Review Article

Pertinence of Maize Wet Milling By-products in Ruminant Feeding-A Review

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Abstract

Limitation of conventional feed resources for livestock, particularly the concentrates, leaves a huge scope for the utilization of agro-industrial by-products. Maize gluten meal (MGM) and maize gluten feed (MGF) are the by-products of maize wet milling process. These are excellent feed-stuffs with practical implications in beef and dairy nutrition. The expected growth of wet milling industry in the developing countries for meeting the commercial demands of starch will increase the availability of these co-products in future. Time has arrived to recognise and utilise the feeding value of such by-products. This review aims to provide an insight into the usefulness of MGM and MGF in ruminant feeding.

Key words: Maize Gluten Meal, Maize Gluten Feed, Ruminants, Wet-Milling

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Introduction

Sustainability in livestock production throughout the globe demands exploration of locally available feedstuffs and agro-industrial by-product, owing to their utilisable nutrient profiles (Eisler *et al*., 2014). The processing of maize grains by wet milling process to produce starch, results in the production of a wide variety of by-products viz. maize gluten meal, maize gluten feed, maize germ meal and condensed fermented maize extractives (Fig. 1). Within the last two decades, the feeding of these by-products (particularly maize gluten meal and maize gluten feed) has received wide acceptance in feedlots. Maize gluten meal also known as corn gluten meal (MGM), a high protein concentrate, is used as a source of protein, energy and pigments in various species of livestock including poultry and aquaculture, besides its use in pet food due to its high protein digestibility (RFA, 2011). Maize gluten meal contains about 60-75%

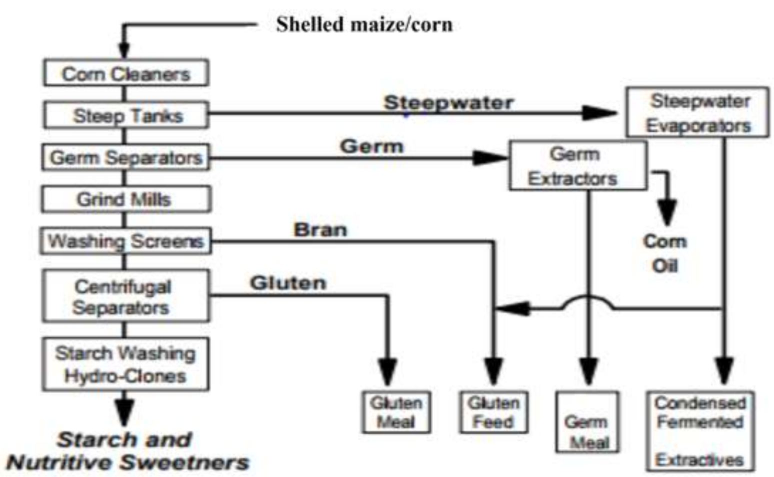
crude protein (CP) on dry matter basis (NRC, 2001; Mahesh *et al.*, 2017). The proteins are highly degradable in rumen; however, the fractional degradation rate is very slow resulting in low effective degradability rates, and making it the highest provider of undegradable protein among vegetable protein sources (NRC, 2001; Habib *et al*., 2013). Maize gluten feed (MGF) (wet or dry), popularly known as corn gluten feed, on the other hand, is a medium protein ingredient (21-27% CP) composed of the bran and fibrous portions. It contains energy, crude protein, digestible fiber, and minerals (Blasi *et al*., 2001) and is considered an excellent feedstuff in dairy industry (Schroeder, 2010). Therefore, in order to explore the nutritional worth of such valuable by-products in livestock sector, an elucidation about their feeding value would be of utmost importance to nutritionists and feed industry. This review sums up the relevance of MGM and MGF in the feeding of ruminants.

Wet Milling Process of Maize

Wet milling is a complex process with a wide variety of unit operations and interdependent steps (Fig. 1).

Figure 1.

Steps in the wet maize milling process



(Hall and Kononoff, 2011)

The process begins with the delivery of shelled maize/corn to the facility. The corn is off-loaded to elevator bins through a cleaning system. From elevator, the corn is conveyed to large steep tanks where it is soaked in a dilute sulfur dioxide solution for 30-50 hours at 120 - 130°F. This is a closely controlled process that results in the softening of the maize kernels. During soaking, the soluble nutrients are absorbed into water. The water is later evaporated to concentrate these nutrients for obtaining condensed maize fermented extractives. Continuing with the milling process, the maize germ is removed from the water soaked kernel.

