A meta-analysis of in situ degradability of corn grains and non-starch energy sources found in Brazil

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Owing to the magnitude and importance of the production of citrus fruits pulp, soybeans and corn in Brazil, considerable research has focused on the main feedstuffs, co-products, and/or byproducts of these crops. The present study is aimed at comparing the ruminal degradability parameters of corn and non-starch energy sources with high pectin content, including soybean hulls and citrus pulp, through meta-analysis. The experiments were designed to include parameters related to potential and effective degradability of the concentrates of these energy feeds. The database (DB) was composed of 62 treatments obtained from 20 papers. No difference (P>0.05) was observed in any of the ruminal degradability parameters of the dry matter (DM) or crude protein (CP), demonstrating that the total replacement of corn grain by non-starch feed is possible. The degradation rates of DM were 6.78 and 6.14%h⁻¹ and those of CP were 5.97 and 5.93%h⁻¹, for corn and non-starch feeds, respectively. Therefore, depending on the cost, corn grain could be substituted by soybean hulls or citrus pulps, which reduce the possibility of the occurrence of metabolic disorders, such as subclinical and/or clinical acidosis, without affecting ruminal fermentation.

Key words: Starch, citrus pulps, soybean hulls, energy, pectin, degradability, non-starch feed, acidosis.

INTRODUCTION

According to official information from the Companhia Nacional de Abastecimento, 32 million hectares of land were cultivated for soybeans and 15.6 million hectares for maize in the 2014/2015 harvest in Brazil (CONAB, 2015). The same agency also reported that the yield of oilseed in the harvest was three tons/hectare and that of cereal

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was 5.3 tons/hectare, generating 96.2 and 84.6 million tons of soybean and corn, respectively. According to Costa and Santana (2015), the soybean production chain is one of the most important industries for Brazilian agribusiness.

Another productive enterprise of great importance in national and international market is of citrus fruits production chain, especially oranges. According to Neves et al. (2010), Brazil annually harvests more than 18 million tons of orange or about 30% of world fruit crop. According to Neves et al. (2014), the country produces more than 50% of the orange juice produced in the world, with more than 90% of the production destined for foreign markets.

Corn grain is usually processed (ground or flaked) for human and/or animal intake, generating few byproducts to be used in animal feed. In contrast, the orange juice production generates citrus fruit pulp, which can be used in ruminant feed. According to Neves et al. (2010), in 2010 the marketing and export of citrus pulp in Brazil, reached the figure of US$178.8 million. Although, the industrial extraction of soybean oil enables the production of various byproducts, the most important energy source for ruminant nutrition is soybean hulls. Both citrus fruit pulp and soybean hulls are rich in pectin, a structural carbohydrate that can be used as energy source in ruminant feeds.

Corn kernel is used worldwide as a major feed ingredient, in the form of starch, in feed concentrates for ruminants, and is an energy source. However, excess degradable feed starch in the rumen can negatively affect ruminal microbiota by decreasing ruminal pH (Russell and Rychlik, 2001; Wang et al., 2009).

Starch is degraded quickly by amylolytic bacteria, leading to an increase in the production of volatile fatty acids affecting the acetate: propionate ratio, which causes the ruminal pH to decrease (Berchielli et al., 1996; Nagaraja and Titgemeyer, 2007). Thereafter, increased lactic acid formed in the rumen minimizes or paralyzes the growth of fibrolytic bacteria, causing antagonism between the amylolytic and fibrolytic bacterial strains (Kamra, 2005). Thus, variation in dietary intake affects the productivity of the animal (Bevans et al., 2005; Plaizier et al., 2009), which, in turn influences the planning of rural enterprise systemically.

One way to minimize such harmful effects on rumen health is to replace the corn grains partially or totally with soybean hulls (SBH) and citrus fruit pulps, which are generated almost constantly throughout the year as byproducts from processing by two of the largest agricultural production chains in Brazil. The pectin present in these products makes them good energy sources. Pectin produces the bulky base, which is essential in ruminant feeds, as it is part of the cell wall neutral detergent fiber (NDF), unlike starch, which is part of cell content. However, unlike fiber, pectin has a high rate of degradation in the rumen (Jung et al., 2012). Based on dry matter, soybean hulls have 60.74% of NDF and 0.14% of starch, whereas corn has 12.34% of NDF and 77.11% of starch (Alcalde et al., 2009). However, based on DM, Tambara et al. (1995) reported 33.82% of crude fiber, 50.86% of acid detergent fiber (ADF) and 1.81% of acid detergent lignin (ADL), as well as 65.49% apparent digestibility of dry matter, 69.27% in vitro digestibility of dry matter, and 67.05% total digestible nutrients (TDN) for SBH. These authors also reported that SBH is classified as roughage energy-concentrate because even with short fiber, it showed effectiveness in stimulation of rumination/salivation in sheep.

