introduction

Feedlot cattle are often fed high-grain diets to maximize growth performance. However, large amounts of rapidly fermentable carbohydrates in the rumen can increase the incidence of digestive disorders such as acidosis (Sauvant et al., 1999). The characteristics of the starch supplied depend on the type of cereal in the diet and how it is processed (Huntington et al., 2006). The starch content of wheat grain and its ruminal degradation rate are greater than starch in barley grain (Offner et al., 2003). Consequently, it is recommended to limit the inclusion of wheat in feedlot diets to reduce the risk of acidosis (Lardy and Dhuyvetter, 2000). Moreover, extensive grain processing disrupts the structure of the grain kernel and increases ruminal fermentation and total tract digestibility of starch (Theurer et al., 1999; Svihus et al., 2005), but if acidosis occurs, growth performance and carcass quality of feedlot cattle can be

Effect of grain type and processing index on growth performance, carcass quality, feeding behavior, and stress response of feedlot steers

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Abstract: One hundred sixty crossbred steers (538 ± 36 kg BW) were used in an 84-d experiment with a randomized block design to study the effects of wheat or barley grain processed to 2 different indices on growth performance, feeding behavior, carcass characteristics, stress, and temperament of finishing beef cattle. Treatments were a wheat-based diet (88.4% of diet DM; WH) and a barley-based diet (89% of diet DM; BA), processed to an index of either 75% (HI) or 85% (LO) of their original volume weight. Cattle were allocated to 16 feedlot pens (10 animals per pen, 4 pens per treatment), 8 of which were equipped with the GrowSafe system for monitoring feeding behavior. Flight speed, hair, and saliva samples were collected on d 1, 28, 56, and 84 to determine temperament, acute, and chronic stress. All steers were slaughtered at the end of the experiment, and carcass quality was evaluated. Cattle fed WH had a lower (P < 0.05) meal length and frequency of visits per meal and tended (P = 0.10) to have a lower DMI, meal size, and feeding time than those fed BA. The LO processing index increased (P = 0.05) DMI and reduced (P < 0.05) the G:F and the percentage of saleable meat of the carcass compared to HI. There was a trend (P = 0.09) for a grain × processing index interaction, where cattle fed BA-LO had a lower incidence of severe liver abscesses compared with cattle fed other treatments. Cattle fed WH had greater hair cortisol concentrations (P = 0.01) and flight speed (P < 0.01) than those fed BA. There was a trend (P = 0.07) for a grain × processing index interaction, where heifers fed WH-LO had a lower salivary cortisol than those fed other treatments. Results suggest that a LO processing index had a negative effect on feed efficiency and carcass performance and that the WH diet caused a range of effects on feed intake and behavior indicative of steers with greater excitability and chronic stress.

Key words: barley, beef cattle, stress, temperament, wheat

INTRODUCTION

Feedlot cattle are often fed high-grain diets to maximize growth performance. However, large amounts of rapidly fermentable carbohydrates in the
compromised (Wang et al., 2003). The extent to which processing increases the risk of acidosis varies among cereal grains (Offner et al., 2003), and there is a lack of data comparing the effect of processing on barley and wheat within a single study with feedlot cattle.

Previous studies suggested that high-starch and low-fiber diets reduce rumination (Faleiro et al., 2011) and ruminal pH (Petherick et al., 2009b), leading to stress responses (Keunen et al., 2002) and temperamental changes (Holroyd et al., 2004) in beef cattle. Hair has been recently validated as a sample matrix for measuring cortisol levels in beef cattle over extended periods of time (Moya et al., 2013), but little is known about the effects of diets on chronic cortisol levels in beef cattle. The objective of this study was to assess the effects of wheat and barley processed at 2 different index levels on growth performance, carcass quality, behavior, and stress response of finishing beef cattle.

