The Journal of Agricultural Science

cambridge.org/ags

Effects of different barley grain preservation techniques on intake, growth and carcase traits of finishing dairy bulls fed grass silage-based rations

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Animal Research Paper

Cite this article: Huuskonen A, Rinne M, Manni K (2020). Effects of different barley grain preservation techniques on intake, growth and carcase traits of finishing dairy bulls fed grass silage-based rations. *The Journal of Agricultural Science* **158**, 748–755. https://doi.org/10.1017/S0021859621000022

Received: 8 September 2020
Revised: 10 December 2020
Accepted: 5 January 2021
First published online: 10 February 2021

Key words:
Beef production; crimped grain; growth performance; *Hordeum vulgare*

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Abstract

The effects of different barley grain preservation techniques on intake, growth and carcase traits of dairy bulls were determined in a feeding trial using 52 Holstein and 48 Nordic Red bulls which were allotted to four feeding treatments (five pens and 25 bulls per treatment). Spring barley was harvested with a conventional combine harvester and four different preservation techniques formed the four experimental treatments. Dry grain (DG) was dried to the targeted dry matter (DM) concentration of 870–880 g/kg and rolled within 7 days prior to feeding. High moisture grain treated with a formic acid-based additive (FA) was harvested and crimped on the targeted DM content of 700 g/kg. Low moisture grain treated with a urea-based additive (UR) and low moisture grain treated with a propionic acid-based additive (PA) were harvested and crimped on the targeted DM content of 800 g/kg. The bulls were fed with total mixed ration *ad libitum*. On DM basis, the diets included grass silage (500 g/kg), barley grain (485 g/kg) and a mineral–vitamin mixture (15 g/kg). Daily DM intake (DMI) and live weight gain were 6% higher when crimped grains were used instead of DG ($P < 0.05$). There were no observed significant differences in DMI, gain or carcase traits between high moisture and low moisture crimped grain treatments or between UR and PA. The current results show that producers have the option to vary grain preservation system without major changes to growth performance or carcase traits.

Introduction

In Nordic countries, diets for growing and finishing cattle are typically based on grass silage and grain. Barley (*Hordeum vulgare*) is commonly used as the cereal grain and is generally used in feeding as a dry grain (DG) at a dry matter (DM) content of 850 g/kg or higher. However, in the future flexibility of the grain storage methods are increasingly important due to climate change and unpredictable weather conditions. It has been demonstrated that ensiling of high moisture grain is an efficient storage method as an alternative to drying (Huhtanen *et al*., 2013). Early harvest, crimping and ensiling with an additive diminishes the challenges of short growing season and rainy weather conditions during the harvesting. Additionally, it enables farmers to harvest, process, store and preserve moist cereals without the use of expensive drying facilities and energy consumption for drying (Huhtanen *et al*., 2013; Franco *et al*., 2019).

It is well demonstrated that ensiling of crimped grain has been successfully performed when the crop is harvested at a DM content of 600–700 g/kg (Jaakkola *et al*., 2009; Huhtanen *et al*., 2013). However, dry weather conditions during the harvesting may result in drier than optimal grains. Reduced moisture content has also technological advantages in harvesting and logistics but simultaneously, the risk of aerobic spoilage increases (Franco *et al*., 2019). Nevertheless, recent results by Franco *et al*. (2019) indicated significant potential to modify drier than optimal crimped grain preservation and aerobic stability by using different additives.

In earlier studies, high moisture grain has been fed successfully to cattle (e.g. Flipot and Pelletier, 1980; Gibson *et al*., 1988; Stacey *et al*., 2007) but the results have been partly contradictory. Similar gain and feed efficiency were observed when dry barley (DM at harvesting 866 g/kg) and high moisture barley (DM at harvesting 748–778 g/kg) were fed *ad libitum* with alfalfa-timothy silage to dairy steers but the steers fed with high moisture barley tended to have higher DM intake (DMI) than those fed with dried barley (Flipot and Pelletier, 1980). Huhtanen (1984*a*) observed that the animals fed with high moisture ensiled barley (DM content 574 g/kg) consumed their concentrate faster than those fed with dried barley (DM content 874 g/kg) whereas the groups showed no significant differences in gain, feed conversion or carcase characteristics. Stacey *et al*. (2007) found that beef steers offered urea-treated whole grain wheat (DM content 746 g/kg) had lower live weight (LW) gain (LWG) and carcase gain than steers offered acid-treated crimped wheat (DM content 705 g/kg) or propionic acid-treated whole grain wheat (DM content 849 g/kg) although urea-treated grain contained more crude protein (CP) compared to other treatments. Stacey *et al.* (2007) concluded that the urea treatment as used in their study was not satisfactory due to the high loss of apparently undigested whole wheat grains through the animals. However, in farming practice such grain would have to undergo a processing such as rolling or crimping.

