Byproducts for Dairy Cows: Unlocking Their Value and Dealing with Their Limitations

P.J. Kononoff, Ph.D.
Department of Animal Science
University of Nebraska-Lincoln, Lincoln, NE
Email: pkononoff2@unl.edu; Twitter: @rumen8er

INTRODUCTION

Byproduct feeds have long been fed to ruminant animals. For example, an ancient Greek writer noted that in an attempt to supplement poor pastures, sheep on the Greek island of Ceos were fed fig leaves, olive leaves, and plant husks (Wilson, 2006). Today feed byproducts still originate from many human activities such as the production of food, fiber, beverages, and more recently bioenergy industries. Many byproducts are produced and available in large quantities and sold as commodities across the country and world; but it is also important to remember that byproducts produced are usually a secondary objective of some process (Crawshaw, 2004). Although they may contain a high concentration of nutrients and improve palatability of dairy rations; their existence, chemical composition, and nutrient availability may be affected by changes in the primary industry and production process. Nonetheless, the dairy industry has historically welcomed the availability of new byproducts and has also learned to adapt to changes in those commonly offered. Obviously, the type of byproducts vary by geographical location, but the objective of this work is to outline some major byproducts used by the dairy industry in the mid-south region of the U.S. and to outline their origin, chemical composition, and nutrient availability.

CORN MILLING BYPRODUCTS

Dry Milling

The dry milling industry produces the following feed products; distillers grains (**DG**), distillers grains and solubles (**DGS**), and distillers solubles (**DS**). Depending on the plant, and whether it is producing wet or dry feed, the proportion of DG and DS that are mixed together may vary. However, our current estimates are that wet distillers grains (**WDG**) + DS are approximately 65 % DG and 35 % DS (DM basis). Distillers grains (and DS) will hereby be referred to as either wet distillers grains (**WDDGS**) or dry distillers grains (**DDGS**) and our assumption is that both contain some solubles. The dry milling process is relatively simple. Specifically corn (or possibly some other starch sources) is ground, fermented, and the starch converted to ethanol and CO_2. Approximately 1/3 of the DM remains as the feed product following starch fermentation. As a result, all the nutrients are concentrated 3-fold because most grains contain approximately 2/3 starch. For example, if corn is 4 % oil, the WDDGS or DDGS will contain approximately 12 % oil; however more recently some of this oil is removed through centrifugation and the crude fat (**CF**) of these feeds may be as low as 6 %.

Feeding Distillers Grains to Dairy Cattle: How Much Can We Feed?

The American dairy industry consumes about 42 to 46 % (National Corn Growers Association, no date; Renewable Fuel Association, 2008) of the total DG produced in the U.S. Several studies have shown the effects of utilizing DG in dairy rations. It has generally been demonstrated to be an effective feed when incorporated into dairy feeding systems as it supports similar or higher milk yield than compared to control diets (Schingoethe et al., 2009). In feedlot diets inclusion of 20 % DDGS (DM) has resulted in greater economic returns (Buckner et al., 2008). It is likely that in dairy rations inclusion of DDGS results in a similar situation as it can replace proportions of highly priced feedstuffs, such as corn and soybean meal and even forages.

Even though DDGS have a valuable nutritional composition, dairy nutritionists tend to limit the inclusion of DDGS to 10 % of the dietary DM (Janicek et al., 2008; Schingoethe et al., 2009). Historically one reason for this is that the fat content was high, generally ranging between 10 and 12 % (Kleinschmit et al., 2006; Schingoethe et al., 2009). This may result in milk fat depression (**MFD**) due to the high content of polyunsaturated fatty acids (**PUFA**) present in DDGS, which has been observed experimentally. For example, Leonardi et al. (2005) reported a linear decrease in milk fat percentage as the inclusion of DDGS increased in the diet. This reduction was only significantly different between 10 and 15 % DDGS when milk fat dropped from 3.33 to 3.24 %. Similarly, Hippen et al. (2010) reported that DDGS fed at 20 % of the diet resulted in a reduction in the concentration of fat in milk. These changes were slight and not very dramatic as diets with no DDGS averaged 3.21 % and 3.13 lb of milk fat; whereas diets with DDGS averaged 3.03 % and 2.82 lb. The reason for this reduction in milk fat is likely due to the high ruminal load of PUFA that may affect the extent of biohydrogenation and lead to accumulation of *trans* fatty acids that may ultimately cause MFD. The recent reductions in fat content of DDGS make the threat of MFD less likely (Ramirez-Ramirez et al., 2016)

