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Article

Digestion in and Performance of Intensively Reared Beef Cattle Fed Diets with a Majority of Maize or Barley, Either Ground or Dry-Rolled

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Simple Summary

Intensive beef meat production relies on high intakes of concentrates (up to 90% of the total ration), which can increase the risk of rumen acidosis. This risk is associated with the rate and extent of starch fermentation, which in turn depends on cereal type and processing. In the present study, two cereals with different rates of starch fermentation (barley vs. maize in proportions 75:25 or 25:75) and two processing methods (grinding vs. dry-rolling) were compared to check their effect on the diet digestion in and performance of feedlot cattle offered straw as a source of fibre. Overall, our results showed that neither the type of majority cereal nor its processing method influenced the average daily gain, intake of straw or concentrate, or feed conversion ratios. Hence, the decision of what cereal has to be included in greater proportion in the concentrate, or what should be its processing method, should depend exclusively on their relative costs, aiming for the optimal profitability of the farms.

Abstract

Barley is more extensively and more rapidly fermentable than maize, thus it is supposed to increase digestive disorders in ruminants. However, the effect of cereal type on animal performance and digestion may vary with processing degree. In the present experiment, the effect of dry-rolling or grinding barley and maize, as the main cereals in a concentrate containing a high proportion of starch with different rates of fermentation, on intensively reared beef cattle performance, diet digestibility, and feed intake amount and pattern, was studied. Thirty-six 3-month-old male calves were allocated to one of four diets consisting of barley straw (BS) and a concentrate with 60% cereals (barley and maize in proportions 75:25 or 25:75) presented dry-rolled or ground through a 3.5 mm sieve. The experimental period was divided into two phases of 10 weeks each: from start to 277 ± 3.6 kg live weight (LW; Growing), and from 289 ± 3.8 kg LW to slaughter (399 ± 4.6 kg; Finishing). For the Growing phase, there were no differences ($p > 0.10$) between the majority cereal in the concentrates, nor between their processing methods, in the daily intake of concentrate and BS, and in the animals' final LW. With respect to Finishing, the interaction between cereal type and processing was significant ($p < 0.05$) for concentrate daily intake. As a result, animals consuming ground barley ate less concentrate than those fed rolled barley, whereas there were no differences between processing methods for animals fed maize-based diets. Animals consuming ground-barley concentrates consumed significantly more straw than those fed on dry-rolled-barley concentrates ($p < 0.05$ for Growing and $p < 0.01$ for

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Finishing) during the first four hours after feeding. No such differences appeared in animals consuming maize-based concentrates. Starch digestibility was higher in animals fed ground cereals vs. dry-rolled cereals during the Growing phase (p = 0.048), whereas NDF digestibility was also higher (p = 0.008) in animals fed ground cereals during the Finishing phase. The faeces from animals fed on rolled-maize concentrates showed a higher concentration of purine bases than the faeces of animals fed on rolled-barley concentrates (p = 0.016), although there were no differences for the ground cereals. Overall, the results reported indicated that replacing maize with barley in diets for feedlot beef cattle did not affect average daily gain, intake of straw or concentrate, or feed conversion ratios (total or considering just the concentrate); hence the inclusion of either cereal in greater proportions should be based on their market price and on the final cost of the compound feed (which may include different ingredients). The processing method of the cereals (grinding or dry-rolling) also had no influence on the above-mentioned variables, so the selection of the method should be based on their relative cost, exclusively in terms of feed efficiency.

Keywords: beef cattle; barley; maize; cereal processing; animal performance

1. Introduction

Intensive beef production is based on young animals from either the dairy industry or beef breeds, which are fed concentrates and roughages (usually low-quality forages) ad libitum [1]. In these conditions, concentrate intake accounts for up to 90% of total dry matter intake [2–5], which allows for very high growth rates, shortened fattening periods, and a high-efficiency use of the energy consumed [6]. However, an excessive intake of concentrates, of which usually more than 60% are cereals, may lead to an overload of readily fermentable carbohydrates (mainly starch) in the rumen, increasing the risk of sub-acute or even acute acidosis [7,8]. In this context, the optimal utilisation of starch, which depends mainly on the extent and site of digestion, is crucial to improve the efficiency of the productive system with respect to energy utilisation. In this respect, both dairy and beef cattle receive more benefit from rapidly fermentable starch in the rumen than from bypass starch [9]. Cereal processing, which generally increases its ruminal fermentation rate, may then notably increase both the starch utilisation by ruminants [10] and the efficiency of use of the energy [11–13].

Maize and barley are the most common cereals used in cattle feeding [14]. Barley has more protein and fibre and less starch than maize [15], and barley starch is more extensively fermented in vitro [16] and in sacco [17,18] than maize starch. Many papers comparing the effect of the majority of maize or barley in diets for beef cattle indicate few differences in animal performance between grain sources [11,19–21], concluding that barley may be substituted for maize without jeopardising the performance of the growing beef cattle [19]. However, these papers greatly differ in terms of the forage source employed, the percentage of grains in the concentrate, or the processing of the latter.

Grain processing increases starch availability and improves the mixing of dissimilar ingredients, thereby enhancing animal performance. The extent of improvement depends on the type of grain and processing method [10,11,20,22,23]. Grinding and rolling are the most common physical processes used in feedlot cattle [24]. Both processes break the barrier of hull and pericarp, and reduce particle size, increasing surface area and, consequently, the exposure of endosperm material to rumen microorganisms and small intestine digestive enzymes [22]. Grinding and pelleting have been claimed to increase intake and starch gelatinisation of the grains [25,26], allowing for an increased microbial fermentation and risk of acidosis. However, grinding may also result in less uniform distribution of particle size and higher production of dust, which may reduce intake and adversely affect performance and health [27]. Cereal-rolling ensures a larger particle size than grinding [28,29], and therefore promotes a slower fermentation rate and reduces the risk of acidosis. Dry-rolling is a common processing method, and increases ruminal digestibility of grain and productivity of animals, but the grain kernels often shatter during processing, producing many fine particles, which have been associated with inconsistent animal performance [29].

Studies comparing whole grains to ground or dry-rolled grains suggest that cold-processing of maize does not substantially increase the performance of growing cattle, due to the ability of cattle to break the seed coat during chewing. In contrast, rolling barley normally increases grain digestibility, daily gain and feed to gain ratio [30,31]. There is very little information comparing the effect of grinding vs. dry-rolling of grains in high-concentrate diets for beef cattle [29]. Concerning the extent of the process, the finer dry-rolling of barley increased total tract starch digestibility and feed efficiency compared to coarse dry-rolling, whereas the finer processing of corn did not improve animal performance in medium-concentrate (40% of grain) growing diets [20]. Mathison et al. [32] conducted an experiment with bull calves fed diets containing 90% concentrate, from which 94.5% was barley grain lightly rolled, medium-rolled, or crushed, which also showed an improved efficiency of gain as the degree of processing was increased. Wang et al. [33] also reported lower dry-matter intake (DMI) and slightly lower average daily gain (ADG), but increased gain-to-feed ratio in cattle fed finely rolled compared to coarsely rolled barley.