Although comparisons have been made between individual crimped grain systems and conventional conserving methods there is still a lack of information within individual experiments on the intake and growth responses of high and low moisture crimped grain compared to dried grain. Limited information exists on the relative long-term responses of growing and finishing cattle offered grass silage supplemented with barley grain ensiled as high or low moisture crimped grain, or as dried grain. Furthermore, in most earlier growing cattle experiments where different preservation methods of grain have been studied, separate feeding of the grains and forage was used, but nowadays the use of total mixed ration (TMR) in beef production systems has become the dominant method of feeding.

The objective of the present experiment was to study the effects of different barley grain preservation techniques on DMI, growth and carcase traits of growing and finishing Holstein (HO) and Nordic Red (NR) dairy bulls fed with grass silage and barley grain-based TMR. Possible interactions between grain preservation techniques and breed were also examined. Current breeds were chosen because they are most common cattle breeds used in Finland. Chosen preservation techniques were (1) conventional drying (DM content 870–880 g/kg) and rolling prior to feeding, (2) crimping at the targeted DM content of 700 g/kg and ensiled with a formic acid-based additive (FA), (3) crimping at the targeted DM content of 800 g/kg and ensiled with a urea-based additive (UR) and (4) crimping at the targeted DM content of 800 g/kg and ensiled with a propionic acid-based additive (PA). The methods were chosen because they are commercially used in temperate humid areas of north-western Europe for grain preservation.

Based on earlier observations by Flipot and Pelletier (1980) and Huhtanen (1984*a*), it was hypothesized that replacement of dried barley grain with high or low moisture crimped grain would increase total daily DMI of the bulls. Furthermore, it was hypothesized that increasing DMI improves LWG and carcase traits of the bulls in TMR feeding. It was also hypothesized that there are no differences in DMI, LWG and carcase characteristics between high and low moisture crimped grain treatments. Still, it was hypothesized that there would be no differences in DMI or growth performance between low moisture urea treatment and low moisture acid treatment although the bulls in urea treatment would probably have a much higher CP intake. Finally, it was hypothesized that there are no interactions between breed and barley grain preservation techniques on DMI, growth performance or carcase traits.

Materials and methods

Animals and housing

A feeding experiment was conducted in the experimental cattle unit of Natural Resources Institute Finland (Luke) in Ruukki starting in January 2019 and ending in June 2019. The experiment was conducted using 52 HO and 48 NR dairy bulls. All animals were purchased from local dairy farms at on average age of 21 days. From 3 weeks to 6 months of age, the animals were housed in an insulated barn and received milk replacer (until the age of 75 days), grass silage and a commercial pelleted calf starter. The bulls were moved to the experimental cattle unit of Luke on 6 months of age, 3 months before the start of the feeding experiment. During this pre-experimental period the bulls were adapted to housing conditions.

During the pre-experimental period and the feeding experiment, the bulls were housed in an uninsulated barn in pens (10.0 m × 5.0 m; five bulls in each pen), providing 10.0 m^2 per bull. The rear half of the pen area was a peat-bedded lying area and the fore half was a feeding area with a solid concrete floor. Animals were managed according to the Finnish legislation regarding the use of animals in scientific experimentation.

At the beginning of the pre-experimental period the bulls were allotted to pens for five animals (two or three HO and two or three NR bulls per pen) which were then randomly allotted to four feeding treatments (five pens and 25 bulls per feeding treatment). At the start of the feeding experiment, the bulls were on average 290 (±6.2) days old and weighed 381 (±31.8) kg. A GrowSafe feed intake system (model 4000E; GrowSafe Systems Ltd., Airdrie, AB, Canada) was used to record individual daily feed intakes so that each pen contained two GrowSafe feeder nodes. The bulls had free access to water at all times during the whole feeding experiment.

