

# Effect of ensiling on the feeding value of flint corn grain for feedlot beef cattle: A meta-analysis

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**ABSTRACT** - The objective of this study was to review the effect of ensiling on the feeding value of flint corn grain and performance of feedlot cattle. In this meta-analysis, ensiled corn grain included both high-moisture corn and rehydrated corn grain. The criteria for a publication enter in the database were: diet was offered as a total mixed ration, diet contained at least 300 g/kg dry matter (DM) of ensiled or dry corn grain, and ensiled grain contained a minimum of 280 g/kg of moisture. The final dataset included 21 paired comparisons from eight publications, from 2002 to 2019. A sub dataset of digestibility trials contained six paired comparisons for starch digestibility and five paired comparisons for DM digestibility. The outcomes were compared using the Mixed procedure of SAS, including a random effect of comparison within study (paired comparison). Ensiling corn grain increased total-tract digestibility of DM (+4.59%) and starch (+3.33%), decreased DM intake by 14.1% (10.3 and 8.85 kg/d for dry and ensiled, respectively) and metabolizable energy intake by 4.39%, but did not affect average daily gain (1.61 and 1.58 kg/d for dry and ensiled corn, respectively). Therefore, ensiling corn grain increased feed efficiency by 18.3% (0.164 and 0.194, for dry and ensiled, respectively). The feeding value was on average 25.7% higher for ensiled corn grain compared with dry corn grain. Ensiling is an efficient strategy to improve the caloric value of flint corn grain for finishing cattle.

**Keywords:** corn grain silage, high moisture corn, reconstituted corn grain

## 1. Introduction

Corn grain is the main energy source in US (Samuelson et al., 2016) and Brazilian (Oliveira and Millen, 2014) beef feedlot diets. Meanwhile, corn hybrids cultivated in Brazil are predominantly flint, with a higher proportion of vitreous endosperm than dent hybrids predominant in the US and other countries with temperate climate. Comparing Brazilian and US corn kernels, Correa et al. (2002) reported a higher proportion of vitreous endosperm for Brazilian (average 0.731) than for US hybrids (average 0.482).

Beyond the pericarp barrier, endosperm vitreousness is negatively related to starch digestibility (Correa et al., 2002). The protein matrix (prolamines) surrounding the starch granules is insoluble in water and hinders the action of ruminal microorganisms and their enzymes in the ruminal environment and intestinal digestion (McAllister et al., 1993; Huntington, 1997; Ngonyamo-Majee et al., 2008). Additionally, flint hybrids with higher proportion of vitreous endosperm are harder to break down during physical processing (Philippeau and Michalet-Doreau, 1997), which might worsen starch digestion.

Ensiling high moisture or rehydrated corn grain is a strategy to improve starch digestibility (Owens et al., 1986; Benton et al., 2005). During the storage period, the action of proteolytic bacteria and kernel proteases break down the protein matrix (Junges et al., 2017), increasing the availability of starch to animal digestion (Hoffman et al., 2011).

For dent corn hybrids, several reviews have shown benefits of ensiling corn grain for feedlot cattle, but in a lesser extension than steam flaking (Owens et al., 1997; Zinn et al., 2011). Owens and Basalan (2013) reported lower dry matter intake (DMI, -5.5%) without decreasing average daily gain (ADG) for ensiled corn compared with dry rolled corn. Therefore, the ensiled grain had greater value of net energy for gain (NEg, +6.7%) and improved feed efficiency (+5.4%) in comparison with dry rolled corn.

For flint corn grain, however, the extent of the benefit is not well established; meanwhile, the use of grain silages has been steeply increasing in the last decade in Brazil (Bernardes and Castro, 2019; Daniel et al., 2019). Considering that integrating data through meta-analysis is an effective approach to summarize results from multiple studies (St-Pierre, 2001), our objective was to review controlled trials and quantify the effects of ensiling on the feeding value of flint corn grain, diet energy intake, and performance of feedlot cattle.

