# Performance of growing and finishing dairy bulls offered diets based on whole-crop barley silage with or without protein supplementation relative to a grass silage-based diet

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This study was conducted to examine the performance of growing dairy bulls offered diets based on whole-crop barley silage with or without protein supplementation when compared to a grass silage-based diet. A feeding experiment comprised 36 bulls which were fed a total mixed ration *ad libitum*. The four dietary treatments were: 1) grass silage (600 g $kg^{-1}$ dry matter) and rolled barley (400), 2) whole-crop barley silage (600) and rolled barley (400), 3) whole-crop barley silage (600), rolled barley (310) and rapeseed meal-based protein supplementation (90), and 4) whole-crop barley silage (600), rolled barley (330) and rapeseed meal + urea -based protein supplementation (70). Replacing grass silage with whole-crop barley decreased the carcass gain and carcass weight of the bulls due to lower energy intake. Protein supplementation either as rapeseed meal or rapeseed meal + urea of whole-crop barley silage based diets had no effects on animal performance.

*Key words*: beef production, whole-crop silage, rapeseed meal, urea, growth, carcass characteristics

## Introduction

Most of the forage for growing cattle in Finland is based on silage mixtures of different grasses, timothy (*Phleum pratense*), meadow fescue (*Festuca pratensis*), tall fescue (*Festuca arundinacea*) and red clover (*Trifolium pratense*). However, other ensiled forages, such as different whole-crop silages, are increasingly being used due to their potentially lower costs. In addition, recent advances in plant breeding, agronomic practices and forage conservation technologies are expanding opportunities for these alternative crops (Wallsten 2008) and nowadays small-grain cereals are widely used as whole crop silages for animal feed in temperate climates. In Finland, barley (*Hordeum vulgare*) is the dominant small-grain species utilized for whole-crop production, but oats (*Avena sativa*) and wheat (*Triticum aestivum*) are also used. The digestibility of whole-crop silages is highly dependent on the proportion of straw and is often lower than that of good quality grass silage but the lower digestibility is largely compensated for by higher dry matter intake (DMI) (Abdalla et al. 1999, Sinclair et al. 2003, Huhtanen et al. 2007). In a review of seven experiments with finishing beef cattle Keady et al. (2013) concluded that the inclusion of whole-crop wheat silage in grass silage-based diets increased forage intake by 1.4 kg DM $d^{-1}$, but did not alter animal performance. However, compared to whole-crop wheat silages there is limited information available on the effects of whole-crop barley silage on the performance of growing cattle relative to grass silage-based diets.

Rapeseed meal (RSM) is the most important supplementary protein feed for cattle in Finland. Huuskonen et al. (2008) and Huuskonen (2009a, 2011) reported that RSM supplementation to grass silage based diets did not affect animal performance of finishing dairy bulls from 6 to 18 months of age, and concluded that there is no reason to use protein supplementation for finishing dairy bulls when they are fed with good quality grass silage and barley-based concentrate. However, whole-crop barley silage typically contains less crude protein (CP) than grass silage (Huuskonen and Joki-Tokola 2010, MTT 2012), and therefore Finnish protein feeding recommendations for growing cattle are not usually fulfilled if whole-crop silage based rations are fed without protein supplementations. In the Finnish Feed Tables (MTT 2012), the metabolisable protein requirements (presented as amino acids absorbed from the small intestine: AAT) are presented only for cattle smaller than 200 kg live weight (LW). For animals over 200 kg, the protein intake is considered adequate if the protein balance in the rumen (PBV) of the total diet is not lower than -10 g $kg^{-1}$ DMI (MTT 2012). PBV describes the balance between the dietary supply of rumen-degradable protein (RDP) and the microbial requirements for RDP (Madsen et al. 1995).

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Generally true protein supplements are expensive ingredients in cattle rations. A partial or entire substitution of a true protein source, such as RSM, with non-protein nitrogen (NPN) source may clearly reduce the feeding costs. Urea is a common NPN source which is used in cattle feeding (Bourg et al. 2012). However, decreasing dietary protein inputs in feeding could potentially decrease environmental concerns related to air and water quality (Cole et al. 2003). According to literature, nitrogen and phosphorus are routinely overfed to ruminants, which in combination with the continuous trend to concentrate animals in intensive units, leads to nutrient surpluses at farm and system levels (Ondersteijn et al. 2002). Therefore it is important to know if protein supplements can be reduced or excluded from the whole-crop barley based diets without compromising animal performance.

The present experiment was conducted to study diet digestibility, feed intake, growth and carcass characteristics of growing dairy bulls offered diets based on whole-crop barley silage with or without protein supplementation relative to a grass silage-based diet. It was hypothesized that the use of whole-crop barley silage impairs performance of dairy bulls compared to a diet based on good quality grass silage. Furthermore, it was hypothesized that the animal performance is impaired if protein supplementation is not used with whole-crop barley silage based diets. Moreover, it was hypothesized that there are no differences in animal performance when RSM based protein supplementation is partly replaced by urea.