**MATERIALS AND METHODS**

**Animals and Experimental Design**

All animals were cared for in accordance with the Canadian Council of Animal Care (2009) guidelines. One hundred sixty British crossbred beef steers (537.9 ± 35.62 kg BW) were used in an 84-d experiment at the Agriculture and Agri-Food Canada Research Centre in Lethbridge (AB, Canada). The experiment was conducted as a completely randomized design with a 2 × 2 factorial arrangement, in which the main treatments were 1) type of grain in the diet (Table 1), barley (BA; 89.0% of diet DM) or wheat (WH; 88.4% of diet DM), and 2) processing index (PI) of the grain, calculated as the ratio of volume weight of rolled grain to the original volume weight, low (LO; 85% of the preprocessed volume weight) or high (HI; 75% of the preprocessed volume weight). Processing indices were selected as the upper and lower ranges of those typically employed for barley and wheat in commercial Canadian feedlots (T. A. McAllister, unpublished data).

Upon arrival at the research facilities, cattle were ear tagged, branded, and implanted with a growth promoter (Component TE-S with Tylan, Elanco Animal Health, Guelph, ON, Canada). One month before starting the study, the steers were divided equally among 4 dietary treatments according to their BW and were allocated to 16 pens (4 pens per treatment, 10 steers per pen). Pens measured 21 × 27 m, with 15 m² of concrete in front of the feed bunk and 12.6 m² of pen space available for each heifer, a stocking density similar to that of a commercial feedlot. Eight out of the 16 pens contained 2 feeding tubs equipped with an electronic monitoring system (GrowSafe Systems, Airdrie, Canada) as described by Moya et al. (2011) for automatic recording of feed intake and feeding behavior.

All feeds were delivered daily at 0900 h as total mixed rations and were provided ad libitum, ensuring a 5% to 10% weigh back. To ensure adequate vitamin and mineral consumption (NRC, 2000), a pelleted supplement was added to all dietary treatments. Monensin was also included in all diets at a concentration of 25 mg/kg feed on a DM basis. Furthermore, 0.6% of urea was added to the WH diets to increase dietary nitrogen concentration to an equivalency of that in BA diets. The processing index of LO and HI treatments was set and monitored by the feed mill at the research facilities according to the equation proposed by Wang et al. (2003). Cattle were provided with a continuous supply of fresh water.

**Data Collection**

**Feed Analysis and Intake.** Samples of the 4 dietary treatments were collected weekly for determination of DM. Values were used to calculate weekly composition of the diets offered on a DM basis. Feed offered was recorded daily for each pen over the length of the experiment, whereas orts were removed, weighed, and sampled weekly for DM determination. Therefore, DMI was determined weekly for each diet and pen as DM offered minus DM refused. The feed and ort DM was determined by oven-drying at 55°C for 48 h. All analyses were performed on each sample in duplicate, and

| Table 1. Composition of total mixed diets fed to heifers in the experiment |
|-----------------------------|-----------------------------|
| Item                        | Barley diet<sup>1</sup> | Wheat diet<sup>1</sup> |
| Ingredient composition, % diet DM |                |                      |
| Barley grain                 | 89.0                      | —                     |
| Wheat grain                  | —                         | 88.4                  |
| Barley silage                | 6.0                       | 6.0                   |
| Urea                         | —                         | 0.6                   |
| Supplement<sup>2</sup>       | 5.0                       | 5.0                   |
| Chemical composition         |                            |                        |
| DM, %                        | 81.3                      | 82.2                  |
| CP, % DM                     | 13.7                      | 13.4                  |
| NDF, % DM                   | 19.6                      | 12.7                  |
| ADF, % DM                   | 6.3                       | 4.7                   |
| Starch, % DM                | 50.5                      | 58.9                  |
| TDN, % DM                   | 77.3                      | 81.3                  |
| NE<sub>imp</sub>, Meal/kg    | 1.9                       | 2.0                   |
| NE<sub>r</sub>, Meal/kg     | 1.2                       | 1.3                   |

<sup>1</sup>A dash indicates ingredient not included in the diet.