Due to the contrasting information found in the literature regarding the effect of grain source and processing on animal performance and digestibility in feedlot steers, the hypothesis drawn is that the cereal type used in the formulation of a concentrate (differing in the fermentation rate of starch: barley vs. maize) and its processing (milling vs. dry-rolling) may or may not, depending on the production conditions, affect the pattern of intake of concentrate and forage, and the digestion in and performance of beef cattle fed high-concentrate diets. Only a few studies have directly compared grinding versus dry-rolling in diets containing 60% cereal, and the present work may contribute valuable information in this regard.

2. Materials and Methods

2.1. Animals and Diets

The experiment was carried out at the facilities of the Servicio de Experimentación Animal at the University of Zaragoza (Spain). Thirty-six 3-month-old Holstein-Friesian male calves (119 ± 2.1 kg live weight-LW) were chosen from milk production farms. Previous to the experiment, animals had been vaccinated against enterotoxaemia and foot and mouth disease, and treated against internal parasites. The care and management of animals were performed according to the Spanish Policy for Animal Protection RD 1201/05, which meets the EU Directive 86/609 on the protection of animals used for experimental and other scientific purposes, and the experimental protocol was approved by the Ethical Committee for Animal Research of the University of Zaragoza (reference PI03/2013).

Cattle were individually housed in boxes provided with a slatted concrete floor, an automatic water dispenser, and two separate troughs for concentrate and roughage. The diets consisted of chopped barley straw (BS) and a concentrate, formulated with 60% cereals (barley and maize in proportions 75:25 -Barley- or 25:75 -Maize-), dry-rolled (R) in a dry-rolling machine (CESEMA S.A., motor model ECOAIR AM 132 S04 of 5.5 kw and 1440 rpm, Cadrete, Spain) equipped with two grooved steel rollers with a gap that varies depending on pressure, or ground in a hammer mill (Rosal, Santa Perpetua de Mogoda, Barcelona, Spain), model MMR 05 × 10, 1500 rpm; 3.5 mm screen; G). The rest of the ingredients of the concentrate (40%) were included, ground at 3.5 mm in both R and G treatments. Concentrate and BS were both administered ad libitum.

2.2. Experimental Design

Upon arrival at the experimental facilities, animals were fed a commercial post-weaning concentrate and BS, both offered ad libitum, for two weeks. Then animals were sorted by weight into nine groups of four, and one animal per group was randomly allocated to one of the four diets in a 2 × 2 factorial arrangement. After two weeks of adaptation to the experimental diets, animals were allowed to initiate the control period with an average LW of 158 ± 3.2 kg. The experimental period was divided into two phases (Growing and Finishing) of 70 days each. Diets were formulated to contain ca. 17% crude protein (CP) for the Growing phase and 14.5% CP for the Finishing phase. For this reason, an adaptation period of ten days was allowed between the two phases. The ingredient composition of the four concentrates is given in Table 1, whereas their chemical composition, together with that of BS, and particle size distribution of the concentrates, is shown in Table 2.

Table 1. Ingredient composition (g/kg, as fed) of the concentrates used during growing (from 158 to 277 kg body weight) and finishing (from 289 to 399 kg body weight) of Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates.

	Growing		**Finishing**	
Majority Cereal	**Barley**	**Maize**	**Barley**	**Maize**
Processing	**R G**	**R G**	**R G**	**R G**
Barley	450	150	450	150
Maize	150	450	150	450
Gluten feed (20 g CP/100 g, as fed)	134	2	104	-
Soybean meal 44	120	144	88	115
Wheat bran	54	44	83	55
Sunflower meal (30 g CP/100 g, as fed)	27	105	4.4	70
Beet pulp	8	49	65	100
Palm oil	20	20	20	20
Calcium carbonate	13	13	13	13
Sepiolite	9	8	8	12
Dicalcium phosphate	8	8	8	8
Vitamin–mineral premix [a]	4	4	4	4
NaCl	3	3	3	3

CP—crude protein. [a] Vitamin–mineral premix declared composition (per kg): 2.5 × 10^6 IU vitamin A, 0.5 × 10^6 IU vitamin D_3, 2.5 g alpha-tocopherol, 20 g sepiolite, 225 mg etoxiquin, 225 mg butylhydroxytoluene, 10 g Mn oxide, 2.1 g Fe sulphate, 25 g Zn oxide, 125 mg Ca iodate, 75 mg Co sulphate, 600 mg Cu sulphate, and 50 mg Na selenite.

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Table 2. Chemical composition (g/kg dry matter) of the concentrates and the barley straw (BS), and particle size distribution (g/kg dry matter) and mean particle size (MPS; mm) of the concentrates used during growing (from 158 to 277 kg body weight) and finishing (from 289 to 399 kg body weight) of Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates.

	Growing					Finishing				
Majority Cereal	**Barley**		**Maize**		**BS**	**Barley**		**Maize**		**BS**
Processing	**R**	**G**	**R**	**G**		**R**	**G**	**R**	**G**	
Number of samples	10	10	10	10	10	10	10	10	10	10
Organic matter	928	923	932	941	875	933	934	933	931	889
Crude protein	170	171	176	170	31	142	150	146	150	27.5
Ether extract	40.1	45.2	50.2	43.1	-	39	39	41	41	-
Neutral detergent fibre	182	188	166	180	733	189	185	155	166	737
Acid detergent fibre	70.3	75.7	89	95	522	74	73	80	86	523
Acid detergent lignin	13.2	14.1	18.5	20.4	108	13	11	15	17	100
Starch	420	407	439	461	-	437	423	459	448	-
Particle size (mesh size)										
>2.4 mm	243	90.4	187	76.3		228	174	184	150	
1.2–2.4 mm	143	225	163	226		213	238	219	244	
0.6–1.2 mm	150	174	155	197		158	169	167	175	
0.3–0.6 mm	94.6	113	93.5	110		70.6	87.0	85.2	92.0	
0.15–0.3 mm	42.4	53.6	43.5	49.7		27.4	36.0	40.8	43.0	
<0.15 mm	327	344	358	341		303	296	304	296	
MPS	1.04	0.78	0.88	0.78		1.24	1.12	1.08	1.05	

2.2.1. Intake Measurements and Animal Weight Recording

After the adaptation period to the experimental diets, intake was recorded for the whole length of each growing phase. The amount of concentrate supplied was adjusted daily to ensure at least 10% refusals. Barley straw was offered twice daily in sufficient quantities to ensure no restriction, and procured to have at least 0.5 kg of straw at any time in the feeder. For the whole experimental period, the amount of concentrate and BS offered to each animal was recorded weekly, and aliquots were taken for chemical analysis and particle size distribution of concentrates. Concentrate refusals were collected daily, and straw refusals were collected twice a week, individually bulked, and their weight recorded weekly.