# Materials and methods

## Animals and housing

A feeding experiment was conducted in the experimental barn of MTT Agrifood Research Finland in Ruukki, Finland starting in January 2012 and ending in February 2013. Animals were managed according to the Finnish legislation regarding the use of animals in scientific experimentation. The feeding experiment comprised in total 28 Nordic Red bulls and 8 Holstein-Friesian bulls. All animals were purchased from local dairy farms. The average LW of the calves was 51 ± 3.1 kg (mean ± standard deviation) and overall age 21 ± 2.6 days. In the pre-experimental period before the beginning of the present feeding experiment the calves were housed in an insulated barn in pens and fed milk replacer, hay, grass silage and concentrates (rolled barley and RSM).

At the beginning of the feeding experiment the animals with average LW of 265 kg (±24.6) and 217 days of age were divided into nine blocks of four animals by LW and breed so that there were seven Nordic Red blocks and two Holstein-Friesian blocks. Within block the animals were randomly allotted to one of four treatments. The bulls were placed in an insulated barn in adjacent tie-stalls. The width of the stalls was 70–90 cm for the first four months and 113 cm until the end of the experiment. The bulls were tied with a collar around the neck, and a 50 cm long chain was attached to a horizontal bar 40–55 cm above the floor. The floor surface was solid concrete under the forelegs and metal grids under the hind legs. No bedding was used on the floor. The animals were fed three times per day (at 0800, 1200 and 1800 hours). Refused feed was collected and measured at 0700 daily. The bulls had free access to water from an open water bowl during the experiment. All bulls were healthy throughout, and all completed the entire study.

## Feeding and experimental design

The bulls were fed a total mixed ration *ad libitum* (proportionate refusals of 5%). The composition (g $kg^{-1}$ DM) of the four treatments (GS, WCB, WCBRSM, WCBU) were:

GS: Grass silage (600) and rolled barley (400).

WCB: Whole-crop barley silage (600) and rolled barley (400).

WCBRSM: Whole-crop barley silage (600), rolled barley (310) and RSM-based protein supplementation (90).

WCBU: Whole-crop barley silage (600), rolled barley (330) and RSM + urea -based protein supplementation (70).

Protein supplementation in treatments 3 and 4 was balanced so that the total amount of the CP in the diet was equal in both treatments, and the protein balance in the rumen fulfilled the Finnish recommendation which is above -10 g $kg^{-1}$ DMI for growing cattle above 200 kg LW (MTT 2012).

RSM-based protein supplementation (Krono35; Hankkija Ltd, Hyvinkää, Finland) was composed of (g $kg^{-1}$ DM) RSM (753), molassed sugar-beet pulp (90), rapeseed cake (79), molasses (45), wheat bran (20), salt (6), $CaCO_3$ (4) and vitamin, mineral and trace element premix (3). RSM + urea-based protein supplementation (Krono45; Hankkija Ltd, Hyvinkää, Finland) was composed of, respectively, RSM (578), wheat bran (239), brewers' grain meal (60), urea (50), molasses (50), salt (5), vegetable oil mix (5), hydrolysed brewers' yeast (Progut®, patent: FI109759) (4) and vitamin, mineral and trace element premix (9). The daily ration for the bulls included also 150 g of a mineral mixture (Seleeni Hertta Muro; Hankkija Ltd, Hyvinkää, Finland: Ca 205, P 15, Na 80, Mg 70 g $kg^{-1}$). A vitamin mixture (Xylitol ADE-Vita; Hankkija Ltd, Hyvinkää, Finland: A 2,000,000 IU $kg^{-1}$, $D_3$ 400,000 IU $kg^{-1}$, E DL-$\alpha$-tocopheryl acetate 1,000 mg $kg^{-1}$, E DL-$\alpha$-tocopheryl 900 mg $kg^{-1}$, Se 10 mg $kg^{-1}$) was given at 50 g per animal weekly.

The silages were produced at the experimental farm of MTT Agrifood Research Finland in Ruukki, Finland (64°44'N, 25°15'E). The grass silage used was the primary growth, comprised of mixed timothy and meadow fescue stands and was harvested at early heading stage of timothy using a mower conditioner, wilted for 5 h and harvested using a precision-chop forage harvester. The whole-crop barley silage was harvested at the early dough stage (growth stage Z83 on Zadoks scale, Zadoks et al. 1974) of the cereal using a direct-cut flail harvester. Harvest dates of grass silage and whole-crop barley silage were June 19 and August 6, respectively. For botanical determinations ten 25 cm × 50 cm forage samples were collected from both grass silage and whole-crop barley silage fields before harvesting. According to these determinations, grass silage contained timothy (410 g DM $kg^{-1}$ DM), meadow fescue (570) and other plants (20). Respectively, whole-crop barley silage contained barley (990) and other plants (10). Both silages were ensiled in bunker silos and treated with a formic acid-based additive (AIV-2 Plus; Kemira Ltd., Oulu, Finland: 760 g formic acid $kg^{-1}$, 55 g ammonium formate $kg^{-1}$) applied at a rate of 5 litres $t^{-1}$ of fresh forage.