## 2. Material and Methods

### 2.1. Literature search and inclusion criteria

The database was created with published data from paired comparisons between ensiled corn grain (high moisture corn and rehydrated corn) and dry corn grain (ground or rolled) in diets for feedlot beef cattle. Our literature search used Google Scholar, PubMed, ScienceDirect, Scirus, CAB, and Portal Periódicos CAPES, investigation of references listed in papers, and contact with researchers in the field. The search included the following keywords: high moisture corn, high moisture maize, rehydrated corn, rehydrated maize, reconstituted corn, reconstituted maize, ensiled corn grain, or ensiled maize grain.

The inclusion criteria were as follows: diet was offered as a total mixed ration, diet contained at least 300 g/kg dry matter (DM) of ensiled or dry corn grain, and ensiled grain contained a minimum of 280 g/kg of moisture, because the moisture content affects the conservation process, digestibility, and energy value of corn grain silage (Owens and Basalan, 2013; Gomes et al., 2018). Nine publications were found, but one failed to attain our criterium for minimum moisture content of ensiled corn (Carareto, 2011). The final dataset included five full articles (Costa et al., 2002; Silva et al., 2007; Henrique et al., 2007; Caetano et al., 2015; Caetano et al., 2019) and three theses (Silva, 2015; Silva, 2016; Jacovaci, 2019), totaling 21 paired comparisons. Nellore bulls were used in five studies, whereas Santa Gertrudes bulls, Simental × Nellore bulls, or Angus × Charolais bulls were used in other three studies.

The main dataset included performance traits, such as DMI, initial body weight (BW), final BW, ADG, feed efficiency, carcass dressing, energy calculations, and feeding value. A sub dataset included apparent digestibility of DM and starch.

### 2.2. Calculations

When the publications did not present data for feed efficiency, this variable was calculated as ADG/DMI. Diet net energy was estimated using the equations proposed by Zinn and Shen (1998), using individual DMI and ADG data. Energy requirement for gain was calculated as:  $Eg$  (MJ/d) =  $4.184 \times (0.0493 \times ((BW \times 478/FW)^{0.75}) \times ADG^{1.097})$ , in which BW is mean body weight, 478 is standard reference weight, and FW is final weight. Energy requirement for maintenance was calculated as:  $Em$  (MJ/d) =  $4.184 \times 0.077 \times BW^{0.75}$ . Diet net energy for maintenance was estimated by the equation:  $NEm$  (MJ/kg DM) =  $4.184 \times ((-b - (b^2 - 4ac)^{0.5})/2a)$ , in which:  $a = -0.877 \times DMI$ ,  $b = (0.877 \times (Em/4.184)) + (0.41 \times DMI) + (Eg/4.184)$  and  $c = -0.41 \times (Em/4.184)$ . Diet net energy for gain was calculated as:  $NEg$  (MJ/kg DM) =  $4.184 \times ((0.877 \times (NEm/4.184)) - 0.41)$ . Diet metabolizable energy

was calculated as:  $ME \text{ (MJ/kg DM)} = ((23.8573 \times NEm/4.184 + 2.3974 \times (NEm/4.184)^2 + 24.7761) \times 0.0362) \times 4.184$ , whereas ME intake (MJ/d) was computed as  $ME \times DMI$ .

The feeding value (FV) of ensiled corn relative to dry corn grain was calculated as (Bremer et al., 2011):  $FV \text{ (\%)} = (((\text{feed efficiency observed for ensiled corn grain diet} - \text{feed efficiency observed for dry corn grain diet}) / \text{feed efficiency observed for dry corn grain diet}) / \text{proportion of ensiled corn grain in the corresponding diet} + 1) \times 100$ .

### 2.3. Statistical analysis

Data were analyzed using the statistical software SAS (Statistical Analysis System, version 9.4). Mean, standard deviation, minimum and maximum values, skewness, and kurtosis were calculated using the MEANS procedure. Animal outcomes were compared using the MIXED procedure. The model included a random effect of paired comparison within study and a fixed effect of grain processing (ensiled or dry). The covariance matrix structure used was the unstructured (UN). Due to different experimental designs and accuracy of the experiments used, data were weighted by the standard error of the mean or by the number of experimental units (when the standard error of the mean was not available in all studies) using the WEIGHT statement in the MIXED procedure (St-Pierre, 2001; Sauvant et al., 2008).