Feeds, feeding and experimental design

Spring barley (cv. Brage) was sown on 25 May 2018 at the experimental farm of Luke in Ruukki (64°44′N, 25°15′E). The sowing rate was 220 kg/ha and commercial N–P–K fertilizers were applied at rates of 67-8-41 kg/ha. The field was sprayed against weeds (Premium Classic 50 SX, Cheminova A/S, Harboore, Denmark; 15 g/ha) on 8 July 2018. Representative areas were harvested with a conventional combine harvester. According to the experimental design four different barley grain preservation techniques were used:

(1) DG treatment was harvested on 7 September 2018 and dried to the targeted DM concentration of 870–880 g/kg. The grain was rolled within 7 days prior to feeding.
(2) High moisture crimped grain treated with an FA was harvested on 15 August 2018. The targeted DM content was 700 g/kg. After harvesting the grain was crimped immediately using a farm scale crimper (Murska 2000 with a tube packing machine, Murska Ltd., Ylivieska, Finland) and treated with an FA containing formic acid (490 g/kg), sodium formate (150 g/kg), propionic acid (100 g/kg) and sodium benzoate (20 g/kg) (AIV 2000 Plus Na, Eastman, Oulu, Finland) applied at a rate of 5 litres/tonne.
(3) Low moisture crimped grain treated with urea-based Maxammon method (UR) was harvested on 28 August 2018. The targeted DM content was 800 g/kg. After harvesting the grain was crimped immediately using a farm scale crimper (Murska 2000 with a tube packing machine, Murska Ltd., Ylivieska, Finland) and treated with 15 kg feed urea and 5 kg Maxammon product (Hankkija Ltd., Hyvinkää, Finland) per tonne of grain. Maxammon product included extruded soybeans, by-products of enzyme

https://doi.org/10.1017/S0021859621000022 Published online by Cambridge University Press

production of *Aspergillus niger*, wheat, calcium carbonate and mixture of flavourings.

(4) Low moisture crimped grain treated with a PA was harvested on 29 August 2018. The targeted DM content was 800 g/kg. After harvesting the grain was crimped immediately using a farm scale crimper (Murska 2000 with a tube packing machine, Murska Ltd., Ylivieska, Finland) and treated with a PA containing propionic acid (540 g/kg), ammonium propionate (310 g/kg) and sodium benzoate (50 g/kg) (Eastman Stabilizer Crimp, Eastman, Oulu, Finland) applied at a rate of 5 litres/tonne.

The DG was stored in a vertical silo. The grains from the experimental treatments 2–4 were stored in plastic tubes with a diameter of 2 m.

Grass silage used in the present experiment was produced at the experimental farm of Luke in Ruukki and harvested from a primary growth of timothy (*Phleum pratense*, cv. Tenho) stand on 19 June 2018. The stand was cut by using a mower conditioner (Elho 280 Hydro Balance, Oy Elho Production Ab, Pännäinen, Finland), harvested with an integrated round baler wrapper (McHale Fusion 3, McHale, Ballinrobe, Co., Mayo, Ireland) approximately 24 h after cutting and treated with an FA (AIV ÄSSÄ, Eastman, Oulu, Finland) applied at a rate of 5.8 kg/tonne of fresh forage.

The bulls were fed with TMR *ad libitum* (proportionate refusals of 5%). TMRs were carried out by using a mixer wagon (Trioliet BW, Oldenzaal, the Netherlands). All four rations were produced every day and feed was offered two times a day. The experimental diets included grass silage (500 g/kg DM), barley grain (485 g/kg DM) and a mineral–vitamin mixture (15 g/kg DM). Barley grain preserved in four different ways formed the four experimental feeding treatments (DG, FA, UR and PA). The composition of the mineral–vitamin mixture (Kasvuape E-Hiven; A-Rehu Ltd., Seinäjoki, Finland) is fully described by Huuskonen *et al.* (2017a). Two bulls (one FA and one UR) were excluded from the study due to pneumonia. There was no reason to suppose that the diets had caused these problems. The other 98 bulls remained healthy throughout the study.

Feed sampling and analysis

During the feeding experiment barley and silage sub-samples were taken twice a week, pooled over periods of 4 weeks and stored at −20°C prior to analyses. Thawed samples were analysed for DM, ash, CP, neutral detergent fibre (NDF), ether extract, starch and fermentation quality (pH, water-soluble carbohydrates (WSC), lactic and formic acids, ethanol, volatile fatty acids and ammonia N content of total N). Silage samples were analysed also for digestible organic matter (DOM) in DM (DOMD, *D*-value). Mineral–vitamin mixture sub-samples were collected every other week, pooled over periods of 8 weeks and analysed for DM, ash, CP, NDF, ether extract and starch.