## Feed and faecal sampling and analysis

Silage sub-samples for chemical analyses were taken twice a week, pooled over periods of four weeks and stored at –20 ºC. Thawed samples were analysed for DM, ash, CP, ether extract, neutral detergent fibre (NDF), acid detergent fibre (ADF), starch, silage fermentation quality (pH, water-soluble carbohydrates [WSC], lactic and formic acids, volatile fatty acids, soluble and ammonia N content of total N) and digestible organic matter (DOM) in DM (D-value). Concentrate sub-samples were collected weekly, pooled over periods of 12 weeks and analysed for DM, ash, CP, ether extract, NDF, ADF and starch.

Fresh silage samples were analysed for fermentation quality as described by Moisio and Heikonen (1989). The DM concentration was determined by drying at 105 °C for 20 h and organic matter (OM) concentration by ashing at 600 °C for 2 h. Oven DM concentration of silages was corrected for the loss of volatiles according to Huida et al. (1986). After drying the samples were milled using sample mill (Sakomylly KT-3100, Koneteollisuus Oy, Helsinki, Suomi) and 1 mm sieve. The CP content of feeds was determined using a Dumas-type N analyser (Leco FP-428, Leco Corporation, St Joseph, MI, USA). Concentration of NDF was determined according to Van Soest et al. (1991) using Na-sulphite, without amylase for forages and presented ash-free. ADF was determined according to Robertson and Van Soest (1981) and starch as described by Salo and Salmi (1968). Ether extract was determined by Soxcap-Soxtec-analyser (AOAC Official Method 920.39, AOAC 1990). The silages were analysed for D-value as described by Huhtanen et al. (2006). The D-value results were calculated with correction equations to convert pepsin-cellulase solubility values into *in vivo* digestibility by equations based on a data set comprising of Finnish *in vivo* digestibility trials.

The ME concentration of the grass silage was calculated as $0.016 \times$ D-value and that of whole-crop silage as $0.0155 \times$ D-value (MAFF 1984). The ME concentrations of the concentrate feeds were calculated based on concentrations of digestible crude fibre, CP, crude fat and nitrogen-free extract described by MAFF (1984). The digestibility coefficients of the concentrates were taken from the Finnish Feed Tables (MTT 2012). The protein values AAT and PBV were calculated according to the Finnish feed protein evaluation system (Tuori et al. 1998, MTT 2012).

Apparent diet digestibility was determined for all animals when the bulls were 407 ± 35.9 kg LW, on average. Feed and faecal samples were collected twice a day (at 0700 and 1500 hours) during the 5-day collection period and stored frozen prior to analyses. The samples were analyzed for DM, ash, CP, NDF and starch as described above. The diet digestibility was determined using acid-insoluble ash (AIA) as an internal marker (Van Keulen and Young 1977).

### Live weight, slaughter procedures and carcass quality measurements

The animals were weighed on two consecutive days at the beginning of the experiment and thereafter single weightings were done approximately every 28 days. Before slaughter the animals were weighed on two consecutive days. The target for average slaughter age in the experiment was 560–580 days which is currently the average slaughter age for dairy bulls in Finland (Huuskonen et al. 2013a). The LWG was calculated as the difference between the means of the initial and final live weights divided by the number of growing days. The estimated rate of carcass gain was calculated as the difference between the final carcass weight and the carcass weight in the beginning of the experiment divided by the number of growing days. The carcass weight at the start of the experiment was assumed to be 0.50 × initial LW based on earlier studies (unpublished data).

The animals were selected for slaughter based on age and LW, and slaughtered in the Atria Ltd. commercial slaughterhouse in Kauhajoki, Finland in two batches. All four feeding treatments were represented in both batches. After slaughter the carcasses were weighed hot. The cold carcass weight was estimated as 0.98 of the hot carcass weight. Dressing proportions were calculated from the ratio of cold carcass weight to final LW. The carcasses were classified for conformation and fatness using the EUROP quality classification (EC 2006). For conformation, the development of the carcass profiles, in particular the essential parts (round, back, shoulder), was taken into consideration according to the EUROP classification (E: excellent, U: very good, R: good, O: fair, P: poor) and for fat cover degree, the amount of fat on the outside of the carcass and in the thoracic cavity was taken into account using a classification range from 1 to 5 (1: low, 2: slight, 3: average, 4: high, 5: very high). 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.