When formulating a ration containing DDGS, nutritionists and producers must be careful to take into account not only the amount of neutral detergent fiber (**NDF**) in the diet but also the source of NDF. Ethanol byproducts have high content of fiber (from the bran fraction of the corn kernel); however it may not be effective fiber, meaning that it does not elicit high rates of ruminal motility, rumination activity, and saliva production. The end result of these factors is that ruminal pH may drop, leading to ruminal acidosis; which has the potential to exacerbate the negative effects of a high load of PUFA in the rumen. It is critical to fully understand the nutritional composition of DDGS, particularly as the fat content; nonetheless, it can also replace corn, which lowers the starch content of the diet and decreases the risk of developing low rumen pH (Ramirez Ramirez et al., 2015).

Nutrient Variation and Distillers Grains and Solubles

Investigations have demonstrated that there may be a high degree of variation in the nutrient content of co-products, such as DG, both within and across production plants (Knott et al., 2004; Spiehs et al., 2002). For example, Knott et al. (2004) demonstrated that the crude protein (**CP**) level in DG may range from 25 – 35 %, with variation also observed in fat (10-12 %), NDF (8-10 %) and phosphorus (0.8 – 1 %). These investigators note that one of the greatest sources of nutrient variation for DDG depends on the amount of solubles that were added to the grains. Along with the concentration of CP, the availability of these nutrients may also vary. Hence researchers are beginning to direct their attention towards creating practical methods for controlling this variation. Research from The Ohio State University (St-Pierre and Weiss, 2015) suggests that routine feed sampling is essential. Because it may be difficult and time consuming to sample and formulate rations based on lab results of individual loads, numerous load samples should be collected and analyzed over time. This will allow for estimation of the mean values and also the variation of these estimates. Consequently, it becomes possible to protect against underfeeding a nutrient, such as protein, by feeding an anticipated mean value of the feed.

Wet Milling

Compared to the dry milling process, the wet milling process is the more complex of the 2 because the corn kernel is partitioned into several components to facilitate high value marketing. For example, the oil is extracted and sold and the corn gluten meal, that contains a large amount of bypass protein, is commonly marketed to the dairy, poultry, or pet industries. Wet milling is a process that requires use of high quality (No. 2 or better) corn that results in numerous products that are produced for primarily human use. During this process, corn is *steeped* and the kernel components are separated into corn bran, starch, corn gluten meal (protein), germ, and soluble components. Wet corn gluten feed (**WCGF**) usually consists of corn bran and steep, with germ meal added if the plant possesses the capabilities. Wet CGF can vary depending on the plant capabilities. Steep liquor contains more energy than corn bran or germ meal as well as protein (Scott et al., 1997). Therefore, plants that apply more steep to corn bran or germ meal will produce wet CGF that is higher in CP and energy. Wet CGF contains 16 to 25 % CP, with a rumen undegradable protein (**RUP**) value of approximately 24 - 30 % CP (NRC, 2001). During wet milling, corn gluten meal is removed and marketed in higher value markets. Corn gluten meal *should not* be confused with CGF, as corn gluten meal contains approximately 60 - 65 % CP and a RUP value of approximately 64 - 75 % CP (NRC, 2001). Distinct differences exist for WCGF, even within companies, due to plant-to-plant variation.

A number of studies demonstrate the general concept that traditional forages may be partially replaced and byproducts may be included to maintain milk production. For example, VanBaale et al. (2001) observed that when fed diets containing 20 % WCGF, cows consumed more DM and produced more milk than those consuming diets higher in alfalfa hay, corn silage, and corn grain. Boddugari et al. (2001) demonstrated that a wet corn milling product, similar to WCGF, may be effective in diets for lactating dairy cows. When used to replace concentrate, the product could be included at 45 % of the ration DM and at over 60 % when used to replace corn and forage. In a feeding trial these investigators also observed that, on average, cows consumed less feed but produced over 10 lb more milk when the WCGF replaced 50 % of the concentrate and 30 % of the forage of the control diet. These results suggest that the optimal inclusion level depends upon the feedstuffs being substituted for, as well as other ingredients contained in the ration.