<sup>2</sup>Supplement contained (per kg DM) 565 g of ground barley, 250 g of limestone, 100 g of canola meal, 30 g of salt, 25 g of molasses, 20 g of urea, 0.66 g vitamin E 500, and 10 g of trace mineral mix containing the following: 58.32 mg of zinc, 26.73 mg of manganese, 14.67 mg of copper, 0.66 mg of iodine, 0.29 mg of selenium, 0.23 mg of cobalt, 4,825 IU of vitamin A, 478 IU of vitamin D, and 32 IU of vitamin E.
Processed wheat vs. barley for feedlot steers

**Feeding Behavior.** The electronic feed bunk monitoring system allowed the collection and storage of animal behavior data from 80 heifers housed in 8 pens (n = 20), 24 h/d from d 1 to 84 of the experiment. The distinct feeding events were pooled into meals using a meal criterion of 300 s, as described by Schwartzkopf-Genswein et al. (2002), to calculate meal frequency of individuals (the number of times per day that a nonfeeding interval length exceeded the meal criterion), meal size (kg DM/meal), and the meal length (min/meal). Frequency of visits was calculated as the number of feeding events per meal. Feeding time was calculated as the sum of the length of all meals within a day (min/d). Feeding rate was determined as the sum of the size of all meals within a day divided by daily feeding time (g DM/min).

**Weight Gain.** Steers were weighed 2 h before feed delivery on d 1, 28, 56, and 84 of the experiment. Initial and final BW were calculated as the average of 2 consecutive weigh days at the beginning and end of the experiment. The ADG of each heifer was determined by dividing weight gain by the number of days on feed. The gain-to-feed ratio was calculated as kilograms of BW gained per kilogram of DM ingested.

**Hair and Saliva Cortisol.** Hair and saliva samples were taken on d 1, 28, 56, and 84 during the experimental period from the 80 steers housed in the pens equipped with GrowSafe. Hair samples were taken from the tail and stored in plastic bags until analyzed for cortisol using an enzyme immunoassay kit (Salimetrics LLC, State College, PA).

**Cattle Flight Speed.** Flight speed of steers housed in pens equipped with GrowSafe was also measured. The flight speed measuring device consisted of 2 light-beam generators and reflectors positioned on stands, a timer, and a laptop computer. The first stand was positioned 1.5 m from the exit of the squeeze chute, and the second stand was 3.5 m beyond the first stand. Every time the steers were weighed (d 1, 28, 56, and 84), on release from the chute, the steer was allowed to proceed down a grooved concrete alley (8.2 × 2.1 m) at its own pace to break the first light beam, starting the timer. The timer was stopped when the steer broke the second beam. The time that the steer required to move the 2 m between the 2 light beams was used to calculate flight speed (m/s).

**Carcass Quality Evaluation.** All steers were slaughtered at a federally inspected facility at the end of the experiment. Hot carcass weight (with kidneys removed), back fat thickness, rib eye area, quality grade (following the Canadian score: AA, AAA, and Prime or AAAA), and marbling score were determined by qualified graders. The USDA marbling scores of 300–390 (slight), 400–480 (small), 490–600 (modest), 610–670 (moderate), and 700–900 (abundant) were equivalent to Canadian scores of AA0–90, AAA0–30, AAA40–60, AA70–90, and Canada Prime, respectively. Saleable meat yield (%) was estimated using the following equation: 57.96 − 0.027 × carcass weight + 0.202 × rib eye area − 0.703 × back fat thickness, as described by Basarab et al. (2003). The percentage of livers with at least 1 abscess was recorded as the incidence of liver abscesses. When the liver had at least 4 small abscesses or at least 1 abscess with diam. greater than 2.5 cm, the incident was labeled as severe (modified from the scoring system described by Klinger et al., 2007), and the percentage of such incidences was recorded.

**Statistical Analysis**

Three sets of data were analyzed using the MIXED model of SAS (version 9.1, SAS Inst. Inc., Cary, NC). Data for growth performance (ADG, DMI, and G:F), plasma constituents, and carcass quality were analyzed with grain type and processing index, and their interaction in the model and pen was used as the statistical unit. Initial BW was used as a covariate for the analyses of growth performance parameters. Feeding behavior traits, including frequency and duration of visits to the feed bunk, meal size, eating rates, and SD of DMI were analyzed using the same model, but with animal as the experimental unit. Tukey’s test was used for multiple comparisons among treatments when the interaction was significant \( P < 0.05; \) SAS version 9.1, SAS Inst. Inc.). Flight speed, hair, and saliva cortisol data were analyzed as a factorial design using the MIXED procedure of SAS for repeated measures over time, where the main factors included the effect of grain type, processing index, time, and associated interactions. Data collected on d 1 of the experiment were also included in the model as pseudo-covariate for the analyses of each variable. Animal was considered the subject of the repeated measures, and the covariance structure was chosen according to best fit statistics and characteristics of the variable tested. The effects of the pen location as well as the ELISA plate were included in the model as random effects. Degrees of freedom were calculated using the Kenward-Rogers method (Kenward and Rogers, 1997). For the study of
the correlation between hair and saliva cortisol concentration and flight speed, a Pearson partial correlation was calculated using the CORR procedure of SAS with adjustment for the day of sampling. For all statistical analyses, significance was declared at $P < 0.05$.