### Statistical methods

The results are shown as least squares means. The normality of analysed variables was checked using graphical methods: box-plot and scatter plot of residuals and fitted values. The data were subjected to analysis of variance using the SAS MIXED procedure (version 9.1, SAS Institute Inc., Cary, NC). The statistical model used was

$$y_{ijkl} = \mu + \beta_j + \gamma_k + \alpha_i + e_{ijkl},$$

where $\mu$ is the intercept and $e_{ijkl}$ is the random error term associated with $l^{th}$ animal. $\alpha_i$ is the fixed effect of the dietary treatment (i=1,2,3,4) while $\beta_j$ and $\gamma_k$ are random effects of the block (j=1,...,9) and the slaughtering batch (k=1,2), respectively.

Differences between the dietary treatments were tested using three orthogonal contrasts: 1) GS vs. others, 2) WCB vs. WCBRSM + WCBU, and 3) WCBRSM vs. WBCU. The first contrast described the effects of whole-crop barley diets compared to the grass silage-based diet. The second contrast described the effects of protein supplementation on diets based on whole-crop barley feeding. Finally, the third contrast described the effects of different protein supplementations.

## Results

The grass silage used in the present experiment was of good nutritional quality as indicated by the high D-value as well as the high AAT and CP contents (Table 1). The whole-crop barley silage had a clearly higher DM concentration than grass silage. CP and AAT concentrations of the whole-crop barley were 33 and 12% lower than those of the grass silage, respectively. The grass silage had a 20% higher NDF concentration and 11% higher energy content than the whole-crop silage. The fermentation characteristics of both silages were good as indicated by the low pH value and the low concentrations of ammonia N in total N and total fermentation acids. Both silages were restrictively fermented with high residual WSC concentration and low lactic acid concentration. Barley grain used in the experiment had typical chemical composition and feed values (Table 1).

The average chemical compositions of the total mixed rations (calculated on the basis of proportions of each ingredient) are presented in Table 2. GS had clearly lower DM and higher NDF concentrations compared to the rations containing whole-crop barley silage. The ME content of the GS ration was 5–7% higher than that of the other rations. Compared to the WCB ration, GS had 23% higher CP content and 7% higher AAT content. Among the whole-crop barley rations there were no remarkable differences in DM, NDF or ME concentrations (Table 2). In accordance with the research plan, the WCB ration had 13–16% lower CP content compared to the WCBRSM and WCBU rations. In the GS, WCBRSM and WCBU rations the PBV value fulfilled the Finnish recommendation for growing cattle (PBV of the diet is above -10 g kg$^{-1}$ DMI for animals above 200 kg LW), but in the WCB ration the PBV value was lower than recommended (Table 2).

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

| | Grass silage | Whole-crop barley silage | Barley grain | Rapeseed meal feed | Rapeseed meal + urea feed |
|---|---|---|---|---|---|
| Number of samples | 13 | 13 | 4 | 4 | 4 |
| Dry matter (DM), g kg$^{-1}$ feed | 255 | 462 | 892 | 875 | 875 |
| Organic matter (OM), g kg$^{-1}$ DM | 931 | 932 | 976 | 915 | 918 |
| Crude protein, g kg$^{-1}$ DM | 151 | 105 | 132 | 328 | 452 |
| Neutral detergent fibre, g kg$^{-1}$ DM | 581 | 484 | 197 | 283 | 285 |
| Acid detergent fibre, g kg$^{-1}$ DM | 353 | 231 | 44 | 187 | 152 |
| Ether extract, g kg$^{-1}$ DM | 45 | 20 | 18 | 36 | 47 |
| Starch, g kg$^{-1}$ DM | 9 | 182 | 564 | 32 | 65 |
| Metabolisable energy, MJ kg$^{-1}$ DM | 10.8 | 9.7 | 13.1 | 11.6 | 10.6 |
| AAT, g kg$^{-1}$ DM | 82 | 72 | 98 | 160 | 135 |
| PBV, g kg$^{-1}$ DM | 29 | -19 | -16 | 128 | 270 |
| Digestible OM in DM, g kg$^{-1}$ DM | 678 | 623 | ND | ND | ND |
| Fermentation quality of silage | | | | | |
| pH | 4.05 | 4.41 | | | |
| Lactic + formic acid, g kg$^{-1}$ DM | 49 | 19 | | | |
| Volatile fatty acids, g kg$^{-1}$ DM | 18 | 5 | | | |
| WSC, g kg$^{-1}$ DM | 45 | 106 | | | |
| In total N, g kg$^{-1}$ | | | | | |
| $NH_4N$ | 60 | 29 | | | |
| Soluble N | 482 | 356 | | | |

ND = Not determined.
AAT = Amino acids absorbed from small intestine.
PBV = Protein balance in the rumen.
WSC = Water soluble carbohydrates.