Representative samples of offered straw and concentrates taken weekly, and of individual weekly refusals, were dried at 105 °C for 24 h to determine DM intake (DMI). Calves were weighed weekly, three hours after feed distribution, throughout the whole experimental period.

2.2.2. Daily Pattern of Intake

The daily pattern of intake of both concentrate and BS was measured every two weeks (five times along each growing phase) by recording the weight of food supplied and residues in the trough at different time intervals throughout the day. Recording intervals in the Growing phase were 8:00–9:00, 9:00–10:00, 10:00–12:00, 12:00–14:00, 14:00–16:00, 16:00–18:00, 18:00–20:00, and 20:00 to 08:00 h of the next day for concentrates, and 8:00–12:00, 12:00–20:00, and 20:00 to 08:00 h for BS. In the Finishing phase, the first recording time was 9:00–10:00 h for concentrates and 9:00–12:00 h for BS, subsequently following the same intervals of time as in the Growing phase. For intervals up to 20:00 h (Growing phase) or 21:00 h (Finishing phase), the percentage of DM of orts was considered to be the same that of offered feeds, whereas for the last interval (20:00 to 8:00 h in the Growing phase, and 21:00 to 9:00 h in the Finishing phase) this percentage was calculated by DM analysis of the feed residuals.

2.2.3. Digestibility

In the middle of each phase (from day 35), a digestibility trial was carried out in four animals per treatment, using Cr_2O_3 (99% purity) as an external marker. Labelled concentrates were prepared to achieve a theoretical concentration of 4000 ppm (Growing) or 2000 ppm (Finishing) of Cr_2O_3 as fresh matter, as previously described [34]. The difference in Cr concentration between Growing and Finishing phases aimed to assess the effects of Cr_2O_3 labelling dose, and of faeces sampling schedule, on faecal Cr concentration and on digestibility estimation [34].

After four days of marker consumption, which allowed for the adaptation to the labelled diets and the achievement of steady-state concentrations of Cr in the rumen, spot samples were taken directly from the rectum at 9:00 and 17:00 h, during four (Growing) or five (Finishing) consecutive days. The pH of spot faecal samples was determined using a portable pH metre (Mettler Toledo Seven2Go, Schwerzenbach, Switzerland) fitted with a penetration electrode 52-00 from Crison (Alella, Barcelona, Spain)).

Four samples of each labelled concentrate were collected on four different days along each experimental period, before distribution, for Cr analysis and chemical composition of diets during the digestibility assessment. Samples of individual (animal) pool samples of concentrate refusals were also collected for Cr analyses.

Half of each spot faeces sample was dried at 60 °C for 48 h and ground to pass through a 1 mm sieve before analyses for Cr concentration, and the other half was pooled on an animal basis, stored fresh at −20 °C, and thawed the day before analysis for purine bases (PB) determination.

2.3. Analysis of Particle Size Distribution

Pooled samples of concentrates taken weekly were wet sieved, in triplicate, following the procedure described by Poppi et al. [35] with some modifications. About 10 g of DM were soaked for 24 h in a solution of 2 mL of Mucasol® in 100 mL of tap water to prevent floatation and to ensure dispersion. Five sieves with different pore sizes (2.40, 1.20, 0.60, 0.30, and 0.15 mm) were placed on a sieve shaker arranged in descending size and suspended in a tank of clean tap water. The equipment was oscillated for 20 min through a vertical distance of 6.5 cm at a frequency of 30 strokes per minute. After sieving, all the sieves were rinsed independently with tap water and their contents collected in filter papers, previously dried at 60 °C, for 48 h and weighed. Filter papers containing residuals were dried at 60 °C for 48 h and weighed to determine residual DM on each one of the sieves.

2.4. Chemical Analysis

Chemical analyses of compound feeds and BS were carried out, in duplicate, from representative samples taken weekly, ground through a 1 mm sieve and pooled on a 3-week basis. Organic matter (OM) in feeds and faeces was obtained by ashing at 550 °C for 8 h [36], and total N following the Kjeldahl method using Cu as a catalyst and a 2300 Kjeltec Analyzer Unit (Foss Tecator TecatorAB, Höganäs, Sweden). Ether extract (EE) in feeds was determined using an ANKOM^{XT15} Extraction System (Ankom Technology, Macedon, NY, USA), following the recommendations of the manufacturer. Neutral detergent fibre (NDF) in feeds and faeces was measured with an ANKOM^{200} Fiber Analyzer (Ankom Technology, Macedon, NY, USA) as described by Mertens [37], and adding amylase. Acid detergent fibre (ADF) and acid detergent lignin (ADL) in feeds were measured as described by AOAC [36] (Official Method 973.18) and Robertson and Van Soest [38] for ADF and

ADL, respectively. Both NDF and ADF were expressed as ash-free residues. The total starch content of the concentrates and faeces was determined enzymatically from samples ground to 0.5 mm using a commercial kit (Total Starch Assay Kit K-TSTA 07/11, Megazyme, Bray, Ireland).

Purine bases in faecal samples were determined by HPLC following the technique described by Reynal and Broderick [39], with some modifications. A Waters equipment (Milford, MA, USA) fitted with an autosampler (Waters 717_{plus}), two peristaltic pumps (Waters-515), and a photodiode array detector (Waters 2996) was used. A 250 × 4.6 mm Inertsil ODS-2 column (Teknokroma Analítica SA, Sant Cugat del Vallès, Barcelona, Spain), protected by a Teknokroma 4.6 mm Inertsil ODS-2 guard, was inserted and held isothermal at 28 °C during the analysis. Absorbance was monitored at 246.7 nm for guanine and at 260.8 nm for adenine. The injection volume was 10 µL at 20 °C, and detector response factors were determined by injecting onto the chromatograph a mixture of 0.5 mM guanine and adenine (diluted in 2 M $HClO_4$) as an external standard, and 2 mM allopurinol as an internal standard, after every ten sample extracts.

Samples of the labelled concentrates and concentrate refusals (dried at 60 °C for 48 h and ground through a 1 mm sieve) and of the dried faeces were analysed for Cr concentration at the Servicio de Análisis Químicos at the University of Zaragoza, as described by de Vega and Poppi [40]. Standards were made by spiking blank samples with different amounts of a Cr solution of known concentration (3.753 g of potassium chromate in 1 L of deionised water) and treating them in the same way as the experimental samples. Marker concentrations were determined by inductively coupled plasma–atomic emission spectroscopy (ICP-AES).