**RESULTS**

Feed Intake, Growth Performance, and Feeding Behavior

Cattle fed BA tended ($P = 0.07$) to have a greater DMI than those fed WH (Table 2). Cattle fed the LO treatment had a greater ($P = 0.05$) DMI and a lower ($P = 0.04$) G:F compared with those fed HI. Cattle fed WH had lower meal length ($P = 0.02$), visits per meal ($P = 0.03$), meal size ($P = 0.08$), and daily feeding time ($P = 0.07$) than those fed BA.

Carcass Traits

Cattle fed LO tended to have greater back fat thickness ($P = 0.09$), lower rib eye area ($P = 0.09$), and reduced ($P = 0.03$) yield of saleable meat compared with those fed HI (Table 3). There was a trend ($P = 0.09$) for a grain type × processing index interaction, where cattle fed BA-LO had a lower incidence of severe liver abscesses than cattle fed the other diets.

Cortisol Level and Flight Speed

Steers fed WH had greater hair cortisol ($P = 0.01$) and flight speed ($P < 0.01$) than those fed BA (Table 4). There was a trend ($P = 0.07$) for a grain type × processing index interaction, where cattle fed WH-LO had lower salivary cortisol than those fed other diets. Flight speed was positively correlated with hair cortisol concentration ($r = 0.21; P < 0.01$), but there was no correlation between saliva cortisol and either hair cortisol ($r = −0.02; P = 0.77$) or flight speed ($r = −0.02; P = 0.78$).

**DISCUSSION**

Effects of Type of Grain on Feed Intake and Feeding Behavior

The use of WH to replace BA reduced DMI and altered feeding behavior, lowering the frequency of visits to the feed bunk, the intake per meal, and the time spent at the feed bunk per meal and per day. Multiple factors are involved in the regulation of feed intake in ruminants (Illius et al., 2002; Forbes, 2003), and the greater starch, TDN, and energy content of WH compared with BA are all factors that could potentially precipitate difference in feeding behavior and voluntary feed intake. A greater proportion of ruminal degradable starch is associated with increased production of organic acids, with proportionally more propionate than acetate, and increased ruminal osmolality (Martin et al., 1999; Philippeau et al., 1999). This increase can, in turn, inhibit feed intake, salivation, and the onset of rumination following meals (Carter and Grovum, 1990; Allen, 2000; Oba and Allen, 2003). The greater energy density of WH could have also enabled steers to meet their energy requirements while consuming less DM (Forbes, 2003). Additionally, there are other potential factors that may account for the difference in DMI of cattle fed BA vs. WH such as differences in NDF content, the rate of nutrient release, or the

Table 2. Intake and growth performance ($n = 4$, pen as the experimental unit) and feeding behavior ($n = 20$, animal as the experimental unit) determined over the 84-d feeding period