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The germ is further processed to recover the oil. The remaining portion of the germ, maize germ meal, is collected for feed use. After the removal of germ, the rest of the maize kernel is screened to remove the bran leaving behind the starch and gluten protein. The bran is combined with other co-product streams to produce maize gluten feed (MGF) (RFA, 2011). The starch and gluten slurry is centrifuged in order to separate the starch fraction and the gluten, which have different densities, resulting in the lighter gluten protein to float to the top and the heavier starch to settle at the bottom (CRA, 2006). The gluten protein is concentrated and dried to form maize gluten meal (MGM), whereas the starch after proper washing and drying is marketed to the food, paper and textile industries or processed into corn syrup (sweetener) or ethanol.

Nutritional Attributes of MGM *vs* MGF

Maize gluten meal is a protein-rich feed containing 60 to 75% CP (on DM basis) (Table 1). Because of its high protein content, MGM is mostly used as a potential alternative to the conventional protein sources. Like maize grain, the amino acid profile of MGM is low in lysine and tryptophan; however, it is relatively high in methionine (Sampath *et al*., 2002). Maize gluten meal is also a good source of energy, on account of its high gross energy content and energy digestibility (Lesson *et al*., 2005). Maize gluten feed is moderately high in protein (20-25% CP) and a richer source of cell wall constituents (Table 1).

Table 1: Chemical composition of MGM, DMGF and WMGF in relation to Maize (DM basis)

Characteristic	Maize	MGM	DMGF	WMGF
Dry matter, %	87.2	90	88.3	47.7
Crude Protein, %	9.7	67	21.7	18.7
Crude Fibre, %	2.6	1.2	8.3	8.1
NDF, %	13.2	4.1	39.6	43.7
ADF, %	4.4	1.6	10.6	12.3
Ether Extract, %	4.2	2.9	3.4	4.8
Ash, %	1.5	2.1	6.9	6.1
Calcium, %	0.02	0.02	0.1-0.2	0.1
Phosphorous, %	0.35	0.7	0.8-1.0	0.45 - 1.0
Magnesium, %	0.13	0.15	0.42 - 0.50	0.15 - 0.50
Potassium, %	0.37	0.45	1.3 - 1.5	0.9 - 1.60
Sulfur, %	0.14	0.83	0.16 - 0.30	0.35 - 0.40
GE, MJ/kg	18.7	23.1	18.8	19
ME, MJ/kg (Ruminants)	13.5	16.6	12.2	12.6
Lysine	3	1.7	2.9	8.9
Methionine	2.9	2.4	1.7	3.7
Trtptophan	0.9	0.5	0.6	1.6

(NRC, 2001; Huze et al., 2015; Mahesh et al., 2018)

The composition of maize gluten feed is influenced by the proportion of steep liquor, which is high in energy and protein relative to maize bran. There are two distinct forms of MGF viz. wet maize gluten feed

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(WMGF) and dry maize gluten feed (DMGF). DMGF is produced by combining maize bran and steep liquor, occasionally maize germ meal. The resulting combination is then dried and passed through a hammer mill prior to pelleting, whereas, the production of WMGF involves pressing of wet maize bran followed by its mixing with maize steep liquor (Blasi *et al*., 2001). Both WMGF and DMGF are comparable to corn in the overall nutrient content (Table 1). Though wet MGF is nutritionally superior to dry MGF, however, in least-cost ration formulation dry form is prioritized as the distance between the milling plant and the livestock operation increases, because of fewer transportation costs.

Utilisation of MGM in Diets for Ruminants

MGM has been utilized extensively in ruminants as a source of rumen undegradable protein (RUP) and metabolisable protein (MP) in addition to an alternative to the conventional protein meals and cakes. It provides the highest undegradable protein among vegetable protein sources, ranging from 45-50% DM (Heuze *et al*., 2015; Mahesh *et al*., 2017). Furthermore, the intestinal digestibility of the MGM protein is high (90%) making it the best vegetable source of metabolizable protein. The rumen undegradable protein (RUP) fraction of MGM is also rich in sulfur containing amino acids, which may complement the bacterial true protein (NRC, 2001).