Table 2. Chemical compositions and nutritional values of total mixed rations used.

| Treatments | GS | WCB | WCBRSM | WCBU |
|---|---|---|---|---|
| Dry matter (DM), g kg$^{-1}$ feed | 357 | 572 | 572 | 572 |
| Organic matter, g kg$^{-1}$ DM | 949 | 950 | 944 | 946 |
| Crude protein, g kg$^{-1}$ DM | 143 | 116 | 133 | 138 |
| Neutral detergent fibre, g kg$^{-1}$ DM | 427 | 369 | 377 | 375 |
| Acid detergent fibre, g kg$^{-1}$ DM | 230 | 157 | 169 | 164 |
| Ether extract, g kg$^{-1}$ DM | 34 | 19 | 21 | 21 |
| Starch, g kg$^{-1}$ DM | 280 | 335 | 287 | 300 |
| Metabolisable energy, MJ kg$^{-1}$ DM | 11.7 | 11.1 | 10.9 | 10.9 |
| AAT, g kg$^{-1}$ DM | 88 | 82 | 88 | 85 |
| PBV, g kg$^{-1}$ DM | 11 | -18 | -5 | 3 |

GS = Grass silage + rolled barley, no protein supplementation.
WCB = Whole-crop barley silage + rolled barley, no protein supplementation.
WCBRSM = Whole-crop barley silage + rolled barley, rapeseed meal as protein supplement.
WCBU = Whole-crop barley silage + rolled barley, rapeseed meal and urea as protein supplement.
AAT = Amino acids absorbed from small intestine.
PBV = Protein balance in the rumen.

Diet apparent DM digestibility (DMD) and organic matter digestibility (OMD) were both 6–7% higher when the GS diet was fed compared to the whole-crop treatments (*p*<0.001), but there were no differences among WCB, WCBRSM and WCBU treatments in DMD or OMD (Table 3). Furthermore, diet NDF digestibility (NDFD) was 40% and starch digestibility 3% higher with the GS than with the whole-crop treatments (*p*<0.001) but again no differences were found among the WCB, WCBRSM and WCBU treatments. Protein supplementation improved diet apparent CP digestibility in whole-crop diets (Table 3). In addition diet apparent CP digestibility was 9% higher with WCBRSM than that with WCBU diet (*p*<0.001).

Table 3. Daily dry matter and nutrient intake and apparent diet digestibility of growing bulls.

| Treatments | GS | WCB | WCBRSM | WCBU | SEM | Contrasts (*p*-value) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 |
| Number of animals | 9 | 9 | 9 | 9 | - | - | - | - |
| Digestibility coefficients | | | | | | | | |
| Dry matter | 0.768 | 0.722 | 0.719 | 0.714 | 0.0079 | <0.001 | 0.58 | 0.70 |
| Organic matter | 0.783 | 0.739 | 0.737 | 0.733 | 0.0080 | <0.001 | 0.68 | 0.70 |
| Crude protein | 0.750 | 0.689 | 0.768 | 0.705 | 0.0098 | 0.02 | <0.001 | <0.001 |
| Neutral detergent fibre | 0.738 | 0.536 | 0.519 | 0.526 | 0.0125 | <0.001 | 0.38 | 0.70 |
| Starch | 0.988 | 0.954 | 0.955 | 0.959 | 0.0041 | <0.001 | 0.57 | 0.45 |
| Intake | | | | | | | | |
| Dry matter, kg $d^{-1}$ | 10.18 | 10.19 | 10.16 | 9.93 | 0.219 | 0.72 | 0.60 | 0.48 |
| Dry matter, g/live weight | 20.8 | 21.8 | 21.7 | 22.1 | 0.67 | 0.16 | 0.90 | 0.64 |
| Metabolisable energy, MJ $d^{-1}$ | 120 | 113 | 112 | 109 | 2.4 | 0.006 | 0.42 | 0.40 |
| Crude protein, g $d^{-1}$ | 1495 | 1207 | 1290 | 1286 | 27.1 | <0.001 | 0.02 | 0.93 |
| AAT, g $d^{-1}$ | 902 | 843 | 883 | 836 | 16.7 | 0.02 | 0.42 | 0.06 |
| PBV, g $d^{-1}$ | 140 | -144 | -72 | -25 | 3.2 | <0.001 | <0.001 | <0.001 |
| Neutral detergent fibre, g $d^{-1}$ | 4238 | 3679 | 3693 | 3622 | 81.5 | <0.001 | 0.83 | 0.54 |
| Starch, g $d^{-1}$ | 2492 | 3514 | 3240 | 3218 | 72.7 | <0.001 | 0.003 | 0.83 |

GS = Grass silage + rolled barley, no protein supplementation.
WCB = Whole-crop barley silage + rolled barley, no protein supplementation.
WCBRSM = Whole-crop barley silage + rolled barley, rapeseed meal as protein supplement.
WCBU = Whole-crop barley silage + rolled barley, rapeseed meal and urea as protein supplement.
SEM = Standard error of the mean.
Contrasts: 1 = GS vs. others; 2 = WCB vs. WCBRSM + WCBU; 3 = WCBRSM vs. WCBU.
AAT = Amino acids absorbed from small intestine.
PBV = Protein balance in the rumen.