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment1</th>
<th>SEM</th>
<th>$P$-value2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>Wheat</td>
<td>Barley</td>
</tr>
<tr>
<td>DMI, kg DM/d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>10.4</td>
<td>9.9</td>
<td>0.13</td>
</tr>
<tr>
<td>Low</td>
<td>10.6</td>
<td>10.3</td>
<td>0.03</td>
</tr>
<tr>
<td>Growth performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADG, kg BW/d</td>
<td>1.43</td>
<td>1.40</td>
<td>0.03</td>
</tr>
<tr>
<td>G:F, kg BW/kg DM</td>
<td>0.137</td>
<td>0.141</td>
<td>0.003</td>
</tr>
<tr>
<td>Feeding behavior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meal frequency, No./d</td>
<td>8.22</td>
<td>8.55</td>
<td>0.436</td>
</tr>
<tr>
<td>Meal size, kg DM/meal</td>
<td>1.28</td>
<td>1.13</td>
<td>0.069</td>
</tr>
<tr>
<td>Meal length, min/meal</td>
<td>8.38</td>
<td>7.15</td>
<td>0.370</td>
</tr>
<tr>
<td>Visits per meal, No./meal</td>
<td>2.42</td>
<td>1.90</td>
<td>0.156</td>
</tr>
<tr>
<td>Feeding time, min/d</td>
<td>64.3</td>
<td>57.7</td>
<td>2.40</td>
</tr>
<tr>
<td>Feeding rate, g DM/min</td>
<td>153.2</td>
<td>160.2</td>
<td>7.17</td>
</tr>
</tbody>
</table>

1Treatments were 1) type of grain in the diet, barley (BA; 89.0% of diet DM) or wheat (WH; 88.4% of diet DM), and 2) processing index of the grain, low (LO; 85% of the preprocessed volume weight) or high (HI; 75% of the preprocessed volume weight).

2Fixed effects were grain (GR), processing index (PI), and their interaction (GR × PI).
Extensive processing maximizes digestibility of grain for cattle (Owens et al., 1997; Offner et al., 2003) but also increases the risk of digestive upsets (Hironaka et al., 1979; De Visser and de Groot, 1980). Beauchemin et al. (2001) noted that the optimal degree of processing of tempered BA was a PI between 65% and 75% and did not recommend coarsely rolled BA (PI = 82%) as it reduced ruminal fermentation and microbial protein synthesis in feedlot cattle. Similarly, Wang et al. (2003) found the optimal PI of tempered BA to range between 74% and 76% for finishing cattle. In our case, from a performance perspective, the HI treatment (PI = 75%) resulted in a more favorable outcome than the LO treatment. However, the trend for a greater incidence of severe liver abscesses in steers fed diets other than BA-LO compared with those fed BA-LO suggests that a coarser particle size reduced the deleterious effects of highly fermentable starch on liver health, a benefit from an animal welfare perspective.

The HI treatment resulted in carcasses with a greater percentage of saleable meat, explained by a larger rib eye area and lower back fat thickness than for LO. Synthesis of intramuscular fat preferentially uses glucose as substrate, whereas subcutaneous fat uses acetate (Smith and Crouse, 1984). Therefore, the greater starch availability of highly processed grains and the

### Table 3. Carcass quality traits determined by pen (n = 4) at the moment of slaughter after the experimental period

<table>
<thead>
<tr>
<th>Item</th>
<th>Barley</th>
<th>Wheat</th>
<th>P-value&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>SEM</td>
</tr>
<tr>
<td>HCW, kg</td>
<td>409.3</td>
<td>403.8</td>
<td>406.0</td>
</tr>
<tr>
<td>Back fat thickness, mm</td>
<td>22.1</td>
<td>23.5</td>
<td>21.7</td>
</tr>
<tr>
<td>Rib eye area, cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>87.5</td>
<td>83.5</td>
<td>88.1</td>
</tr>
<tr>
<td>Quality grade, % Canada AAA</td>
<td>100.0</td>
<td>87.5</td>
<td>94.5</td>
</tr>
<tr>
<td>USDA marbling score&lt;sup&gt;3&lt;/sup&gt;</td>
<td>509.7</td>
<td>495.5</td>
<td>527.5</td>
</tr>
<tr>
<td>Saleable meat, %&lt;sup&gt;4&lt;/sup&gt;</td>
<td>49.1</td>
<td>47.4</td>
<td>49.6</td>
</tr>
<tr>
<td>Incidence of liver abscesses, %&lt;sup&gt;5&lt;/sup&gt;</td>
<td>73.4</td>
<td>70.0</td>
<td>71.8</td>
</tr>
<tr>
<td>Severe incidents, %</td>
<td>44.7</td>
<td>17.5</td>
<td>45.8</td>
</tr>
</tbody>
</table>

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<sup>4</sup>Saleable meat yield (%) was estimated using the following equation: 57.96 − 0.027 × carcass weight + 0.202 × rib eye area − 0.703 × back fat thickness.

