of energy and fiber (Meachern et al., 2009; Belyea et al., 2010; Castillo-Lopez et al., 2013; Gao et al., 2015). Urea is a low-cost alternative to be added to the supplement to increase CP and RDP contents (Golluscio et al., 1998). However, positive responses to urea supplements are more variable in grazing sheep than in cattle, partly because of sheep grazing selectivity.
Therefore, higher-quality diet intake provides enough RDP to support rumen fermentation. Furthermore, there is a large individual variability in supplement intake that can result in urea toxicity in some animals and variation in performance (Dove, 2002). Dietary supplementation with DDGS is safer than urea and increases rumen ammonia and total volatile fatty acid (VFA) concentrations in sheep (Radev, 2012).

Depending on the type and quantity of supplement offered and the quality of the forage available, the voluntary forage intake (VI) can be reduced (substitution effect), increased (complementary effect), or unaltered (additive effect) (Dove 2002; Kawai et al., 2010). Concentrate feeding stimulated the intake of low-quality forages, was additive with a medium-quality forage, and reduced the intake of a high-quality forage (Huston et al., 1988). Supplements increased VFI when the forage total digestible nutrients (TDN):CP ratio was greater than 7 (N deficit) (Moore et al., 1999).

The DDGS is classified as a protein feed. The true protein supplements also include plant protein sources, such as grain legumes (e.g., lupins, vetches), pulses (e.g., peas, fava beans), oilseeds and oilseed meals (e.g., whole cottonseeds, cottonseed meal, SBM, sunflower meal), plus animal protein sources, such as fish meal (O’Reagain and McMeniman, 2002). However, due to its energy content, DDGS also can replace partially or, depending on the animal category, totally, the energy high-carbohydrate feeds such as corn, sorghum grain, millet, barley, wheat, and oats. Research has shown (Wysocka et al., 2015) that DDGS is a source of inexpensive and highly available proteins. Most of the studies were conducted in feedlot, though. A recent review (Neville et al., 2021) provided an overview of research on growth performance and carcass characteristics and addressed some of the perceived barriers to increasing the use of DDGS in lamb feedlot rations.

Dietary additives (e.g., buffers, anaerobic hormones, feed enzymes, synthetic amino acids, essential oils, and microorganisms) have been used to improve animal performance and efficiency, prevent certain diseases, and preserve feeds (Azzaz et al., 2015). The mode of action of feed additives is generally to manipulate the rumen fermentation environment, bring improvements in ruminant nutrition by increasing feed conversion efficiency and productivity, stabilize rumen pH to reduce acidosis risk, increase DMI, reduce methanogenesis, enhance rumen development and stability during dietary transitions, reduce pathogen load and shedding, improve meat quality, and buffer against dietary health risks (e.g., mycotoxins) (Frater, 2014).

The most important and widely used feed additives in ruminant diets are ionophore antibiotics (e.g., monensin, lasalocid, laiddomycin propionate, salinomycin, and narasin), but feed enzymes, probiotics (live microbial feed supplements), buffering agents, methane inhibitors, and many other additives are used depending on the situation (Mackie et al., 2002; Azzaz et al., 2015). Another additive that has been studied is polyethylene glycol. This substance can reduce the antinutritional effects of condensed tannins and improve the feeding value of many plants in a rangeland (Navaz et al., 2011; Bailey et al., 2019). However, the effects of the inclusion of these additives in supplements for ruminants in rangelands or fed high-forage diets on animal performance or efficiency vary considerably (Huston et al., 1990; Kunkle et al., 2000; Piñeiro-Vázquez et al., 2009; Nagpal et al., 2015). Therefore, in a commercial sheep operation, their applicability must be carefully analyzed, case by case, by the nutritionist.

5.3 How to Incorporate DDGS into Sheep Supplementation Programs

The most economical way to incorporate DDGS into the sheep supplementation program at the ranch level is to purchase DDGS in bulk from a commodity broker, then store and mix feed on site and feed each category of animal according to the nutrient requirements and performance objectives. In addition, the size of the business in terms of the number of animals, infrastructure, and investment capacity should be considered during the process of decision-making regarding the best management practices for DDGS in the production system.

Figure 5 is a diagram that shows the process of incorporating DDGS in a sheep supplementation program, including purchasing, trucking, storing, mixing, and feeding.

Very limited studies were conducted studying DDGS in sheep supplementation programs. From a practical standpoint, DDGS can be included in supplementation programs for all sheep categories and physiological phases, such as ewes (breeding, gestation, lactation), rams, and lambs (preweaning and post-weaning).

Ely et al. (1991) evaluated the utilization of 1/3 of the diet of DDGS vs. SBM to feed ewes with twin lambs from 14 to 56 days post-partum (using fescue-hay based diets) and discovered that ewes fed DDGS lost less weight and produced greater total milk fat per day. Distillers grain with solubles can be used as a protein supplement to low-quality forage, most likely during mid-gestation or when ewes are not pregnant (Pezzanine et al., 2010). According to these authors, levels of 0.5% to 1.0% of BW daily of DDGS can be fed to ewes consuming low quality forages, and during late gestation and lactation, DDGS can be used as a source of protein or energy depending on forage quality.