The difference of ME intake in dry and ensiled corn grain diets adjusted by a random effect of study was regressed against ME intake in dry corn diet adjusted by a random effect of study (both obtained by the mixed model described above) and correlated with the proportion of forage NDF and grain in diet using the REG procedure. A bar graph was constructed with the feeding value of ensiled corn grain relative to dry corn grain.

## 3. Results

Diet characteristics and animal performance traits had a large range of values, indicating that the dataset covered a great part of practical situations in Brazilian beef feedlots (Table 1). The moisture

**Table 1 - Dataset used in the data analysis**

Item	Mean	Median	Minimum	Maximum	SD	Skewness <sup>1</sup>	Kurtosis <sup>1</sup>
Moisture of ensiled corn grain (g/kg as fed)	362	386	300	399	43.5	-0.555	-1.66
Diet level of ensiled or dry corn grain (g/kg DM)	576	605	380	798	112	-0.555	-0.612
Diet level of forage (g/kg DM)	226	170	50.0	500	127	0.995	0.0207
Diet level of forage NDF (g/kg DM)	135	109	32.0	260	58.4	0.846	0.0905
Initial BW (kg)	346	373	236	438	50.7	-0.720	-0.369
Final BW (kg)	489	505	414	536	33.3	-1.039	-0.154
Dry matter intake (kg/d)	9.11	9.05	7.24	11.8	1.24	0.232	-0.816
Average daily gain (kg/d)	1.54	1.55	1.00	1.97	0.223	-0.312	-0.465
Feed efficiency	0.170	0.170	0.122	0.223	0.0241	0.0520	-0.224
Carcass dressing (g/kg)	560	561	512	605	17.7	-0.204	1.63
Total tract DM digestibility	0.782	0.771	0.753	0.812	0.0232	0.301	-2.01
Total tract starch digestibility	0.976	0.976	0.941	0.998	0.0189	-0.282	-1.06
Diet ME (MJ/kg DM)	12.3	12.2	10.3	14.4	0.954	0.152	-0.160
Diet NEm (MJ/kg DM)	8.25	8.17	6.52	10.0	0.790	0.0804	-0.146
Diet NEg (MJ/kg DM)	5.52	5.45	4.00	7.02	0.693	0.0804	-0.146
ME intake (MJ/d)	111	114	83.9	134	12.5	-0.546	-0.187
Relative feeding value of corn grain silage <sup>2</sup> (%)	128	131	94.2	159	16.1	-0.175	-0.101

SD - standard deviation; DM - dry matter; NDF - neutral detergent fiber; BW - body weight; ME - metabolizable energy; NEm - net energy for maintenance; NEg - net energy for gain.

<sup>1</sup> Skewness and kurtosis are dimensionless.

<sup>2</sup> Feeding value of ensiled relative to dry corn grain. Dry corn value is assumed 100%.

content of ensiled corn grain varied from 300 to 399 g/kg, and dietary inclusion of corn grain (dry or ensiled) ranged from 380 to 798 g/kg DM, encompassing most of practical conditions in feedlots using corn grain silage. Forage level and concentration of forage neutral detergent fiber (NDF) ranged from 50.0 to 500 g/kg DM and 32.0 to 260 g/kg DM, respectively. The dataset had a predominance of Nellore cattle, with a wide variation in BW at the beginning of the feeding trials (from 236 to 438 kg).