Although, having similar NDF content, based on DM, SBH showed less effectiveness in stimulating rumination and chewing in lactating goats than did chopped-off hay coast cross grass. According to Gentil et al. (2011), the ingredient composition in SBH was 70.3% of NDF and 17.9% of peNDF, whereas that in chopped-off hay is 67.6% of NDF and 51.1% of peNDF. A linear reduction in ruminal pH was detected with the increase in SBH content. However, the opposite is true when replacing concentrated ingredients with bulky ones. Because of high biodegradability of its fiber and its increased buffering capacity of saliva due to the presence of sodium bicarbonate, the use of soybean hulls in place of corn can increase rumen pH, reducing the ruminal-acidosis risk associated with diets having high share of feed concentrates. Pectin is a carbohydrate that is highly degradable in rumen, and, unlike starch, produces less lactate, thus causing minor decreases in ruminal pH (Bampidis and Robinson, 2006).

On the other hand, citrus fruit pulp has lower NDF content and protein when compared with SBH. Based on DM, Santos et al. (2007) recorded 9.17, 6.90 and 11.96% CP; 6.12, 23.41 and 63.79% NDF; 1.22, 15.76 and 46.27% ADF; and 73.39, 0.5 and 3.6% starch, for corn, citrus fruit pulp and soybean hulls, respectively. Rodrigues et al. (2008a) found that the substitution of one third of the maize by citrus fruit pulp improved the dry matter intake and performance of lambs fed with this concentrate. The low protein content of dehydrated citrus fruit pulp, as well as its limited digestibility, is the biggest nutritional limitation of this ingredient, because according to the NRC (2007), it contains less digestible protein than corn (3.3 versus 5.1%, based on DM).

Owing to the magnitude and importance of the production chains of citrus, soybean, and corn in Brazil, many studies have been conducted using the main raw material and/or their byproducts. Therefore, a meta-analysis is possible for identifying and/or solving the gaps in the production systems, which have passed unnoticed in the assessed works conducted independent of each other. The objective of the present study was to perform a meta-analysis to assess the differences, if any, in the in situ degradability of maize grain and non-starch feeds with high pectin content, from Brazil.
MATERIALS AND METHODS

The overall database (ODB) was constructed by including scientific works available in the public domain, in journals published in Brazil. The data were collected from experiments published between January 1998 and December 2013. After the collection of data, analysis of all the work was performed in its entirety for subsequent tabulation of the information contained in the methodology and results, using an Excel® spreadsheet, following the criteria proposed by Lovatto et al. (2007).

Estimations were performed using parameters related to potential degradability of dry matter (DM) and crude protein (CP) according to the methods described by Oñskov and McDonald (1979) as obtained by: 

\[ p = a + (1 - a) * 10^{-e}, \]

where “p” = potential degradability in time “t”;

\[ a = \text{water soluble fraction}; \]

\[ b = \text{insoluble, but potentially degradable fraction}; \]

\[ c = \text{degradation rate of the fraction “b”}, \]

and “e” = natural logarithm. The effective ruminal degradability of dry matter (EDDM) and crude protein (EDCP) was calculated from the formula EDDM and EDCP = \( a + \left( \frac{b \times c}{c + k} \right) \), where “k” = passage rate of particles in the rumen.

The passage rates used for experiments in Brazil have been recommended by the AFRC (1993): 2% h\(^{-1}\) for animals with low level of feed intake, that is, once in a given maintenance period; 5% h\(^{-1}\) for calves and cows producing less than 15 kg of milk per day, beef cattle, and sheep with intake lower than twice of that necessary for maintenance; and 8% h\(^{-1}\) for dairy cows with a milk yield above 15 kg per day, with intake of more than twice than necessary for maintenance.