There were no significant treatment differences in daily DMI or DMI in relation to LW (Table 3). However, ME intake was 8% higher with GS than that with the whole-crop diets (*p*<0.01). There were no differences among the WCB, WCBRSM and WCBU treatments in ME intake. The CP, AAT and PBV intakes were clearly higher with GS than that with the whole-crop diets, and protein supplementation increased the CP and PBV intakes in the whole-crop diets (Table 3). There was no difference in the CP intake between WCBRSM and WCBU diets but AAT intake was higher and PBV intake lower in WCBRSM diet compared to WCBU diet. Furthermore, NDF intake was 16% higher and starch intake 25% lower with GS than with the whole-crop treatments (*p*<0.001). In NDF intake there were no differences among the whole-crop treatments but protein supplementation decreased the starch intake of them (Table 3).

The slaughter age, final LW and carcass weight of the bulls were on average 562 days, 675 kg and 343 kg, respectively (Table 4). There were no treatment differences in the slaughter age but the carcass weight of the GS bulls was 5% higher compared to the bulls fed the whole-crop diets (*p*<0.05). Among the whole-crop treatments there were no differences in carcass weights. Live weight gain and carcass gain of the GS bulls were 6 and 8% higher, respectively, compared to the bulls fed the whole-crop diets but there were no differences in gain parameters among the whole-crop treatments (Table 4). There were no treatment differences in dressing proportion. Carcass conformation score tended to improve 9% (*p*=0.06) and carcass fat score was 19% higher (*p*<0.01) with the GS bulls compared to the bulls fed with the whole-crop diets. There were no differences in carcass conformation or fat scores among the whole-crop treatments. Feed conversion rates were better for the GS bulls compared to the bulls fed with the whole-crop diets but there were no differences in feed conversion among the whole-crop based diets (Table 4).

Table 4. Growth performance, carcass characteristics and feed conversion of growing bulls.

| Treatments | GS | WCB | WCBRSM | WCBU | SEM | Contrasts (*p*-value) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 |
| Number of animals | 9 | 9 | 9 | 9 | - | - | - | - |
| Age at slaughter, d | 561 | 563 | 562 | 561 | - | - | - | - |
| Initial live weight, kg | 267 | 262 | 266 | 266 | - | - | - | - |
| Final live weight, kg | 695 | 671 | 667 | 666 | 12.1 | 0.06 | 0.74 | 0.98 |
| Carcass weight, kg | 356 | 339 | 339 | 336 | 6.6 | 0.03 | 0.87 | 0.77 |
| Live weight gain (LWG), g $d^{-1}$ | 1252 | 1193 | 1173 | 1175 | 33.1 | 0.07 | 0.64 | 0.96 |
| Carcass gain, g $d^{-1}$ | 666 | 620 | 620 | 613 | 18.6 | 0.03 | 0.85 | 0.80 |
| Carcass characteristics | | | | | | | | |
| Dressing proportion, g $kg^{-1}$ | 512 | 505 | 509 | 505 | 4.6 | 0.26 | 0.73 | 0.57 |
| Conformation score | 5.0 | 4.4 | 4.5 | 4.8 | 0.20 | 0.06 | 0.41 | 0.37 |
| Fat score | 3.3 | 2.8 | 2.7 | 2.8 | 0.14 | 0.003 | 0.89 | 0.82 |
| Feed conversion | | | | | | | | |
| Kg dry matter/kg LWG gain | 7.99 | 8.64 | 8.71 | 8.95 | 0.362 | 0.07 | 0.66 | 0.64 |
| Kg dry matter/kg carcass gain | 15.0 | 16.5 | 16.5 | 17.2 | 0.69 | 0.04 | 0.72 | 0.50 |
| MJ ME/kg LWG | 89 | 99 | 98 | 101 | 4.1 | 0.04 | 0.85 | 0.52 |
| MJ ME/kg carcass gain | 167 | 189 | 185 | 195 | 7.7 | 0.02 | 0.90 | 0.38 |

GS = Grass silage + rolled barley, no protein supplementation.
WCB = Whole-crop barley silage + rolled barley, no protein supplementation.
WCBRSM = Whole-crop barley silage + rolled barley, rapeseed meal as protein supplement.
WCBU = Whole-crop barley silage + rolled barley, rapeseed meal and urea as protein supplement.
SEM = Standard error of the mean.
Contrasts: 1 = GS vs. others; 2 = WCB vs. WCBRSM + WCBU; 3 = WCBRSM vs. WCBU.
Carcass conformation score according to EUROP: 1 = poor, 15 = excellent.
Carcass fat score according to EUROP: 1 = low, 5 = very high.
ME = Metabolisable energy.