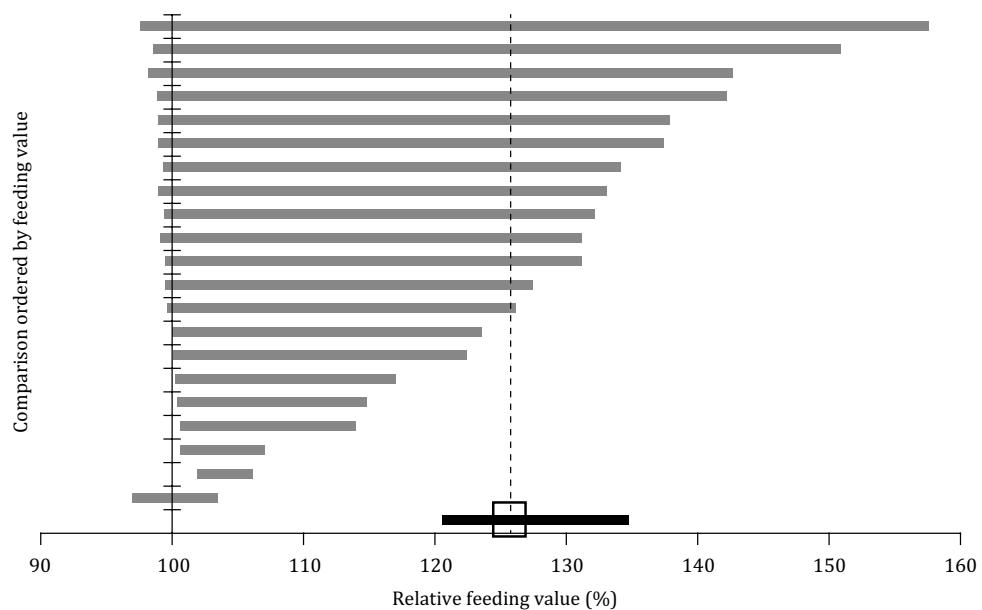
No differences were observed for initial and final BW (Table 2). Ensiling corn grain decreased DMI by 14.1% ( $P < 0.01$ ) and ME intake by 4.39% ( $P < 0.01$ ), without affecting ADG ( $P = 0.21$ ). Compared with diets containing dry corn, diets balanced with ensiled corn increased feed efficiency by 18.3% ( $P < 0.01$ ). Replacing dry with ensiled corn did not change carcass dressing ( $P = 0.61$ ).

Total tract apparent digestibility of DM and starch were increased by 4.59 ( $P < 0.01$ ) and 3.33% ( $P < 0.01$ ), respectively, when the ensiled grain replaced the dry grain. The feeding value was on average 25.7% higher for the ensiled corn grain compared with the dry corn grain (Figure 1). Difference of ME intake upon replacing dry with ensiled corn was negatively correlated with ME intake (Figure 2).

**Table 2** - Performance of feedlot beef cattle fed flint dry or ensiled corn grain

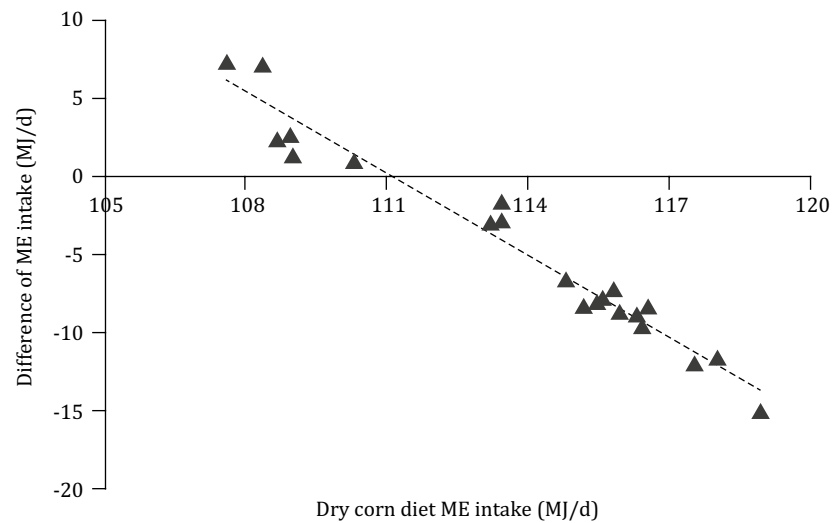
Item	N	Dry	Ensiled	SEM	P-value
Initial body weight (kg)	21	363	362	8.99	0.44
Final body weight (kg)	21	510	506	2.97	0.12
Dry matter intake (kg/d)	21	10.3	8.85	0.295	<0.01
Average daily gain (kg/d)	21	1.61	1.58	0.044	0.21
Feed efficiency	21	0.164	0.194	0.0045	<0.01
Carcass dressing (g/kg)	21	558	559	4.3	0.61
Total tract DM digestibility	5	0.763	0.798	0.0063	<0.01
Total-tract starch digestibility	6	0.959	0.991	0.0040	<0.01
Diet ME (MJ/kg DM)	21	11.7	12.9	0.15	<0.01
Diet NEm (MJ/kg DM)	21	7.79	8.73	0.128	<0.01
Diet NEg (MJ/kg DM)	21	5.12	5.94	0.112	<0.01
ME intake (MJ/d)	21	114	109	2.7	<0.01