2.5. Calculations

The average daily gain (ADG; kg/day) was calculated as the regression coefficient of individual LW on time. Daily DMI for concentrate and straw were calculated as the average daily intake determined weekly (10 weeks in each phase). The total feed conversion ratio was calculated as the ratio between the average daily total DMI and the ADG, and the concentrate conversion ratio was calculated as the average daily concentrate DMI to the ADG ratio.

Mean particle size (MPS) of concentrates, defined as the theoretical sieve size that would retain 50% of the particles, was estimated by fitting the percentage of cumulative DM oversize from each sieve to the exponential model proposed by Pond et al. [41].

Digestibility values obtained with the measured concentration of Cr in the compound feeds were rather abnormal. New estimates were calculated using the theoretical instead of the analysed Cr concentration, and the new values were much more in accordance with those found in the literature, emphasising the importance of a perfect homogenisation of the marker with the feed [34].

2.6. Statistical Analysis

Data from each growing phase were analysed separately using the SAS statistical package (version 9.4). Two animals from the Finishing phase (treatments Barley-G and Maize-G) were not considered due to respiratory problems.

The effect of cereal type and its processing on animal performance, digestibility, and faecal pH and concentration of PB was studied by ANOVA as a completely randomised design, using the PROC MIXED procedure (Proc GLM). Cereal type and processing method were considered as fixed effects. Where appropriate, the average daily gain, the concentrate, straw and total DM intake, and the feed conversion ratios were corrected by covariance, using initial live weight as a covariate. The LSMEANS were compared using the PDIFF procedure.

The pattern of intake was analysed as repeated measures using the PROC MIXED procedure. Cereal type, processing method, and day and hour of sampling were considered as fixed factors, and animal nested within cereal type by processing method was considered as a random factor. The interaction between day and hour of sampling was used as a repeated measure. Differences between mean values were tested using the Bonferroni test for pre-planned comparisons. Differences between treatments were considered significant if $p < 0.05$, and as a trend to significance when $0.05 \leq p < 0.10$.

3. Results

3.1. Particle Size Distribution of Concentrates

On average, the MPS of concentrates made with rolled cereals was 23% (Growing) and 7% (Finishing) higher than that of concentrates made with ground cereals (Table 2), mainly due to a higher proportion of particles >2.4 mm in rolled cereals. On the other hand, differences in MPS between ground and rolled concentrates were more evident in those including the majority of barley compared to those including the majority of maize.

3.2. Animal Performance

Animal performance data obtained in the Growing and Finishing phases are shown in Tables 3 and 4, respectively. In the Growing phase, there were no differences ($p > 0.10$) between the majority cereal in the concentrates or between their processing methods, for any of the measured variables. The interactions between main factors were also not significant ($p > 0.10$).

Concerning the Finishing phase (Table 4), only the interaction between cereal type and processing was significant ($p < 0.05$) for concentrate DMI when expressed either as kg/day or as g/kg $LW^{0.75}$. In this latter case, concentrate DMI showed a tendency ($p = 0.074$) to be higher in animals fed Barley-R than in those fed Barley-G, and also in animals fed Barley-R than in those fed Maize-R ($p = 0.078$). In any case, these differences were lower than 10% and did not affect ADG or feed conversion ratio.

Table 3. Animal performance of Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates during growing phase (from 158 to 277 kg body weight-LW).

Majority Cereal (Ce)	Barley		Maize		SEM	*p*-Value		
Processing (P)	R	G	R	G		Ce	P	Ce × P
Number of animals	9	9	9	9				
ILW (kg)	161	156	159	158	6.7	0.98	0.68	0.79
FLW (kg)	276	270	272	272	7.5	0.91	0.69	0.70
ADG (kg/day)	1.64	1.63	1.62	1.63	0.040	0.81	0.92	0.70
CDMI (kg/day)	5.74	5.83	5.60	5.69	0.137	0.32	0.53	0.98
CDMI (g/kg $LW^{0.75}$)	101	103	99	100	2.2	0.29	0.43	0.93
SDMI (kg/day)	0.43	0.55	0.57	0.51	0.050	0.54	0.31	0.21
SDMI (as % of TDMI)	6.96	8.50	8.45	8.20	0.668	0.38	0.34	0.19
TDMI (kg/day)	6.17	6.37	6.13	6.21	0.161	0.51	0.39	0.71
TDMI (g/kg $LW^{0.75}$)	108	112	108	109	2.5	0.47	0.31	0.60
CFCR	3.51	3.58	3.46	3.50	0.089	0.43	0.51	0.84
TFCR	3.77	3.92	3.78	3.81	0.097	0.58	0.35	0.55

SEM—standard error of the mean; ILW—initial live weight; FLW—final live weight; ADG—average daily gain; CDMI—concentrate dry matter intake; SDMI—straw dry matter intake; TDMI—total dry matter intake; CFCR—concentrate feed conversion ratio; TFCR—total feed conversion ratio.

Table 4. Animal performance of Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates during finishing phase (from 289 to 399 kg body weight-LW).

Majority Cereal (Ce)	Barley		Maize		SEM	*p*-Value		
Processing (P)	R	G	R	G		Ce	P	Ce × P
Number of animals	9	8	9	8				
ILW (kg)	291	290	289	285	7.9	0.67	0.76	0.90
FLW (kg)	406	395	398	395	9.4	0.67	0.43	0.66
ADG (kg/day)	1.64	1.50	1.56	1.56	0.068	0.88	0.30	0.28
CDMI (kg/day)	7.50	6.82	6.88	7.22	0.247	0.57	0.51	0.049
CDMI (g/kg $LW^{0.75}$)	93	86	86	90	2.8	0.66	0.58	0.046
SDMI (kg/day)	0.64	0.86	0.81	0.78	0.081	0.58	0.25	0.14
SDMI (as % of TDMI)	8.01	11.08	10.41	9.84	0.981	0.56	0.21	0.07
TDMI (kg/day)	8.13	7.68	7.69	8.00	0.243	0.73	0.79	0.12
TDMI (g/kg $LW^{0.75}$)	101	97	96	100	2.7	0.81	0.94	0.13
CFCR	4.57	4.58	4.47	4.68	0.158	0.97	0.47	0.53
TFCR	4.97	5.15	5.00	5.20	0.174	0.83	0.28	0.96

SEM—standard error of the mean; ILW—initial live weight; FLW—final live weight; ADG—average daily gain; CDMI—concentrate dry matter intake; SDMI—straw dry matter intake; TDMI—total dry matter intake; CFCR—concentrate feed conversion ratio; TFCR—total feed conversion ratio.