The DM concentration was determined by drying at 105°C for 20 h. Samples for chemical analyses were dried at 60°C for 16 h and milled using sample mill (Sakomylly KT-3100, Koneteollisuus Ltd., Helsinki, Finland) with a 1 mm sieve. Oven DM concentration of silages was corrected for the loss of volatiles according to Huida *et al.* (1986). The ash concentration was determined by ashing at 600°C for 2 h. Nitrogen (N) content was determined by the Dumas method (AOAC method 968.06; AOAC, 1990) using a Leco FP 428 nitrogen analyzer (Leco, St Joseph, MI, USA). The CP concentration was calculated as 6.25 × N content. Concentration of NDF was determined according to Van Soest *et al.* (1991) using Na-sulphite and a heat stable amylase and presented ash-free. Ether extract was analysed according to the official method 920.39 (AOAC, 1990) and starch according to Salo and Salmi (1968). The measurement of DOMD of silage samples was based on the *in vitro* pepsin-cellulase method and calculated according to Huhtanen *et al.* (2006).

Frozen and thawed samples were analysed for fermentation quality. Lactic acid was analysed according to Haacker *et al.* (1983), VFA according to Huhtanen *et al.* (1998), WSC according to Somogyi (1945) and ammonia N according to McCullough (1967). Formic acid was determined using a commercial kit (cat. no. 979732; Boehringer Mannheim GmbH, Mannheim, Germany). Ethanol content was measured using an enzymatic kit (cat. no. 981680; KONE Instruments Corporation, Espoo, Finland) and the selective clinical chemistry analyser Pro 981489 (KONE Instruments) according to application instructions given by KONE.

The metabolizable energy (ME) concentration of grass silage was calculated as ME (MJ/kg DM) = 16.0 × DOMD (kg/kg DM) (MAFF, 1984). The ME concentration of barley grain was calculated based on the tabulated digestibility coefficients and analysed chemical composition, except for crude fibre concentrations tabulated values were used (Luke, 2020). The protein value of the feeds is expressed as amino absorbed from the small intestine (metabolizable protein, MP) and the protein balance value (PBV) in the rumen according to Luke (2020). The relative intake potential of silage DM (SDMI index) was calculated as described by Huhtanen *et al.* (2007).

Live weight and carcase measurements

The bulls were weighed on 2 consecutive days at the beginning of the feeding experiment and thereafter approximately every 28 days. Before slaughter, they were weighed on 2 consecutive days. The target for the average carcase weight was 310–320 kg. The LWG was calculated as the difference between the means of the initial and final LW divided by the number of growing days. The estimated rate of carcase gain was calculated as the difference between the final carcase weight and the carcase weight at the beginning of the experiment divided by the number of growing days. The carcase weight at the start of the experiment was assumed to be 0.50 × initial LW based on earlier studies (Huuskonen and Huhtanen, 2015).

The bulls were slaughtered in the Atria Ltd. commercial slaughterhouse in Kauhajoki, Finland. After slaughter the carcases were weighed hot. The cold carcase weight was estimated as 0.98 of the hot carcase weight. Dressing proportions were calculated from the ratio of cold carcase weight to final LW. The carcases were graded for conformation and fatness using the EUROP quality classification (EC, 2006). For conformation, the development of the carcase profiles, in particular the essential parts (round, back and shoulder), was taken into consideration according to the EUROP classification (E: excellent, U: very good, R: good, O: fair, P: poor). Each level of the conformation scale was subdivided into three sub-classes to produce a transformed scale ranging from 1 to 15, with 15 being the best conformation. For fat cover degree, the amount of fat on the outside of the carcase and in the thoracic cavity was taken into account using a classification range from 1 (low) to 15 (very high).

Table 1. Chemical compositions and feeding values of the experimental feeds

	GS	DG	FA	UR	PA	MM
Number of samples	6	6	6	6	6	3
DM, g/kg	400	874	708	799	822	986
Organic matter (OM), g/kg DM	930	975	971	968	973	65
CP, g/kg DM	119	126	145	178	141	9
NDF, g/kg DM	507	208	207	204	206	25
Starch, g/kg DM	9	550	493	500	495	7
Ether extract, g/kg DM	36	17	19	19	19	6
ME, MJ/kg DM	11.0	13.1	13.0	12.8	13.0	5.0
MP, g/kg DM	84	98	100	105	100	5
Protein balance in the rumen, g/kg DM	−6	−20	−5	23	−8	1
Digestible OM in DM, g/kg DM	689	ND	ND	ND	ND	ND
Silage DMI index	110					

GS, grass silage; DG, dried barley grain; FA, high-moisture crimped barley grain treated with a formic acid-based additive; UR, low-moisture crimped barley grain treated with urea-based Maxammon method; PA, low-moisture crimped barley grain treated with a propionic acid-based additive; MM, mineral–vitamin mixture.