# Discussion

In accordance with earlier studies (Abdalla et al. 1999, Sinclair et al. 2003) the apparent digestibility of the whole-crop barley-based diets was lower than that of the GS diet. In general, the digestibility of whole-crop cereals is highly dependent on the proportion of straw (Sinclair et al. 2003). In the present experiment the apparent NDFD of the GS diet was clearly higher than that of the whole-crop barley diets. However, the differences in DMD and OMD between treatments were clearly smaller than the differences in NDFD. This indicates that the starch concentration of whole-crop silages, together with high starch digestibility could compensate for the reduced NDFD, which was also suggested by Wallsten (2008).

In accordance with Huuskonen et al. (2008) and Huuskonen (2009a, 2011), the apparent CP digestibility increased with protein supplementation. Most of this increase was probably only apparent, i.e. related to the decreased proportion of faecal metabolic nitrogen recovered in faeces when the CP content increased (Minson 1982) and the true digestibility of dietary CP is generally almost complete (Huhtanen et al. 2006). Similarly as in many earlier studies in grass silage-barley-based diets (Huuskonen 2009a, 2011, Pesonen et al. 2013), protein supplementation had no effects on diet DMD, OMD or NDFD. Most of the experiments in which protein supplementation resulted in positive effects on OMD or fibre digestion, have been conducted with poor quality roughages (Huuskonen 2009b). With grass silage-based diets, inclusion of a protein feed has been found to improve OMD when poor fermentation quality silages have been used (Gill and England 1984, England and Gill 1985). With well-preserved silages, the inclusion of a protein feed in the diet had only a small effect (Steen 1992, Aronen et al. 1992) or no effect at all (Steen 1988, 1989, Aronen 1990, Jaakkola et al. 1990).

In general, the DMI of silage can be affected by its DM content, fermentation characteristics, NDF concentration, OMD and NDFD (Huhtanen et al. 2007). Both dairy cows (Ahvenjärvi et al. 2006) and finishing beef cattle (Keady et al. 2013) have often been able to maintain or even increase silage DMI after inclusion of whole-crop silage into the diet, although the digestibility of whole-crop silage has been lower than that of the grass silage. According to

Huhtanen et al. (2007), the dairy cows responses to replacing grass silages partially or totally with whole-crop silages on DMI could not be accurately predicted from differences in silage D-value, DM concentration or fermentation characteristics. The maximum silage DMI increase was obtained when the proportion of the whole-crop silage was 0.48 of total silage DM, and the effect was quadratic (Huhtanen et al. 2007). In the present study, grass silage was totally replaced by whole-crop barley which could explain the result that the bulls were not able to increase DMI compared to GS diet. With dairy cows the rumen evacuation data of Ahvenjärvi et al. (2006) showed that the animals were able to increase the ruminal NDF pool at lower inclusion rates of whole-crop barley silage, but at higher inclusion rates (0.60), the ruminal NDF pool started to decline.

In accordance with the present data, Huuskonen et al. (2013b) observed, based on a large dataset of feeding experiments, that the effect of dietary CP concentration was not significant when modelling the factors affecting DMI of growing cattle fed silage-based diets. Furthermore, Huuskonen et al. (2013b) reported that the intake response to protein supplementation was minimal with maximum predicted response less than 2%, which is clearly smaller than the corresponding response in lactating cows (Huhtanen et al. 2008). In the meta-analysis by Huuskonen et al. (2013b) the forage and concentrate components of the diets as well as the total diets displayed wide ranges in chemical composition and calculated feeding values. On average, the silages were well fermented, but the maximum values of silage ammonia N and acid concentrations indicate that the datasets also included both extensively and poorly fermented silages.