3.3. Pattern of Concentrate and Straw Intake

Figures 1 and 2 show the daily pattern of concentrate intake in the Growing and Finishing phases studied in the present experiment, expressed as a percentage of total daily concentrate DMI per hour. In the Growing phase, daily concentrate DMI varied from 110.4 ± 1.65 g/kg $LW^{0.75}$ in the first rate of intake control to 105 ± 2.41 g/kg $LW^{0.75}$ in the fifth, whereas in the Finishing phase, these values were 92.8 ± 1.52 g/kg $LW^{0.75}$ and 96.0 ± 2.53 g/kg $LW^{0.75}$, respectively. Animals showed the highest rate of intake in the first hour after feeding ($p < 0.001$), during which calves ate 21% of daily concentrate intake in the Growing phase and 24% in the Finishing phase. The rate of concentrate intake decreased to less than 5–6% of total daily intake per hour until the evening, when there was a slight increase. During the night, the rate of intake decreased to less than 2% per hour. There were no differences between treatments ($p > 0.10$) in the rate of concentrate intake for both Growing and Finishing phases at any recording interval.

With respect to straw intake, its pattern is shown in Figure 3 (Growing) and Figure 4 (Finishing). On average, straw intake represented 7.4% of total DMI during the first four hours after feed distribution in the Growing phase, and 9.6% in the Finishing phase. In the first recording interval of the Growing phase, animals fed Maize-R ate a higher percentage of straw than those fed Barley-R, and calves fed Barley-G ate a higher percentage of straw than those fed Barley-R ($p < 0.05$). In the second interval of the Growing phase, animals consuming Barley-G ate more straw than those consuming Barley-R ($p < 0.05$). Regarding the Finishing phase, in the first recording interval, calves fed Barley-G ate a higher percentage of straw than those fed Barley-R, and animals consuming Barley-G ate a higher percentage of straw than those fed Maize-G. In the third recording interval, animals fed Maize-R consumed a higher percentage of straw than those consuming Barley-R ($p < 0.05$).

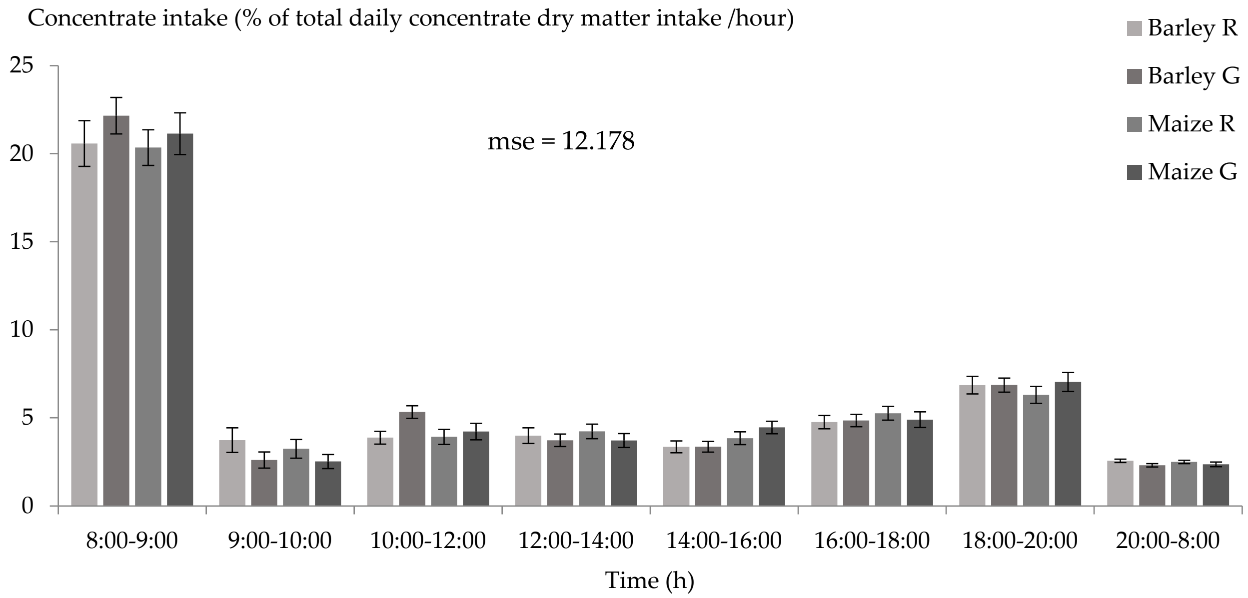

Figure 1. Pattern of concentrate intake in Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates during the growing phase (from 158 to 277 kg body weight). For proportions of barley and maize, see Table 1. mse—mean square error of the analysis of variance. Bars represent the standard error of the means of the interaction between the majority cereal, processing method, and recording interval.