DM - dry matter; N - number of paired comparisons; SEM - standard error of the mean; ME - metabolizable energy; NEm - net energy for maintenance; NEg - net energy for gain.



Bars are ordered by ensiled corn grain feeding value. Each gray bar represents one comparison. The black bar indicates mean (126%) and 95% confidence interval (121 to 134%).

**Figure 1** - Feeding value (%) of ensiled corn grain relative to dry corn grain (assumed 100%), adjusted for a random effect of comparison within study and weighted by the number of experimental units.



Difference of ME intake =  $194 - 1.75 \times \text{ME intake in dry corn diet}$ ;  $P < 0.01$ ,  $R^2 = 0.96$ ,  $\text{RMSE} = 1.30$ .

**Figure 2** - Relationship between the difference of metabolizable energy (ME) intake in ensiled and dry corn-based diets and the ME intake in dry corn-based diet, adjusted for a random effect of comparison and weighted by the number of experimental units.

#### 4. Discussion

Grain processing methods to reduce particle size or alter the protein matrix in kernel endosperm have been successfully used at farm level to increase the extent of grain digestion. In Brazil, the use of corn grain silage in feedlots, either rehydrated (reconstituted) or high moisture corn, is steeply increasing (Bernardes and Castro, 2019; Daniel et al., 2019).

As expected, replacing dry corn with ensiled corn in finishing diets increased starch and DM digestibility. During the storage period, the action of proteolytic bacteria and kernel proteases broke down the protein matrix (Junges et al., 2017), increasing the availability of starch (Hoffman et al., 2011) both in the rumen and in the small intestine (Owens et al., 1986; Owens et al., 1997). Hence, diets based on ensiled corn had higher energy contents (ME, NEm, NEg) than diets based on dry corn.

Replacing dry corn with ensiled corn markedly decreased DMI. In diets with high proportion of concentrates, replacing dry corn with corn grain silage frequently decreases DMI (Owens et al., 1997; Zinn et al., 2011), because higher ruminal starch fermentability induces hypophagia. Greater starch fermentability is associated with higher production and absorption of volatile fatty acids in the forestomach, including propionate (Oba and Allen, 2003). Therefore, a higher net portal flux of propionate likely occurs in diets with ensiled corn compared with dry corn. In the liver, a high propionate offer increases the anaplerosis in the tricarboxylic acid cycle (oxidation of fuels) and ATP production, which causes satiety mainly by decreasing meal size (Allen et al., 2009; Allen, 2020). Jacovaci (2019) observed a decreased meal size in animals fed corn grain silage compared with dry rolled corn. In our meta-analysis, the reduction in DMI (-14.1%) was larger than previously reported for dent corn (-5.5%; Owens and Basalan, 2013).

Although the ensiled corn decreased DMI, the ADG was similar between diets, which led to a marked improvement in feed efficiency (+18.3%) when ensiled corn replaced dry corn. For dent hybrids, Owens and Basalan (2013) also reported improvements in feed efficiency in favor of ensiled corn, but to a lesser extent (+5.4%). Based on feed efficiency, the feeding value was on average 25.7% higher for the ensiled corn grain compared with the dry flint corn grain. It means that NE values of flint corn grain silage were markedly higher (i.e., +20.7% for NEm and +27.7% for NEg) than dry flint corn (ground or rolled). Previous studies have suggested that NE of dry ground flint corn is lower than tabular values in nutritional models (e.g., NRC, 1996; NASEM, 2016). Pereira et al. (2007) reported similar or slightly