MGM as a Substitute Protein in Growing Diets

Collins and Pritchard (1992) reported MGM as an effective substitute for soybean meal (SBM) in crossbred sheep feed corn stalks based diets. In lambs, the inclusion of MGM based diets in comparison to SBM and urea mixture, as investigated by Tufarelli *et al*. (2009) did not affect the growth rate and average daily gain. Azevedo *et al*. (2011) replaced a part of energy concentrate with MGM in the diet of Brazilian Nellore heifers without any ill effect on DMI, nutrient digestibility, microbial nitrogen efficiency and nitrogen retention. Abe *et al*. (1997) reported lysine deficiency in post-weaned Holstein calves fed MGM based diets up to 11 weeks of age on account of restricted ruminal microbial protein synthesis by undegradable protein contributed by MGM. More recently, Malik *et al.* (2017) studied the effect of replacing groundnut cake with gluten meals of maize and rice in growing Sahiwal calves at 75% level on crude protein basis and reported a highly comparable nutritional worth of MGM and RGM in terms of nutrient intake and digestibility. However, MGM was found more efficacious in improving the growth rate (Fig. 2).

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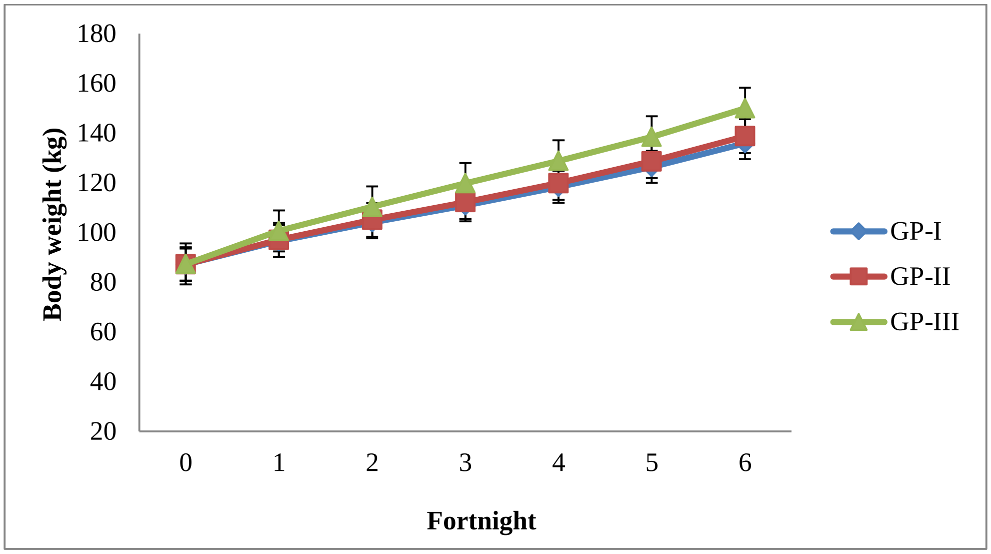

Fig 2: Fortnightly change in the body weights (kg) among experimental calves fed GNC; GP-I, RGM (replacing 75% of GNC protein); GP-II and MGM (replacing 75% of GNC protein); GP-III (Malik *et al*., 2017).

MGM in Relation to Lactating Diets

Maize gluten meal has been extensively studied in lactating cows. In most of the experiments, MGM fed alone or in combination with other protein sources gave similar or better results than the control diets. Marghazani *et al*. (2012) incorporated MGM (at 7% of concentrate mixture), thereby maintaining RDP: RUP level of 61:39 in lactating Sahiwal cows and did not observe any variation in intake as well as digestibility of DM and CP. The impact of increasing RUP by MGM and fish meal (FM), partially replacing steam rolled barley and SBM in Holstein cows as reported by Aboozar *et al*. (2012) resulted in increased DMI, milk yield, milk protein content, body condition score and post-calving conception rate. Similarly, Nisa *et al*. (2008) evaluated the response to increased levels of MGM protein in concentrate mixture of NIli-Ravi buffaloes and reported increased DMI, milk yield, yield of milk protein and fat as well as nitrogen balance and overall post-partum reproductive performance.