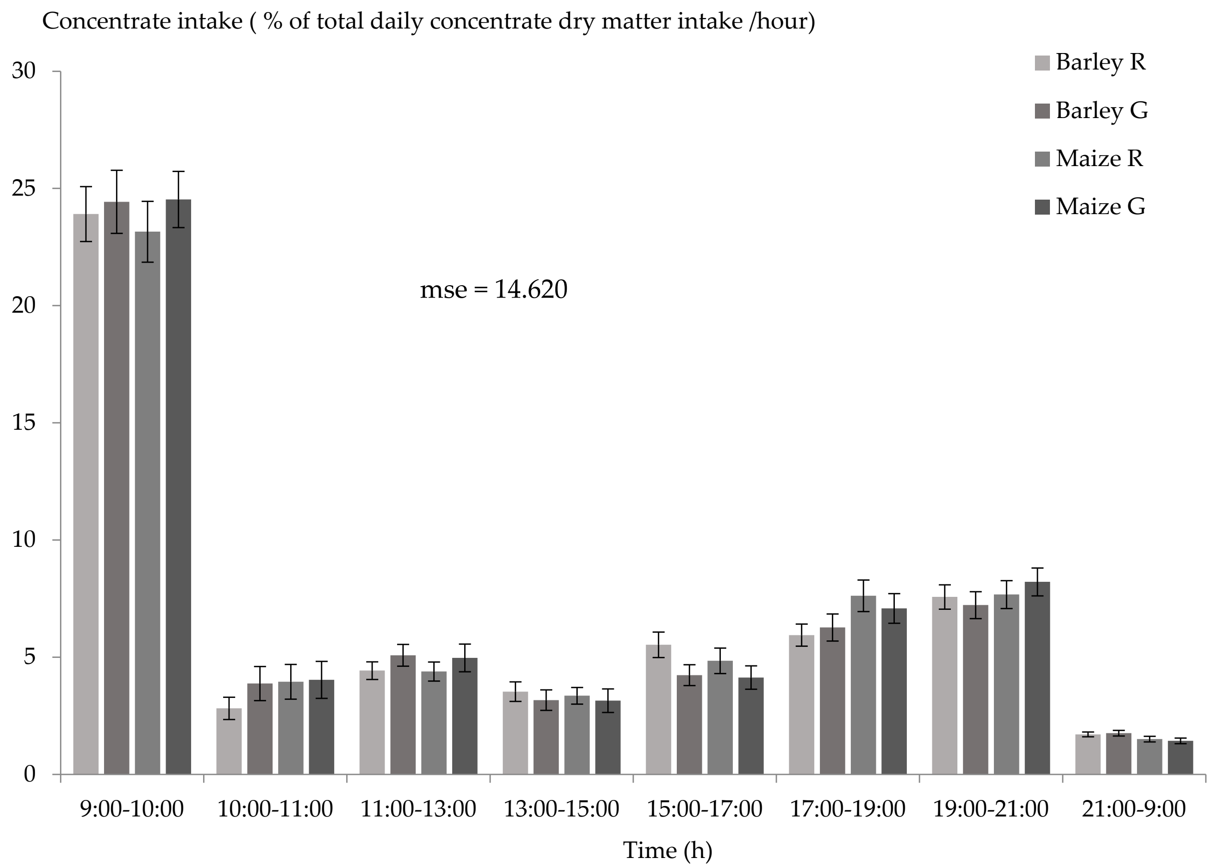

Figure 2. Pattern of concentrate intake in Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates during the finishing phase (from 289 to 399 kg body weight). For proportions of barley and maize, see Table 1. mse—mean square error of the analysis of variance. Bars represent the standard error of the means of the interaction between the majority cereal, processing method, and recording interval.

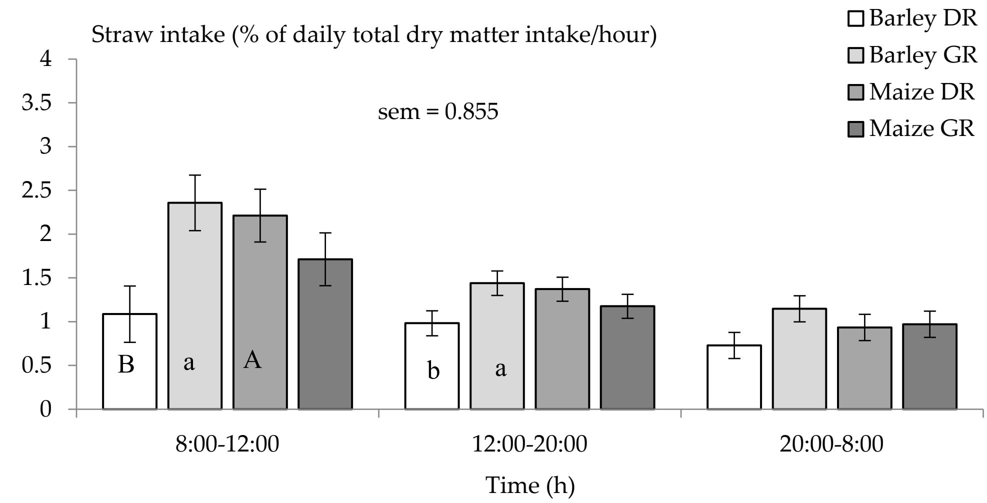

Figure 3. Pattern of straw intake in Holstein-Friesian male calves fed dry-rolled (DR) or ground (3.5 mm; GR) high-barley or high-maize concentrates during the growing phase (from 158 to 277 kg body weight). For proportions of barley and maize, see Table 1. sem—standard error of the mean of the analysis of variance. Bars represent the standard error of the means of the interaction between the majority cereal, processing method, and recording interval. A, B—Different upper-case letters indicate differences ($p < 0.05$) between cereals within each processing method. a, b—different lower-case letters indicate differences ($p < 0.05$) between processing methods within each cereal.

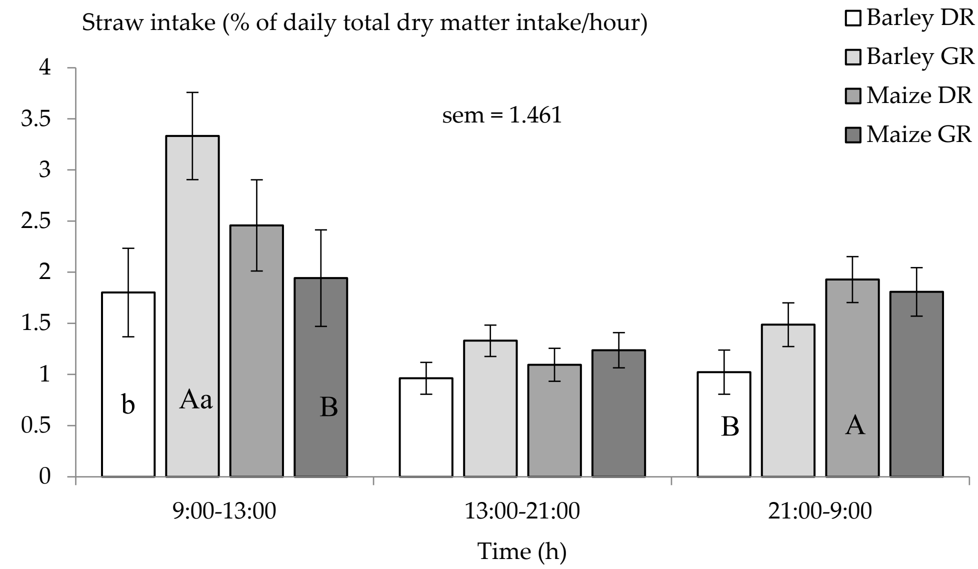

Figure 4. Pattern of straw intake in Holstein-Friesian male calves fed dry-rolled (DR) or ground (3.5 mm; GR) high-barley or high-maize concentrates during the finishing phase (from 289 to 399 kg body weight). For proportions of barley and maize, see Table 1. sem—standard error of the mean of the analysis of variance. Bars represent the standard error of the means of the interaction between the majority cereal, processing method, and recording interval. A, B—Different upper-case letters indicate differences ($p < 0.05$) between cereals within each processing method. a, b—different lower-case letters indicate differences ($p < 0.05$) between processing methods within each cereal.

3.4. Digestibility, and Faecal pH and Concentration of Purine Bases

During the Growing phase (Table 5), there were no significant differences between treatments for the apparent digestibility of DM, OM, and NDF, whereas starch digestibility was higher in animals fed diets including the cereal ground than in those fed diets including the cereal rolled ($p < 0.05$). There was also a tendency ($p = 0.070$) for Barley diets to show a higher CP digestibility than Maize diets. On the other hand, faeces from animals fed on concentrates made with Maize-R showed a higher concentration of PB than the faeces of animals fed on concentrates made with Barley-R ($p < 0.05$), but there were no differences between ground cereals (interaction cereal type by processing method, $p < 0.05$). There were no differences in faeces pH.