Statistical analyses

The results are shown as least squares means. The data were subjected to analysis of variance using the SAS GLM procedure (version 9.4, SAS Institute Inc., Cary, NC, USA). The statistical model used was:

$$y_{ijkl} = \mu + \alpha_i + \gamma_j + (\alpha \times \gamma)_{ij} + \theta_{ijl} + \beta x_{ijk} + e_{ijkl}$$

where μ is the intercept and e_{ijkl} is the residual error term associated with lth animal. α_i, γ_j and $(\alpha \times \gamma)_{ij}$ are the effects of ith diet (DG, FA, UR and PA) and jth breed (HO and NR) and their interaction, respectively, while θ_{ijl} is the effect of pen. The effect of pen was used as an error term when differences between treatments were compared. Initial LW was used as a covariate (βx_{ijk}) in the model.

Differences between the treatments were tested using orthogonal contrasts: (1) HO *v.* NR, (2) DG *v.* crimped grains (FA, UR and PA), (3) high moisture crimped grain (FA) *v.* low moisture crimped grains (UR and PA), (4) urea-based additive-treated low moisture crimped grain (UR) *v.* propionic acid-based additive-treated low moisture crimped grain (PA), (5) interaction between contrasts 1 and 2, (6) interaction between contrasts 1 and 3 and (7) interaction between contrasts 1 and 4. As the interactions between breed and feeding treatments were not statistically significant ($P > 0.10$ for all variables), the P values of the interactions are not presented.

Results

Chemical composition and feeding values of the experimental feeds are available in Table 1. The DM concentrations of barley grain were at the targeted levels. According to feed analyses, DG had slightly higher starch concentration and lower CP concentration compared to crimped grains. The UR treatment had the highest CP concentration due to the urea added as the preservative.

The grass silage used in the present experiment was of good nutritional quality as indicated by DOMD, MP and PBV values (Table 1). The fermentation characteristic of the silage was good as indicated by the pH value and the low concentration of ammonia N and total acids (Table 2). The silage used was restrictively fermented with high residual WSC concentration and low lactic acid concentration.

The fermentation characteristics of all three crimped grains were good (Table 2). The addition of feed urea increased pH and ammonia-N content of UR but otherwise the differences between the crimped treatments in fermentation quality were minor.

Due to the differences in chemical composition and feeding values of the grains, TMR composition slightly differed among the treatments (Table 3). Replacing DG by crimped grain in TMR increased CP concentration and PBV value and starch concentration decreased. Additionally, DM concentration decreased when DG was replaced by crimped grains.

The feeding experiment lasted 168 days and the average slaughter age of the bulls was 458 days (Table 4). No significant breed × diet interactions were observed. Daily DMI was 11.0 kg/day, on average, during the feeding experiment and was approximately 6% higher when crimped grains were used instead of DG ($P < 0.05$). There were no significant differences in DMI among the crimped grain treatments. The bulls receiving crimped grains had 5% higher ME intake ($P < 0.05$) and 18% higher CP intake ($P < 0.001$), on average, compared to the DG bulls. There were no differences in ME intake among the crimped grain treatments. The UR bulls had higher CP intake compared to the PA bulls ($P < 0.001$). Breed did not affect feed or nutrient intake of the bulls (Table 4).

The average LWG and carcase gain of the bulls was 1390 and 752 g/day, respectively. The LWG was approximately 6% higher ($P < 0.05$) and carcase gain tended to be 4% higher ($P < 0.1$) when crimped grains were used instead of DG (Table 4). There were no significant differences in LWG or carcase gain among the crimped grain treatments. Dietary treatments had no effects on DM or energy conversion rates. However, the use of DG improved CP conversion rate (kg CP/kg LWG) compared to the crimped grain treatments ($P < 0.001$). Furthermore, the PA bulls had superior CP conversion compared to the UR bulls

https://doi.org/10.1017/S0021859621000022 Published online by Cambridge University Press

Table 2. Fermentation quality of crimped barley grains and grass silage (GS)