lower values of NEm and NEg for diets based on dry ground flint corn compared with diets based on citrus pulp. Assuming the value of NEg for dry ground flint corn equal to that of citrus pulp listed in NRC (1996) (5.62 MJ/kg DM), ensiling corn grain may increase the NEg to 7.18 MJ/kg DM. In a review, Zinn et al. (2011) reported a value of 6.74 MJ/kg DM for ensiled dent corn. These values are comparable to NEg of steam-flaked dent corn (6.98 MJ/kg DM) listed in NASEM (2016).

Meanwhile, ME intake slightly decreased when ensiled corn replaced dry corn. However, the difference of ME intake (ensiled grain minus dry grain) was dependent on ME intake. When ME intake of dry corn-based diet was higher than 111 MJ/d, the replacement of dry with ensiled grain decreased ME intake, whereas in animals with lower caloric intake ( $\leq 111$  MJ/d), ensiled corn improved ME intake. Krehbiel et al. (2006) reported a curvilinear relationship between dietary content of ME and ADG, which reflects ME intake. In that case, the maximum ME intake was approximately 118 MJ/d (ME content of 13.2 MJ/kg  $\times$  average DMI of 8.91 kg/d). Such value is slightly higher than the 111 MJ/d capable of reverting the benefit of replacing dry with ensiled grain on ME intake in our meta-analysis. In our review, there was a predominance of Nellore cattle (*Bos taurus indicus*), whereas in US trials reviewed by Krehbiel et al. (2006), there was a predominance of *B. taurus taurus* cattle. *Bos taurus* cattle have been claimed to have a greater capacity of consuming energy relative to their maintenance requirements than *B. indicus*, especially in diets with high levels of concentrates (Olbrich Jr., 1996; Krehbiel et al., 2000; Carvalho et al., 2016; Favero et al., 2019; Antonelo et al., 2020).

Nutritional strategies capable of increasing ME intake in diets based on ensiled corn would benefit beef operations handling zebu cattle. One practical strategy is altering the site of starch digestion, from rumen to intestine, to decrease the hypophagic effect of propionate, for instance by including more NDF from forage or byproducts in the diet. Owens and Basalan (2013) reported an increase of ME intake when more NDF was added to diets based on ensiled corn, as well as a decrease in the level of ensiled corn. On the other hand, Caetano et al. (2015 and 2019) reported no interaction between corn processing method (dry ground or ensiled corn) and diet proportions of forage NDF or starch, respectively. In our dataset, neither the proportion of forage NDF ( $r = 0.16$ ,  $P = 0.48$ ) nor grain proportion in diet ( $r = -0.09$ ,  $P = 0.68$ ) were significantly correlated with the difference in ME intake upon replacing dry grain with ensiled grain.

Owens and Basalan (2013) reported that the dilution of the diet energy would be more beneficial with ensiled corn grain than with the other forms of grain processing. Therefore, an option for changing the pattern of starch digestion is to partially replace ensiled corn with dry ground corn (e.g., 1/4 or 1/3 of dry ground). Stock and Erickson (2006) summarized trials from Nebraska to evaluate the associative effects of feeding mixtures of ensiled and dry corn in high-grain diets. Blends of 250 to 330 g/kg of dry corn and 750 to 670 g/kg of ensiled corn produced a positive associative effect of improved cattle performance compared with only dry corn or ensiled corn or other blends. Meanwhile, more studies are warranted to fine-tune those nutritional adjustments for flint corn grain offered to zebu cattle.

## 5. Conclusions

Ensiling is an efficient strategy to improve the caloric value of flint corn grain for finishing cattle. The feeding value is on average 25.7% higher for the ensiled corn grain compared with the dry corn grain.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Formal analysis: F.A. Jacovaci and J.L.P. Daniel. Writing-original draft: F.A. Jacovaci. Writing-review & editing: P.A.R. Salvo, C.C. Jobim and J.L.P. Daniel.

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