Table 5. Apparent digestibility (g/100 g), and faecal pH and concentration of purine bases (PB; µmol/g dry matter) in Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates during growing phase (from 158 to 277 kg body weight).

Majority Cereal (Ce)	**Barley**		**Maize**		**SEM**	***p*-Value**		
Processing (P)	**R**	**G**	**R**	**G**		**Ce**	**P**	**Ce × P**
Number of animals	9	9	9	9				
Dry matter digestibility	70.4	71.7	71.8	72.4	1.28	0.42	0.46	0.80
Organic matter digestibility	73.2	74.3	73.9	75.2	1.29	0.58	0.37	0.94
Crude protein digestibility	75.2	75.7	72.5	74.6	0.96	0.070	0.22	0.41
Starch digestibility	94.6	96.3	95.2	96.4	0.64	0.58	0.048	0.69
NDF digestibility	27.4	34.8	34.3	38.6	4.64	0.27	0.23	0.74
pH	6.22	6.13	6.03	6.27	0.132	0.84	0.60	0.22
PB	11.2 B	13.2	14.5 A	12.4	0.72	0.11	0.92	0.016

SEM—standard error of the mean; NDF—neutral detergent fibre. A, B—different upper case letters indicate differences ($p < 0.05$) between cereals within each processing method.

Concerning the Finishing phase (Table 6), the majority cereal had no effect on any of the variables considered, whereas NDF digestibility was higher in animals fed ground cereals than in animals fed dry-rolled cereals. The interaction between cereal type and processing method was close to significant for faecal pH ($p = 0.068$) because this was numerically lower when the cereals were rolled than when they were ground with Maize diets, whereas the trend was the opposite with Barley diets.

Table 6. Apparent digestibility (g/100 g), and faecal pH and concentration of purine bases (PB; µmol/g dry matter) in Holstein-Friesian male calves fed dry-rolled (R) or ground (3.5 mm; G) high-barley or high-maize concentrates during finishing phase (from 289 to 399 kg body weight).

Majority Cereal (Ce)	**Barley**		**Maize**		**SEM**	***p*-Value**		
Processing (P)	**R**	**G**	**R**	**G**		**Ce**	**P**	**Ce × P**
Number of animals	9	8	9	8				
Dry matter digestibility	72.5	73.2	71.5	71.2	1.36	0.29	0.87	0.73
Organic matter digestibility	74.8	75.1	74.3	74.6	1.40	0.73	0.83	0.99
Crude protein digestibility	69.7	70.1	69.9	68.7	1.47	0.70	0.79	0.57
Starch digestibility	95.3	95.5	96.4	94.7	0.80	0.84	0.38	0.25
NDF digestibility	30.1	44.5	34.5	49.0	4.54	0.35	0.008	1.00
pH	6.15	5.97	6.05	6.25	0.095	0.38	0.92	0.068
PB	12.7	12.9	13.4	13.8	0.59	0.20	0.63	0.99

SEM—standard error of the mean; NDF—neutral detergent fibre.

4. Discussion

The aim of the present work was to study the effect of some factors that may affect beef cattle performance, such as the majority cereal in the concentrate (barley vs. maize) and its processing method (ground vs. dry-rolled). It should be acknowledged that, because the diets were balanced to maintain similar starch and protein levels, variations in the inclusion of complementary ingredients, such as gluten feed, soybean meal, wheat bran, sunflower meal and beet pulp were necessary to achieve nutrient uniformity. Therefore, the differences observed among treatments should not be interpreted as the exclusive result of the majority cereal or the processing method per se, but rather as the combined outcome of these factors and the accompanying dietary adjustments required for nutritional balance.

Even though the results should be interpreted within the context of the experimental design, the present findings offer a realistic perspective on how feedlot cattle respond to different cereals in the ration, and to their physical processing (grinding vs. dry-rolling). As the processing of the cereals may affect them depending on their physico-chemical properties, the design chosen in the present trial was a 2 × 2 factorial.

Regardless of the processing method, concentrates with a majority of barley produced numerically higher proportions of particles > 2.4 mm than those with a majority of maize, especially during growing, with very similar figures for particles < 0.15 mm (Table 2). As a result, the MPS of barley-based concentrates was slightly higher than that of maize-based concentrates, particularly when dry-rolling was applied. Barley presents a higher fibre content than maize, although with a low degree of lignification [42], and this may make grain particles more resistant to physical processing. Differences in particle size distribution between the Growing and Finishing phases might have been due to differences in the characteristics of the ingredients (different cereal batches and slightly different proportions of ingredients; Table 1), as the processing conditions were the same.

The apparent digestibility of DM, OM, and starch was very similar in the Growing (Table 5) and Finishing (Table 6) phases (differences lower than 1%), showing the low effect of the variation in the characteristics of the ingredients pointed out above. The differences outlined in Section 3.4 in straw intake between animals fed Barley-G vs. Barley-R, and between animals fed Maize-R vs. Barley-R, were not enough to affect apparent digestibility values of DM, OM, and starch. Slightly higher (less than 7%) CP digestibility of the diets during the Growing phase can be explained by the fact that, although in the same factory, compound feeds for the Growing and Finishing phases were made with different proportions of different ingredients (Table 1), and at different times. Moreover, CP apparent digestibility was positively related to diet CP content [43], which was higher during the Growing phase.

The results obtained in the present experiment, however, were based on a substitution of maize by barley on a weight basis, without considering the different proportions of starch in each cereal. The lower supply of starch from barley was counterbalanced by including a higher proportion of gluten feed in the Barley concentrates, which provided approximately 7% and 5% of total starch during the Growing and Finishing phases, respectively. The question remains whether the results could have been different if the substitution had been made on an iso-starch basis. Moreover, Barley concentrates included lower proportions of sunflower meal and beet pulp (Table 1). The conjunction of all these factors may have affected the results obtained.

Values of total DMI, ADG, total feed conversion ratio, and proportion of straw in total DMI were within the range expected for Holstein-Friesian male calves reared in the same conditions as in the present experiment [2,34,44].

Concentrate DMI was higher during the rate of intake controls than for the rest of the experimental periods for both Growing and Finishing phases, which might be explained by the manipulation of the animals during the rate of intake control periods, which in turn could have stimulated the consumption of the diets. This argument might also be applicable to the first control period, where the movement of persons on the farm was much more frequent than in the rest of the day.

4.1. Effects of Majority Cereal in the Concentrate

There were no effects of the majority cereal (barley vs. maize) on the steers' performance in either the Growing (Table 3) or Finishing (Table 4) phases. These results agree with those found previously in Montbéliarde cattle fed diets containing 45% of ground barley or maize [3], as in the present trial, or in other breeds fed different proportions of cereals, and with different degrees of processing [11,19–21,45,46].