According to Held (2006), ewes fed a DDGS supplemented diet produced 16.5% more milk fat per day. Their lactation study, evaluating the use of DDGS to replace 2/3 of the corn, resulted in a

Figure 5. Diagram of how to incorporate dried distillers grain with solubles in a sheep supplementation program.
12% improvement in reared lamb growth for ewes nursing triplets. They also discovered that ewes fed DDGS had greater BCS at parturition and at weaning than those fed corn or haylage rations.

Radunz et al. (2011), comparing winter-feeding systems with haylage, limit-fed corn, or limit-fed DDGS (~1.2 lbs/day), reported the heaviest BW of ewes at parturition when DDGS was fed. Ewes fed corn and DDGS had greater BCS at parturition than haylage, and at weaning, ewes fed DDGS had greater BCS than those fed corn or haylage rations. Body weight of lambs at birth tended to be heavier from ewes fed corn and DDGS compared to haylage, but there was no effect of ewe gestation diet on lamb weaning weight. Body composition of lambs at birth, ewe milk production, as well as preweaning lamb growth rate and mortality were not affected by feeding program.

Van Emon et al. (2015), testing diets with different levels of metabolizable protein contain up to 43% of DDGS, observed DDGS supplementation during the last period of gestation had a strong positive effect on ewe BW and BSC, but minimal effect on lamb birth weight and development after birth.

Erdogan et al. (2018) found DDGS can be included as protein source in pregnancy rations up to 15% of DM to obtain reproductive performance outcomes equal to or exceeding those obtained with SBM. They also reported no significant differences in BW or BCS among the groups fed DDGS or SBM at either the start or the end of the flushing period, with no significant effect on lamb weight at birth.

Alshdaifat and Obeidat (2019), testing a diet with 50:50 roughage:concentrate ratio, with up to 30% of DDGS and approximately 2.4kg/day (5.3 lbs/day, 30% of DDGS) for nursing ewes for 8 wk, obtained increased milk production and no effects on milk composition with the increasing of DDGS in the diets, whilst being cost effective.

Knowing that supplemental feed costs is a significant factor in profitability and sustainability of rangeland sheep production systems, especially during winter months and periods of drought, we believe that 60% DDGS based supplement can be used for ewes with positive effect on pregnant ewe productivity, lambing rate, and health, and lamb weaning weight feed, while costs can be reduced by 30% compared to commercial pelleted supplements. For rams, based on the work of Crane et al. (2018), it expected no negative effects in the reproductive traits due to increasing DDGS in the diet at levels up to 45%. For lambs preweaning, creep-feeding at 1% increased ADG and minimized forage quality fluctuation (Santos et al., 2018). When used as a feedstuff for growing/finishing lambs, DDGS can be fed at a level of 25% to 50% of the diet dry matter (Pezzanite et al., 2010). After studying 2.5% of BW of DDGS for finishing lambs on pasture, Felix et al. (2012) observed DDGS-supplemented lambs had greater ADG (double) compared to the lambs that had not received supplementation, and DDGS supplementation reduced the percentage of lambs requiring treatment for internal parasites.

**Final Remarks**

Dried distillers grains with solubles is undoubtedly a great source of protein, energy, and other nutrients in ruminant diets, with possible cost-benefit advantages when compared with other traditional feed ingredients. Therefore, its inclusion in sheep supplementation programs is recommended, since the interactions among pasture, supplement, feeding characteristics, and herd category have been used to align the supplementation plan with the expected and measured reproductive efficiency and growth performance.

Currently, U.S. research efforts have focused on the effects of DDGS on ruminal fermentation, methane production, digestion, N balance, and animal performance. Another line of research is about the effects of drying and other DDGS manufacturing processes on RDP and RUP and the postruminal digestibility of RUP. Additionally, some research groups have evaluated how color can be used as an indicator of the nutritional quality of DDGS.

Upcoming U.S. research may evaluate how novel corn ethanol conversion processes can affect the uniformity and nutritional value of DDGS, for instance, high-protein and reduced-oil DDGS. Food safety has increasingly assumed a key role in ruminant production systems. Consequently, methods to minimize the risks of spoilage during transit and storage have been developed, and research to understand how corn growing conditions can affect aflatoxins and other mycotoxins in DDGS has been conducted. Another trend is to study the potential solutions to overcome flowability problems, such as the effects of particle size, temperature when loading, moisture content, the proportion of solubles added to the grains, and the number of times DDGS has been handled and unloaded during transit.

Compared to beef and dairy cattle, DDGS has been insufficiently studied for small ruminants. In parallel, the producer’s assistance is deficient in this field. Thus, more research and extension are necessary to develop feasible models of including DDGS in sheep diets to increase yield and reduce costs, contributing to amplifying the popularity and market of sheep products, notably lamb meat and processed meat products.

**Literature Cited**