The feeds were classified into energy source concentrates according to the chemical composition guidelines enforced in Brazil, according to Ministério da Agricultura, Pecuária e Abastecimento (MAPA, 2013). The data were processed and a partial database constructed to compare corn grain with non-starchy feeds (BDPM) such as citrus fruit pulp and soybean hulls, which constitute 62 treatments obtained from 20 papers, namely Beran et al. (2005), Fortaleza et al. (2009), Fernandez et al. (2002), Fortaleza et al. (2009), Franzolin Neto et al. (2000), Garcia et al. (2003), Goes et al. (2004, 2011), Marcondes et al. (2009), Martins et al. (1999), Mizubuti et al. (2007), Moreira et al. (2009), Mouro et al. (2002), Nussio et al. (2002), Oliveira et al. (2003), Porcionato et al. (2004), Prado et al. (2000), Santos et al. (2012), Silva et al. (1999), Simas et al. (2008) and Zulda et al. (1999). The analysis of variance was performed using the statistical software SAS® (SAS Institute, 2002), employing the mixed model procedure (PROC MIXED), with the dataset considered as a random variable.

RESULTS AND DISCUSSION

Ideal feed with carbohydrates as the main energy source should be assessed by the fractionation of the constituents into fibrous carbohydrates (cellulose, hemicellulose and lignin) and non-fibrous carbohydrates (starch, soluble sugars and fructose) (Lanzas et al., 2007). However, besides being a laborious and expensive technique, the value of non-fibrous carbohydrates is estimated by the difference and tends to accumulate mistakes made in the calculations of other parameters (crude protein, mineral matter, ether extract and neutral detergent fiber) (Detmann and Filho, 2010). Therefore, most of the studies conducted in Brazil focus on the evaluation of DM and CP.

The values for DM (Table 1) of both starch and non-starch ingredients in pectin are adequate for its use in animal feed. Unlike soybean hulls, citrus fruit pulp can be used fresh, dried, or pressed in pelletized form (Rodrigues et al., 2011; Santos et al., 2014). Therefore, it is important to note that there are farms that use fresh citrus pulp and pressed citrus fruit pulp as they are cheaper than the pelleted pulp (Pereira et al., 2008). However, fresh and pressed citrus fruit pulps have high moisture content, they must be used quickly so that the quality of the feed is maintained (Macedo et al., 2007). An alternative to the use of fresh citrus fruit pulp would be the ensilage with feed or forages with high DM (Chaudhry and Naseer, 2006; Volanis et al., 2006; Tanaka et al., 2010; Lashkari et al., 2014).

There was no difference (P>0.05) in any of the evaluated parameters of DM and CP of corn when compared with those of the non-starchy energy sources (Tables 1 and 2). The results obtained from the meta-analysis are extremely important, because the studies were carried out in different conditions and show synchrony in the degradation of carbohydrates and nitrogenous constituents of these feeds. According to Tylutki et al. (2008), the fermentative bacteria use non-fibrous carbohydrates starch, pectin and soluble sugars; they grow faster than fibrolytic bacteria and can use ammonia or amino acids as nitrogen sources. However, we must be mindful of pectin being part of the cell wall (NDF), although it is degraded in a differentiated manner of other fibrous components (hemicellulose and cellulose) (Bampidis and Robinson, 2006). The growth rates of the different bacterial strains mentioned are established by the quantity of carbohydrates degraded in the rumen and by the degradation rate, subject to the availability of nitrogen in the rumen ecosystem in time and amount required (Chumpawadee et al., 2006).

The Cornell Net Carbohydrate and Protein System (CNCPs) assumes that the bacterial growth rate is proportional to the rate of degradation of starch, considering the hypothesis that the rumen experiences substrate (carbohydrates) limitation owing to excess enzymes derived from the rumen microflora (Fox et al., 2004; Tylutki et al., 2008). Therefore, the DM and CP degradation rates indicate that both corn grain and non-starch feeds, when used in the right physiological proportions in the rumen, stimulate greater intake of DM throughout the day (Franco et al., 2010).

Considering that pectin fermentation does not involve lactic acid formation, it might be better for replacing starch, which when fermented results in the decrease in ruminal pH, causing the occurrence of metabolic disorders, such as subclinical and/or clinical acidosis (Cañizares et al., 2009; Plaizier et al., 2009). Therefore, the use of pectin should be recommended for animals that consume feeds in the order of two to three times more than the requirements for maintenance.