Barley starch is not as extensively surrounded by a slowly degradable protein matrix as maize starch [47,48]; hence, its rumen degradability is higher than that of maize [16]. Animals eating ground barley could then have a higher amount of starch fermented in the rumen than animals fed on ground maize, even with the same amount and pattern of concentrate intake (Figures 1 and 2). It can be argued that animals might be able to eat more straw during the day to counterbalance this situation, but the intake of forage DM was limited by the underlying NDF characteristics of the fibrous foods that posed a physical upper limit, which could not be overridden [49]. It can be speculated that the only leeway for the animals to alleviate the higher starch fermentation, especially in the first hours after feed offer, would be to increase the proportion of straw intake in those hours as well (Figures 3 and 4). However, the situation was the opposite when the cereals were offered dry-rolled, and the reason might be the higher NDF content of barley with respect to maize, leading to a lesser need for straw by the animals consuming HB than HM concentrates. In any case, daily intake of straw as a proportion of the total DMI was not significant for either the Growing (Table 3) or the Finishing (Table 4) phase, and differences in straw intake during the first 4 h after feeding were significant only for dry-rolled cereals during the Growing phase (higher for maize than for barley; Figure 3) and for ground cereals during the Finishing phase (higher for barley than for maize; Figure 4).

The higher (29%) faecal PB excretion, and quantitatively lower faecal pH, in the Growing phase animals fed rolled maize compared with those fed rolled barley (Table 5) could be explained by a higher proportion of starch not being fermented in the rumen or absorbed in the small intestines, but fermented in the lower intestines [50]. Grinding might increase the accessibility of maize starch by rumen bacteria or intestinal enzymes, hence reducing differences with barley starch. Reasons for the lack of differences between dry-rolled cereals in the Finishing phase animals (Table 6) are unknown.

4.2. Effects of Cereal Processing

Dry rolling produced systematically higher proportions of large particles (>2.4 mm) and lower proportions of medium-sized (between 0.15 and 1.2 mm) particles than grinding (Table 2), and this was reflected in larger MPS. Our results agree with those reported by Dehghan-banadaky et al. [29], who stated that dry-rolling produced more uniform particle size distribution and fewer fine particles than grinding, although the effectiveness of the process may vary with feed characteristics.

Differences in performance traits due to cereal processing were scarce, although the Finishing phase animals fed rolled barley ate more concentrate (10%) than those fed ground barley (Table 4). Our results were in accordance with those found by Mathison [31], among others, who reported a 5% reduction in feed intake and 0.09 kg/d less body weight gain (0.14 in our case) with reduced feed efficiency in finishing steers fed ground barley versus those fed rolled barley. In our case, however, there was no reduction in feed efficiency.

However, animals fed on concentrates made with ground barley ate a significantly higher proportion of straw (as a percentage of daily DM intake) than animals fed on concentrates made with dry-rolled barley during the first four hours after feed distribution. This suggests that the calves attempted to compensate for faster rumen fermentation by increasing early roughage intake. However, there was no effect of processing on the pattern of straw consumption for animals fed maize-based diets (Figures 3 and 4), probably due to the slower fermentation rate of maize starch.

Wang et al. [33] reported lower DMI and ADG in growing cattle fed finely rolled barley than in those fed coarsely rolled barley, with no effect on gain efficiency. Similar results were reported by Hironaka et al. [51] and Bengochea et al. [20], who found that increasing the degree of processing of rolled barley decreased DMI in finishing steers, whereas Bengochea et al. [20] stated that finer processing of maize did not result in improved growth or gain efficiency.

Even though it has been argued [25,26,44] that grinding and pelleting increase intake and starch gelatinisation of the grains, allowing for an increased microbial fermentation and risk of acidosis compared to dry-rolling, the lack of differences in concentrate intake between ground and dry-rolled cereals (Tables 3 and 4) could be due to the lack of pelleting in the present experiment. Also, the difference in MPS (Table 2) could not have been large enough to elicit differences.

To the authors' knowledge, no studies appear to have been published relating barley or maize processing and pattern of intake of both concentrates and roughage in growing steers fed ad libitum. However, it is assumed that increasing the particle size of the diets would decrease meal size and increase chewing time, therefore reducing the amount of acid production in the rumen [52].

In the present experiment, differences were found in the percentage of daily straw intake consumed by animals fed on ground or rolled cereals (Figures 3 and 4). These differences, though of small importance in absolute terms, could be related to the possible effect of processing on rumen environment [2,44].

Only starch digestibility was affected by cereal processing during the Growing phase (Table 5), with higher values for ground vs. dry-rolled cereals. During the Finishing phase (Table 6), only NDF digestibility was influenced, with higher values also for ground cereals. This was expected, as concentrates including ground cereals had smaller MPS (Table 2) and hence likely more surface available for microbial adhesion and fermentation [22,53]. It must be pointed out that DM and the rest of its fractions also showed slightly lower digestibilities (although not significant) in animals fed rolled cereals during the Growing phase.

Some authors [20] evaluated the site of digestion with treatments consisting of 40% coarsely rolled barley (2770 μm), moderately rolled barley (2127 μm), and finely rolled barley (1385 μm), and found that the digestibility of DM, OM, CP, and NDF was not affected by the degree of barley processing but total tract digestibility of starch increased with the finer processing. Others [28] have found that increasing the extent of processing of barley-based diets reduced the amount of postruminal starch digestion, resulting in a higher faecal pH. They also mentioned that reduced faecal pH may be associated with overfeeding of highly fermentable carbohydrates for maize-based diets, for which considerable amounts of starch can be digested postruminally. Gressley et al. [54] have shown that abomasal infusions of a large dose of starch (ca. 4 kg/d) induced hindgut acidosis as indicated by decreased faecal pH and watery faeces. Our results of faecal pH and concentration of PB, however, do not support any significant difference attributable to cereal processing. Nevertheless, animals consuming ground barley had numerically higher faecal concentration of PB and lower pH than animals fed rolled barley (Tables 5 and 6), and this might indicate a higher fermentation of starch in the lower gut. The contrary was observed with HM diets, indicating higher post-ruminal fermentation in animals fed the rolled material compared to those fed the ground cereal.

5. Conclusions

Substitution of maize with barley in diets for feedlot beef cattle does not affect average daily gain, intake of straw or concentrate, or feed conversion ratios (total or considering just the concentrate), at least in the conditions of the present experiment; hence, the inclusion of either cereal in greater proportions should be based on their market price and on the final cost of the compound feed (which may include different ingredients).

On the other hand, the processing method of the cereals (grinding or dry-rolling) also had no influence on the above-mentioned variables, so the selection of the method should be based on their relative cost, exclusively in terms of feed efficiency.

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