	FA	UR	PA	GS
Number of samples	6	6	6	6
pH	5.57	8.72	5.40	4.55
In DM, g/kg				
Acetic acid	1.24	3.95	1.39	7.18
Propionic acid	0.62	0.12	4.80	2.58
Butyric acid	0.01	0.01	0.01	0.34
Valeric acid	0.01	0	0	0.13
Isovaleric acid	0.02	0.04	0.01	0.10
Isobutyric acid	0.01	0.01	0	0.02
Formic acid	2.33	0	0	4.59
Lactic acid	2.29	0.39	1.31	20.5
Ethanol	1.55	0.03	0.71	4.71
Water soluble carbohydrates	33	18	24	161
Ammonium N, g/kg N	13	165	18	36

FA, high-moisture crimped barley grain treated with a formic acid-based additive; UR, low-moisture crimped barley grain treated with urea-based Maxammon method; PA, low-moisture crimped barley grain treated with a propionic acid-based additive.

Table 3. Calculated chemical compositions and feeding values of the TMRs used in the feeding experiment

	DG	FA	UR	PA
DM, g/kg	549	511	533	538
OM, g/kg DM	953	951	949	952
CP, g/kg DM	123	132	149	130
NDF, g/kg DM	358	357	356	357
Starch, g/kg DM	280	251	255	252
Ether extract, g/kg DM	27	28	28	28
ME, MJ/kg DM	12.1	12.0	11.9	12.0
MP, g/kg DM	91	92	95	92
Protein balance in the rumen, g/kg DM	−13	−6	9	−7

DG, TMR including dried barley grain; FA, TMR including high-moisture crimped barley grain treated with a formic acid-based additive; MA, TMR including low-moisture crimped barley grain treated with urea-based Maxammon method; PA, TMR including low-moisture crimped barley grain treated with a propionic acid-based additive.

($P < 0.001$). Breed had no effects on LWG, carcase gain or feed conversion of the bulls (Table 4).

Carcase weight of the bulls was 317 kg, on average, and tended to be 2% higher when crimped grains were used instead of DG ($P < 0.1$). The dressing proportion, carcase conformation score and carcase fat score of the bulls were, on average, 516 g/kg, 4.9 and 4.8, respectively, and there were no significant differences among the feeding treatments. However, the dressing proportion of the PA bulls tended to be slightly higher ($P < 0.1$) compared to the UR bulls. Furthermore, the bulls receiving high moisture crimped grain tended to have slightly higher fat score compared to the bulls receiving low moisture crimped grain ($P < 0.1$) (Table 4). Breed did not affect carcase weight or dressing proportion of the bulls. However, the carcase conformation score of the NR bulls was 4% higher compared to the HO bulls ($P < 0.01$). In addition, the NR bulls tended to have 4% higher carcase fat score compared to the HO bulls ($P < 0.1$) (Table 4).

Discussion

Effects of breed

There were only minor differences between HO and NR breeds, and no interactions between the breeds and the grain preservation treatments were observed, so the breed effects are discussed very briefly. Consistent with the present experiment, Huuskonen *et al.* (2017b) reported no difference in DMI, growth performance or feed conversion rate between HO and NR bulls in grass silage and barley grain-based TMR feeding. Earlier, based on on-farm data set, Huuskonen (2014) observed that the conformation score of the NR bulls was 14% higher compared to the HO bulls which is in line with the present experiment. However, contrary to previous observations by Huuskonen (2014), there was no significant difference in carcase gain between NR and HO bulls in the present study. Instead, Huuskonen (2014) reported that the carcase gain of the NR bulls was slightly but significantly lower compared to the HO bulls.

Effects of grain preservation techniques

The organic matter, CP, NDF and starch concentrations of DG in the present experiment were typical corresponding well to average values in the Finnish Feed Tables (Luke, 2020). As expected, the addition of feed urea increased the CP concentration of UR compared to other treatments and the addition of feed urea increased pH and ammonia-N content of UR. In urea-based Maxammon method grains are typically conserved in an alkaline state (pH 8.5–9.5) with the ammonia releasing process (Nikulina *et al.*, 2018).

Consistent with Huhtanen (1984*b*), Pettersson *et al.* (1998) and Stacey *et al.* (2007) dried grain had higher starch concentration compared to ensiled grains. Huhtanen (1984*b*) found that after ensiling, barley grain contained more sugars than before ensiling despite increased concentrations of lactic and acetic acids and suggested that starch was hydrolysed during storage. Pettersson *et al.* (1998) stated that amylolytic enzymes from the grain or microbes could probably be responsible for the reduction in starch concentration. According to McDonald *et al.* (1991) glucose resulting from the decomposition of starch can be further fermented to compounds such as lactic acid, acetic acid and ethanol.