Clearly the dairy cow is adaptable and can use non-traditional feedstuffs as sources of nutrients to make milk; however there clearly are limitations to her abilities. In a study designed to test the inclusion of corn gluten feed, Rezac et al. (2012) formulated diets in which both corn silage and alfalfa were completely removed from the ration and substituted with CGF and tallgrass prairie hay. On average, the complete removal of corn silage and alfalfa resulted in a reduction in the concentration of NE_L from 0.74 Mcal/lb to 0.72 Mcal/lb and resulted in a reduction of almost 5 lb of energy corrected milk (**ECM**). Certainly these results are not ideal; but the rations used in the study were dramatically different. For example, the concentration of starch was reduced from 21 to 13 % and forage NDF was reduced from 15 to 11 %. These treatments were designed to test strategies that could be used when the availabilities of traditional forages are poor and feeding conditions are not ideal. A more recent study evaluated the inclusion of WCGF at 20 or 30 % of the diet DM (Shepherd et al., 2014), both concentrations of inclusion maintained milk production and composition, but the authors suggested that the increase to 30 % requires careful consideration of effective fiber. Care should be taken to ensure that animals are consuming enough forage NDF to maintain healthy rumen conditions.

Effective Fiber Corn Milling Co-Products

Effective fiber is the portion of the diet that is believed to stimulate rumination, chewing activity, and saliva secretion; all of which is designed to help to maintain healthy rumen function and pH levels. Nutritionists are often concerned about rumen pH because, when pH levels fall below 6.0 fiber digestion may be impeded and milk fat levels may become depressed (Russell and Wilson, 1996). It is believed that rumen pH is a function of lactic acid and VFA production and is buffered by saliva (Maekawa et al., 2002). Because of this finding, it is a common practice to feed diets of longer particle size; therefore a greater amount of effective fiber, so that salvia production is stimulated. In support of this hypothesis, Krause et al. (2002) noted that the intake of particles > 19.0-mm was negatively correlated with the amount of time rumen pH was below 5.8. However, it is also known that diets should not be excessively long or coarse as they are more difficult to mix and may induce cattle to sort out ration ingredients (Kononoff et al., 2003). When co-products are used to substitute forage in the TMR, chewing activity is believed to be reduced due to the finer particle size. Nutritionists should not necessarily use this logic to infer that feeding co-products will result in lower rumen pH. In fact it is likely that diets may be balanced so that the inclusion of co-products will not influence rumen pH. When evaluating a dairy diet to determine a possible risk of subclinical acidosis, it is important to also consider levels of fiber and non-structural carbohydrates, along with their associated fermentability (Yang et al., 2001). Currently it is difficult to find robust feeding recommendations for effective fiber. Recently studies in which byproduct NDF replaced forage, concentrate, or both; have been conducted (Bradford and Mullins, 2012) and in some cases provide good examples for formulation but research on a field-ready, robust system to estimated effective fiber is still needed. Without this system it is wise to follow particle size recommendations previously established, which suggest that 3-8 % of the TMR should be retained on the top (19 mm) screen of the Penn State Particle Separator and 30 - 40 % should be retained on the second (8 mm) sieve (Heinrichs and Kononoff, 2002).

CANOLA MEAL

Canola is a trademarked name for rapeseed which contains < 2 % erucic acid in the oil and < 30 µmoles of alkenyl glucosinolates/g of oil-free DM. As a result canola meal contains less erucic acid and glucosinolates than conventional rapeseed meal (Bell, 1993). This is important because glucosinolates are bitter and negatively affect palatability and may even impair the uptake of iodine and interfere with the synthesis of thyroid hormones (Woyengo et al., 2016). In a summary of publication studies Huhtanen et al. (2011) reported that when fed to dairy cattle canola meal was at least as good as soybean meal and that some improved responses are due to increases in feed intake. It should however not be forgotten that feeding high concentration of canola meal may affect iodine status of the animals. Although feeding additional iodine to cattle has been shown to improve iodine status (Weiss et al., 2015), this practice is not common and additional research and recommendations must be made to fully understand the potential effects on humans consuming this milk.