The fairly high growth rates measured in the present study implies a good quality of the feed rations. However, the higher energy content and similar total daily DMI of the GS diet compared with the whole-crop based diets was reflected also as larger daily ME intake of the bulls. This difference in ME intake is probably a crucial explanation for the improved growth rate of the GS bulls compared to the bulls fed with the whole-crop diets. Earlier, Huuskonen and Joki-Tokola (2010) observed that ME intake and growth rate of dairy bulls was higher with a grass silage based diet than with a whole-crop wheat based diet, but a whole-crop barley based diet did not differ from the grass silage based diet in ME intake or gain. Some previous studies have reported that the inclusion of whole-crop wheat silage in grass silage-based diets decreased (O'Kiely and Moloney 1999), had no effect (Keady et al. 2007) or increased (O'Kiely and Moloney 2002) the carcass gain of finishing beef cattle. In an Irish study, Walsh et al. (2008) reported clearly lower animal performance when growing crossbred steers were fed a grass silage-based diet instead of a whole-crop wheat silage-based diet. However, grass silage in the study by Walsh et al. (2008) had a relatively low nutritive value due to advanced maturity of the crop, wet weather at harvesting and relatively poor preservation quality. Keady et al. (2013) concluded from a review of seven beef cattle studies that inclusion of whole-crop wheat silage in grass silage-based diets did not affect carcass gain of beef cattle. It can be concluded based on the present and earlier experiments that the effects of replacing grass silage by whole-crop silages on the performance of growing cattle differs largely depending on the stage of maturity of the plants at harvest, cutting height, plant species and variety, growing and harvesting conditions as well as harvesting and storage techniques, which all affect the chemical composition, preservation quality and relative proportions of the different crop components, i.e. grain and straw.

Protein supplementation had no effects on gain among the whole-crop treatments even though in the WCB diet PBV was below the Finnish recommendation. In accordance to meta-analysis by Huuskonen et al. (unpublished manuscript) the results of the present experiment indicate that recommended PBV could even be reduced without adverse effects on gain. According to literature, the amounts of nitrogen recycled into the gastrointestinal tract was 27 g kg$^{-1}$ DMI in cattle fed a low CP (80 g kg$^{-1}$ DM) diet and approximately 40 g kg$^{-1}$ DMI in cattle fed higher CP diets (Marini & Van Amburgh 2003). These values indicate that in growing cattle rumen PBV can be negative with minimal, if any, adverse effects on gain. Similar calculations by Titgemeyer & Löest (2001) showed that while amino acids were the limiting factor with lighter weight calves, energy availability was the limiting factor with heavier steers.

In general, the responses to protein supplementation seem to be related also to the level of concentrate supplementation, greater effects being observed with small amounts of concentrates (Huuskonen 2009b). According to Huuskonen (2009b), a medium level of concentrates together with well preserved silage sustains efficient microbial protein production. In addition, results are dependent on the preservation quality of silage which may vary considerably depending on the ensiling conditions and techniques applied. With poorly preserved silage the response in animal performance to protein supplementation is greater than with well-preserved silage (Hussein & Jordan 1991). There are also differences between extensively and restrictively fermented silages, which both may be well-preserved. Jaakkola et al. (1990) reported that the gain response of growing cattle to fishmeal was greater when enzyme solution (cellulose–glucose oxidase) was used as a silage additive instead of formic acid.

Furthermore, Jaakkola et al. (2006) observed that restriction of silage fermentation by formic acid is positively related to the synthesis of microbial protein in the rumen. In the present experiment the fermentation quality of the whole-crop silage was good and the silage was restrictively fermented with high residual WSC concentration and low lactic acid concentration. The responses to protein supplementation may be greater with untreated and/or poorly preserved silage than with well preserved restrictively fermented silage.

The improved conformation score of the GS bulls compared to the bulls fed with the whole-crop barley silage can be explained by their higher average carcass weight because it is established that carcass conformation increased with increasing carcass weight (Kempster et al. 1988). Higher carcass weights probably also explained the increased fat score of the GS bulls as measures of fatness generally increase with higher carcass weight (Keane & Allen 1998). Also reducing energy intake usually decreases carcass fat content (Fishell et al. 1985, Herva et al. 2011), which could partly explain the lower fat classification of the bulls with the whole-crop barley based diets. In accordance with several earlier studies (Huuskonen et al. 2007, Huuskonen 2009a, 2011, Manninen et al. 2011, Pesonen et al. 2013), there were no effects of protein supplementation on the dressing proportion, carcass conformation score or carcass fat score.

# Conclusions

Replacing grass silage with whole-crop barley silage decreased the carcass gain and weight of growing dairy bulls due to lower energy intake and poorer feed conversion rate. However, the fairly high growth rates measured in the present study indicate that grass silage could be totally replaced by whole-crop barley in the diet of dairy bulls when the concentrate constitutes 0.4 of the diet. If production costs of whole-crop cereals are lower than those of grass silage and including them in crop rotation brings benefits, using them may increase the overall profitability of the farm. Protein supplementation had no effects on animal performance among the whole-crop treatments even though in the WCB diet PBV was below the Finnish recommendation. This indicates that recommended PBV for growing cattle above 200 kg live weight could even be reduced without adverse effects on gain. This would be justified because the amount of protein supplements increases the production costs in beef production, and feeding supplementary protein increases the N and P excretion. There were no differences in animal performance parameters when RSM based protein supplementation was replaced partly by urea.

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