On the other hand, the diets with high proportion of citrus fruit pulp can cause parakeratosis, especially when the level of fiber in the diet is low (Arthington et al., 2002;
Table 1. Adjusted average dry matter (DM), water-soluble fraction (a) of the DM, potentially degradable fraction (b) of the DM, degradation rate (c) of the DM, and effective degradability at 2%.h$^{-1}$, 5%.h$^{-1}$, and 8%.h$^{-1}$ of the DM of corn grain and non-starchy ingredients.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ingredients</th>
<th>E</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (% of natural matter)</td>
<td>Corn</td>
<td>90.66</td>
<td>89.28</td>
</tr>
<tr>
<td>Water-soluble fraction (a)*</td>
<td>Non-starchy</td>
<td>33.12</td>
<td>24.97</td>
</tr>
<tr>
<td>Potentially degradable fraction (b)*</td>
<td></td>
<td>66.70</td>
<td>65.72</td>
</tr>
<tr>
<td>Degradation rate (c)*</td>
<td></td>
<td>6.78</td>
<td>6.14</td>
</tr>
<tr>
<td>Effective degradability 2%.h$^{-1}$†</td>
<td></td>
<td>72.70</td>
<td>74.31</td>
</tr>
<tr>
<td>Effective degradability 5%.h$^{-1}$†</td>
<td></td>
<td>63.12</td>
<td>52.56</td>
</tr>
<tr>
<td>Effective degradability 8%.h$^{-1}$†</td>
<td></td>
<td>56.37</td>
<td>54.40</td>
</tr>
</tbody>
</table>

*Values determined using the model of Ørskov and McDonald (1979); †Values determined considering passage rates indicated by the AFRC (1993).

Table 2. Adjusted average crude protein (CP), water-soluble fraction (a), potentially degradable fraction (b), degradation rate (c) and effective degradability at 2, 5 and 8%.h$^{-1}$ passage rates of the CP of corn grain and non-starchy ingredients.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ingredients</th>
<th>E</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein (% DM)</td>
<td>Corn</td>
<td>9.25</td>
<td>10.33</td>
</tr>
<tr>
<td>Water-soluble fraction (a)*</td>
<td>Non-starchy</td>
<td>24.87</td>
<td>15.93</td>
</tr>
<tr>
<td>Potentially degradable fraction (b)*</td>
<td></td>
<td>56.49</td>
<td>52.85</td>
</tr>
<tr>
<td>Degradation rate (c)*</td>
<td></td>
<td>5.97</td>
<td>5.93</td>
</tr>
<tr>
<td>Effective degradability 2%.h$^{-1}$†</td>
<td></td>
<td>49.20</td>
<td>49.00</td>
</tr>
<tr>
<td>Effective degradability 5%.h$^{-1}$†</td>
<td></td>
<td>42.29</td>
<td>35.88</td>
</tr>
<tr>
<td>Effective degradability 8%.h$^{-1}$†</td>
<td></td>
<td>22.86</td>
<td>25.61</td>
</tr>
</tbody>
</table>

*Values determined using the model of Ørskov and McDonald (1979); †Values determined considering passage rates indicated by the AFRC (1993).

Bampidis and Robinson, 2006). In addition, the citrus fruit pulp and soybean hulls expand when in contact with rumen fluid; a diet with a high proportion of carbohydrates in the form of pectin might limit consumption (Wing, 1982).

Briefly, in case of ruminants used as beef cattle, the use of these pectin sources as substitutes for corn in diets with high share of concentrates generally increases DM intake and nutrient digestibility and maintains similar carcass traits, but reduces feed efficiency (Pinheiro et al., 2000; Caparra et al., 2007; Rodrigues et al., 2008b). On the other hand, in studies with animals bred for milk production, an increase in milk production and changes in milk composition as well as ingestion behavior are observed (Belibasakis and Tsirgogianni, 1996; Miron et al., 2002; Mendes Neto et al., 2007; Pedroso et al., 2007).

Therefore, in addition to the afore-mentioned biological advantages, the use of these two byproducts, instead of corn, in feeding and ruminant nutrition is also justified by the cost. This is because when the main soybean products, such as soybean oil and citrus fruit product, that is, orange juice are extracted, soybean hulls and citrus fruit pulp, respectively, are generated from the raw materials as byproducts of the process, and therefore, can be sold for the cost below that of the corn grain.

Conclusion

Corn grains can be replaced with soybean hulls or citrus pulps in the feed of ruminants, which reduces the possibility of the occurrence of metabolic disorders, such as subclinical and/or clinical acidosis, without damaging ruminal fermentation.

Conflict of Interests

The authors have not declared any conflict of interest.

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