Keery and Amos (1993) did not report any effect on milk yield; composition and efficiency of utilization of NE_L by incorporating undegraded protein, being contributed by MGM in postpartum primiparous cows. De Gracia *et al*. (1989) observed similar lactation performance in mid lactating Holstein cows with SBM and mixture of MGM and blood meal. Similar results have been reported in dairy cows with different combinations of extruded whole soybeans and corn gluten meal as protein sources in comparison to SBM (Annexstad *et al*., 1987), MGM and dried brewer's grains each replacing 50% of SBM (Cozzi and Polan (1993). In contrast, Huffman and Duncan (1950) reported an increased milk yield in Holstein and Jersey cows upon replacing equal amount of alfalfa hay energy with MGM. Spain *et al*. (1990) documented increased milk fat and lactose% with greater FCM yield in multiparous Holstein cows fed MGM than either

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fish meal or SBM based diets. Similarly, Taylor *et al*. (1991) reported higher milk yields in heat stressed Holstein cows upon inclusion of MGM and blood meal in the concentrate mixture. However, no effect on milk yield was observed when MGM was alone incorporated in the concentrate. The complementary effect of the two protein meals fed in combination with respect to amino acids was proposed as the probable reason for the better yield. Furthermore, the use of diets containing 8 and 16% of MGM as a substitute for maize silage increased milk yield and protein, total solids and lactose yields in lactating Dutch cows, without modifying the levels of milk components and metabolic parameters (Alves *et al*., 2007). In lactating Italian Jonica goats, Lauadadio and Tufarelli (2010) reported higher CP digestibility and milk fat, protein and casein concentrations with MGM feeding in comparison to a mixture of SBM, sunflower meal and urea (highly rumen degradable). Recently, Mahesh and Thakur (2017) investigated the effect of partial substitution of groundnut cake protein with CGM or rice gluten meal (RGM) on lactation performance of Murrah buffaloes. The results of the study revealed that treatments did not affect intake and digestibility of nutrients as well as plane of nutrition. However, yields of milk and milk components were higher in CGM fed group.

The negative impacts of feeding MGM on lactation performance are also well documented. Klusmeyer *et al*. (1990) fed either SBM or MGM in Holstein cows and found higher milk yield and milk protein content with SBM based diets. The lower lysine flow to intestine upon MGM feeding was ascribed as the reason behind the results. Similarly, Wohl *et al*. (1991) investigated the incorporation of different levels of SBM, FM and MGM in Holstein cattle fed a basal diet of corn silage and reported a significant decrease in DMI and milk yield in MGM fed group. This reduction was attributed to a combined limitation of lysine in both MGM as well as corn silage. Furthermore, in lactating Saanan goats Macedo *et al*. (2003) substituted MGM with SBM isonitrogenously at graded levels of 0, 10, 30, and 50%. Though, the substitution did not affect nutrient intake but lactation performance was negatively impacted.

Usefulness of Maize Gluten Feed in Diets for Ruminants

Maize gluten feed is a relatively high fibre, medium-energy, medium-protein product that is essentially fed to ruminants, particularly beef and dairy cattle. It can be substituted for grains, such as maize grain, to reduce the starch load in the rumen. Its highly digestible fibre content may help to reduce the severity of rumen acidosis (Krehbiel *et al*., 1995). MGF is, however, low in lysine, therefore amino acid supplementation could be considered if dietary lysine concentration is a concern (Heuze *et al*., 2015). The rumen undegradable protein in MGF is about 24-30% (NRC, 2001). As a consequence, the incorporation of MGF should be minimized in diets composed of ingredients high in soluble protein, such as silages. Additionally, the bitter taste and lower mean particle size of MGF may affect the palatability and chewing, respectively, until animals adapt to it (Rausch *et al*., 2006).

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Efficacy of MGF for Supporting Growth