OTHER NONFORAGE FIBER SOURCES

In a study designed and conducted at the William H. Miner Research Institute (Chazy, NY) to test the impact of feeding rations lower in both starch and forage, 4 treatments were formulated to contain decreasing proportions of forage (52, 47, 43 and 39 % of diet DM) by increasing the proportion of non-forage fiber sources (**NFFS**), namely wheat middlings (Farmer et al., 2014). Additionally, in an attempt to maintain energy and effective fiber in the rations, these investigators increased the proportion of rumen protected fat and wheat straw as the proportion of forage was reduced. In this study, DM intake increased with reducing forage but no differences were observed in milk production or composition. Interestingly, these ration strategies successfully maintained milk production over 94 lb/d and 3.6 % fat and 3.0 % protein. It should be noted while reducing forage in the ration, that this strategy involved careful attempts to maintain effective fiber. The reduction of forage did reduce the proportion of particles greater than 8.0 mm; however, no reductions were observed in rumination times, which suggests that effective fiber was still adequate.

In a similar study, Hall and Chase (2014) tested the impact of feeding varying proportions of chopped wheat straw and sugar beet pellets, which replaced a portion of both corn and alfalfa silage. Specifically forage was reduced from 61 % of the diet DM in the control to 40 % in the treatments containing variable mixes of straw and beet pulp pellets. The study included 48 cows in late lactation (average days in milk = 280 ± 79) and although the inclusion of the straw and beet pellets resulted in an increase in feed intake, the investigators successfully maintained fat and protein corrected milk yield. The partial replacement of forages with NFFS in close-up diets has also been evaluated at the William H. Miner Research Institute (Dann et al., 2007). In that study, oat hay was reduced from 30 to 15 % and beet pulp was increased to 15 % and fed to 64 cows from d -21 relative to expected calving date. Despite pronounced differences in ration particle size no differences were observed in periparturient intake or metabolism of production.

In vitro Laboratory Measures to Understand the Fermentability of Fiber

Today a number of assays are commercially available that attempt to measure the nutritional value of rumen feeds. For example investigators at Cornell University have developed an assay which attempts to estimate the RUP and intestinal digestibility of RUP (**dRUP**) in feed samples (Ross et al., 2013). Additionally, investigators at University of Wisconsin have developed an *in vitro* NDF fermentation assay to estimate total-tract digestibility (**TTNDFD**; Lopes et al., 2015a,b). Assays such as this hold great promise as the cost of routine testing feeds *in vivo* is prohibitive. These methods may be useful in screening feeds for differences between sources or manufacturing facilities. For example we have recently used the TTNDFD assay to test for differences in fiber digestion between DDGS originating from different corn-ethanol facilities (Dufour et al., 2017). In this study TTNDFD was observed to be 65.5 ± 1.59 % and differences between production sites were observed with differences > 10 %. It is difficult to identify driving factors responsible for observed differences in TTNDFD, but results support the notion that in addition to differences in chemical composition (Spiehs et al., 2002) differences in nutrient availability also exist between production facilities. The TTNDFD method represents an important and powerful tool to estimate *in vivo* fiber digestibility; but it should also be noted that the method does not account for selective retention of feed particles in the rumen (Huhtanen et al., 2007; Lopes et al., 2015b) which is affected both by particle fragility and particle size (Grant, 2010) and as a result it may be difficult to compare estimates of TTNDFD across feedstuffs.

CONCLUSIONS

The dairy cow is adaptable and can use byproduct feedstuffs as sources of nutrients to make a high quality food, namely milk. Although there are limitations in her ability to do so, extensive research has been conducted on the topic. This research on inclusion levels, chemical composition, and nutrient availability helps us understand how these byproducts can be included in a formulation. The dairy industry will continue to make extensive use of feed byproducts and the availability, type, and composition will likely change over time. To overcome these changes the practice of regular and consistent characterization of feed is important.

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