In agreement with Huhtanen (1984*a*), the daily DMI was higher when crimped grains were used instead of DG. Huhtanen (1984*a*) reported that the palatability of high moisture ensiled barley grain tended to be better than that of dried barley grain and DMI per kg metabolic LW was higher. Furthermore, the animals fed with ensiled barley grain consumed their concentrate faster than those fed with dried barley grain (Huhtanen, 1984*a*). Also, Flipot and Pelletier (1980) observed that steers fed with dried barley grain tended to consume less feed than those fed with high moisture barley grain. In contrast, Kennelly *et al.* (1988) reported no significant differences in DMI of feedlot steers fed with dry and high moisture barley grain. In the present experiment the explanation for the increased DMI of the bulls fed with the crimped grains compared to DG is partly unclear.

https://doi.org/10.1017/S0021859621000022 Published online by Cambridge University Press

Table 4. Intake, growth performance and carcase characteristics of the bulls fed with different TMRs

	Barley preservation method				Breed			Orthogonal contrasts (*P* values)			
	DG	FA	UR	PA	HO	NR	S.E.M.	1	2	3	4
Number of bulls	25	24	24	25	50	48					
Duration of the experiment, day	168	168	168	168	168	168					
Final LW, kg	604	615	622	616	618	611	5.1	0.704	0.022	0.517	0.450
Slaughter age, day	457	458	460	458	459	458	1.2	0.623	0.246	0.289	0.164
Intake											
Total DM, kg/day	10.6	11.2	11.4	11.0	11.1	11.0	0.23	0.709	0.018	0.969	0.143
ME, MJ/day	128	134	136	132	133	132	2.8	0.704	0.036	0.942	0.253
CP, kg/day	1.30	1.47	1.70	1.43	1.48	1.47	0.031	0.770	<0.001	0.019	<0.001
Starch, kg/day	2.95	2.81	2.91	2.76	2.87	2.85	0.059	0.703	0.073	0.678	0.092
LWG, g/day	1330	1394	1434	1401	1409	1371	30.4	0.456	0.022	0.517	0.450
Carcase gain, g/day	729	756	756	766	759	745	16.3	0.702	0.095	0.795	0.660
Feed conversion											
kg DM/kg LWG	8.01	8.11	8.08	7.88	7.95	8.10	0.208	0.450	0.941	0.595	0.506
MJ ME/kg LWG	97	98	96	95	96	97	2.5	0.456	0.877	0.534	0.682
kg CP/kg LWG	0.98	1.07	1.20	1.03	1.06	1.08	0.028	0.417	<0.001	0.190	<0.001
Carcase characteristics											
Carcase weight, kg	313	318	318	319	318	316	2.7	0.444	0.095	0.795	0.660
Dressing proportion, g/kg	518	516	510	518	515	516	3.0	0.615	0.401	0.528	0.074
Conformation, EUROP	4.8	4.9	4.9	4.9	4.8	5.0	0.07	0.003	0.169	0.816	0.566
Fat score, EUROP	4.7	5.0	4.6	4.8	4.7	4.9	0.14	0.070	0.587	0.085	0.332

DG, TMR including dried barley grain; FA, TMR including high-moisture crimped barley grain treated with a formic acid-based additive; UR, TMR including low-moisture crimped barley grain treated with the urea-based Maxammon method; PA, TMR including low-moisture crimped barley grain treated with a propionic acid-based additive; HO, Holstein; NR, Nordic Red; S.E.M., standard error of mean.
Orthogonal contrasts: (1) HO *v.* NR, (2) DG *v.* crimped grains (FA, UR, PA), (3) high moisture crimped grain (FA) *v.* (low moisture crimped grains (UR, PA)) and (4) urea-based Maxammon method-treated low moisture crimped grain (UR) *v.* propionic acid-based additive-treated low moisture crimped grain (PA).

Theoretically, the higher protein intake could partly explain the increased DMI. Based on the meta-analysis, Huuskonen *et al.* (2013) found that increasing the concentrate CP concentration had small but statistically significant positive effect on total DMI of growing cattle. However, in that meta-analysis the DMI response of growing cattle was minimal with maximum predicted response less than 2% (Huuskonen *et al.*, 2013) that is much smaller than the corresponding DMI response in lactating cows (Huhtanen *et al.*, 2008). Therefore, it is unlikely that the higher CP intake would explain the increased DMI in the present experiment.