Growing ruminant diets chiefly consist of grains (low degradable intake protein), on which the rumen microflora depends in order to synthesize microbial protein. MGF, if replacing dry-rolled corn can meet the increased requirements of rumen microbes for degradable intake protein (Bowman and Paterson, 1988; Richards *et al*., 1998). DMGF has been proved to balance nitrogen and protein-N flow to the abomasum of cattle and create a faster rate of gain in yearling heifers (Cordes *et al*., 1988). Research suggests that wet or dry MGF could completely replace finely ground maize in finishing cattle diets containing greater than 50% roughage without any negative consequences on feed efficiency and net energy (Ham *et al*., 1995; Heuze *et al*., 2015). Firkins *et al*. (1985) reported steers, fed wet and dry MGF, to show a faster utilization of DM than those fed wet or dry distiller grains. Wet maize gluten feed incorporation up to 25 or 50% of dietary DM did not affect the feedlot performance, digestibility of nutrients, or carcass characteristics of beef cattle (Hussein *et al*., 1995). However, replacement of various levels of dry-rolled maize grain with WMGF had a positive effect on average daily gain and feed efficiency (Stock *et al*., 1999). Feed efficiency generally improves upon addition of wet maize gluten feed to dry-rolled maize based finishing diets (Richards *et al*., 1998). Armentano and Dentine (1988) declared wet MGF is an efficient substitute for concentrate in heifer diets. Heifers fed wet MGF at 30% of the diet showed first lactation performance similar to those fed concentrate (Armentano and Dentine 1988). In feedlot cattle the various combinations of WMGF and wet distillers grain solubles (WDGS), up to 75% of diet DM, resulted in similar or improved performance in terms of DMI and ADG compared to corn (Loza *et al*., 2010). Loy *et al*. (2004) declared reduced cost as the major implication of using dry maize gluten feed in growing heifers compared to grazing along with conventional hay and protein supplementation. Furthermore, DMGF, when included in growing ewes (10 or 20% dietary levels), fed rice straw/concentrate diet resulted in improved daily gain and feed efficiency (Heuze *et al*., 2015).

Feeding Value of MGF in Lactating Diets

In lactating dairy cows MGF has been used as an effective substitute for corn grains and soybean meal (Staples *et al*., 1984; Armentano and Dentine, 1988), a portion of the forage (Allen and Grant, 2000), or all of the grain mixture and a portion of the forage (Boddugari *et al*., 2001).

Fellner and Belyea (1991) replaced 60% of the diet DM in dairy cows with dry MFG without any negative consequences on intake or milk production. Van Baale *et al*. (1999) noticed an increased DM intake and improved milk production in cows fed wet MGF based diets in contrast to a control diet containing alfalfa hay and corn silage. Increased milk protein and lactose yields were reported by VanBaale *et al*. (2001) upon feeding of maize gluten feed, without any effect on milk fat yield. Kononoff *et al*. (2006) formulated lactating diets containing up to 37.5% wet maize gluten feed (DM basis) and observed reduction in milk

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fat percentage, however, the increased milk yield compensated for the overall milk fat yield. Hao *et al*. (2017) effectively replaced a portion of alfalfa hay in the rations of lactating dairy cows with DMGF and Chinese wild ryegrass in combination without any negative consequences on milk production and yield of milk fat and lactose. Dried maize gluten feed (22% of DMI) also supported milk production levels similar to diets based on maize grains and soybean meal in mid lactating dairy cows (Bernard *et al*., 1991). Similarly, in dairy goats feeding of DMGF resulted in higher milk protein concentration comparative to faba beans, sunflower meal or cottonseeds based diets (Sampelayo *et al*., 1999). However, not all studies have been entirely favorable. A linear decline in DM intake and milk yield was observed in dairy cows with maize silage-based diets containing from 0 to 40% (diet DM) wet maize gluten feed (Staples *et al*., 1984). A similar decrease in milk yield was noted when 30% of wet maize gluten feed or more was included in the diet of dairy cows (Schroeder, 2003). Therefore, an optimal inclusion level of 10-20% has been suggested for the lactating cows.

Potential Constraints Associated with MGM and MGF

Like other maize products, MGM and MGF are at the risk of mycotoxin contamination, reducing the scope for their long-term storage. Addition of sulfur dioxide, during the steeping process to aid in the extraction of starch, may increase the sulfur content of these by-products and predispose cattle to higher than the upper safe limits of sulfur. Furthermore, lysine deficiency and low palatability of MGM and lysine deficiency coupled with low energy and higher dietary fibre content of MGF limits the usage of these co-products in poultry and swine nutrition.

Conclusion

Maize gluten meal and maize gluten feed have been exclusively tried as alternative feedstuffs for the conventional protein sources with satisfactory results. Therefore incorporation of these by-products seems an attractive proposition, for bridging up the gap between the demand and supply of proteinaceous feeds and formulation of least cost ruminant rations.

Conflict of Interest

The authors declare that they have no competing interest.

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