In the current study, no differences were observed in DMI among the crimped grain treatments. In earlier experiments with separate feeding Stacey *et al.* (2007) and Keady *et al.* (2008) observed that steers fed with urea-treated wheat had 14–17% higher silage DMI compared to steers fed with acid–treated wheat. Keady *et al.* (2008) found 7% higher total DMI in urea treatment relative to acid treatment and speculated that the increased intake due to urea treatment was probably associated with changed rumen fermentation patterns. The ammonia supplied by the urea-treated grain may have promoted the higher minimum rumen pH, thereby increasing the rate of fibre digestion and thus of DM disappearance from the rumen. Distinctions between the current study and earlier observations in DMI can be due to different feeding methods. One rationale for TMR feeding is to achieve a relatively stable rumen pH and fermentation pattern throughout the day which would facilitate better cellulose digestion and a higher lipogenic to non-lipogenic VFA ratio (Kaufmann, 1976).

Higher daily DMI of the bulls fed with crimped barley grain treatments compared to the DG bulls was reflected also as larger ME and CP intake. Observed difference in ME intake is probably a crucial explanation for the improved LWG of the crimped grain treatments compared to DG. Diet digestibility was not determined in the current experiment but there are indications that ensiling the grains may increase their digestibility (Buchanan-Smith *et al.*, 2003), which would contribute to increased energy intake of the animals. Based on the meta-analysis of growing cattle feeding experiments, Huuskonen and Huhtanen (2015) reported that energy intake was clearly the most important variable affecting LWG of growing cattle, whereas the results showed only marginal effects of protein supply on growth performance on grass silage plus grain-based diets. In the current study, the addition of feed urea increased CP intake of the UR bulls compared to the PA bulls. However, as hypothesized, this was not reflected in the growth results. In growing cattle growth responses to increased protein intake have been minimal, if any, when animals are fed with diets based on high quality forages and moderate levels of

https://doi.org/10.1017/S0021859621000022 Published online by Cambridge University Press

grain-based concentrate (Huuskonen et al., 2008, 2014; Huuskonen, 2011).

Consistent with the present experiment, Flipot and Pelletier (1980), Huhtanen (1984a) and Kennelly et al. (1988) reported no significant difference in feed DM conversion ratio for dried barley diets compared to ensiled and high moisture barley diets. In the current study, protein conversion efficiency declined with increasing diet CP concentration when DG was replaced by crimped grain treatments and the poorest CP conversion rate was observed in the UR treatment. It is documented that relatively low protein concentration (110–120 g/kg DM) in the diet of growing cattle feeding can be seen as an environmental advantage (Huuskonen et al., 2014). Recent results by Huhtanen and Huuskonen (2020) indicate that decreasing dietary N inputs in growing cattle diet would be an effective way to decrease urinary and manure N output, and to reduce excretions per kg LWG and carcase gain in grass silage plus grain-based diets.

In accordance with previous experiments (Huhtanen, 1984a; Kennelly et al., 1988; Keady et al., 2008), different barley grain preservation had only minor and statistically non-significant effects on carcase traits of the bulls. Previously, it is documented that increased energy intake increases carcase conformation (Caplis et al., 2005; Pesonen et al., 2013; Huuskonen and Huhtanen, 2015) and carcase fatness (Huuskonen et al., 2007; Huuskonen and Huhtanen, 2015; Manni et al., 2016). However, these effects were not observed in the current experiment.

Conclusions

Crimping of grain and ensiling with an additive offers an opportunity to harvest cereals earlier than traditional harvesting for DG. Additionally, crimping and ensiling can be carried out under more humid conditions, reducing the weather dependency of grain harvesting and decreasing the energy consumption needed for drying. The results of the present experiment indicated that crimped and ensiled grain may improve DMI and LWG of dairy bulls when compared with dried grain in TMR feeding. There were no observed differences in DMI or animal performance when different additives were used and when grain was preserved at different moisture concentrations. The current results show that beef producers have the option to vary their cereal grain conservation system without major changes to animal performance or carcase traits in TMR feeding. Options in grain preservation rather than drying provide a viable option which may improve the biological efficiency but are also less dependent on fossil fuels in drying and provide more flexibility concerning the weather conditions around harvesting.

Financial support. This study was partially funded by the Centre for Economic Development, Transport and the Environment for Northern Ostrobothnia, Oulu, Finland, Hankkija Ltd., Eastman Chemical Company and Berner Ltd.

Conflict of interest. The authors declare there are no conflicts of interest.

Ethical standards. The experimental animals were managed according to Finnish and EU legislation regarding the use of animals in scientific experimentation.

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