<sup>5</sup>The percentage of livers with at least 1 abscess was recorded as the incidence of liver abscesses. When the liver had at least 4 small abscesses or at least 1 abscess with a diam. greater than 2.5 cm, the incident was labeled as severe.

### Effects of Grain Processing on Feed Intake and Carcass and Growth Performance

The reduced DMI and increased G:F of cattle fed grain processed at a HI vs. LO index are in agreement with the results of previous studies (Mathison et al., 1997; Wang et al., 2003; Bengochea et al., 2005). These observations likely reflect the fact that more extensively processed grains have a greater starch degradation in the rumen, improving feed efficiency but also increasing the level of propionate metabolism in the liver, leading to satiety (Allen, 2000). There is considerable debate regarding the ideal extent to which grains should be processed (Dehghan-banadaky et al., 2007). Extensive processing maximizes digestibility of grain for cattle (Owens et al., 1997; Offner et al., 2003) but also increases the risk of digestive upsets (Hironaka et al., 1979; De Visser and de Groot, 1980). Beauchemin et al. (2001) noted that the optimal degree of processing of tempered BA was a PI between 65% and 75% and did not recommend coarsely rolled BA (PI = 82%) as it reduced ruminal fermentation and microbial protein synthesis in feedlot cattle. Similarly, Wang et al. (2003) found the optimal PI of tempered BA to range between 74% and 76% for finishing cattle. In our case, from a performance perspective, the HI treatment (PI = 75%) resulted in a more favorable outcome than the LO treatment. However, the trend for a greater incidence of severe liver abscesses in steers fed diets other than BA-LO compared with those fed BA-LO suggests that a coarser particle size reduced the deleterious effects of highly fermentable starch on liver health, a benefit from an animal welfare perspective.

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Table 4. Hair and saliva cortisol and flight speed determined in 80 steers at d 1, 28, 56, and 84 of the experiment

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>Barley</th>
<th>Wheat</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortisol level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hair, pg/mg</td>
<td>High</td>
<td>1.74</td>
<td>1.69</td>
<td>2.06</td>
<td>1.87</td>
</tr>
<tr>
<td>Saliva, µg/dL</td>
<td>Low</td>
<td>0.66</td>
<td>0.67</td>
<td>0.67</td>
<td>0.44</td>
</tr>
<tr>
<td>Log transformation</td>
<td></td>
<td>−0.18</td>
<td>−0.17</td>
<td>−0.18</td>
<td>−0.36</td>
</tr>
<tr>
<td>Flight speed, m/s</td>
<td></td>
<td>1.58</td>
<td>1.71</td>
<td>1.94</td>
<td>1.97</td>
</tr>
</tbody>
</table>

1Treatments were 1) type of grain in the diet, barley (BA; 89.0% of diet DM) or wheat (WH; 88.4% of diet DM), and 2) processing index of the grain, low (LO; 85% of the preprocessed volume weight) or high (HI; 75% of the preprocessed volume weight).

2Fixed effects were grain (GR), processing index (PI), and their interaction (GR × PI). The model also included the effects of time (T), GR × T, PI × T, and GR × PI × T, which turned out to be nonsignificant (P > 0.10), except for T (P < 0.01) in the analyses of saliva cortisol and flight speed.

3A base 10 logarithm transformation was applied to all saliva cortisol values to obtain a normal distribution of data.

A consequent increase in the propionate and glucose supply to the animal (Church, 1988) may have increased the diameter of intramuscular adipocyte (hypertrophy) and reduced subcutaneous fat deposition (Schoonmaker et al., 2004). Owens and Gardner (2000) reviewed 552 studies and concluded that grain processing led to less ruminal escape of dietary starch and increased subcutaneous fat deposition. The different grain-processing techniques and types of cereal used in the present study and those studies reviewed by Owens and Gardner (2000; dry-rolled barley and wheat vs. steam-flaked corn and milo, respectively) may have caused the former to have smaller particle size and a shorter rumen transit time. As a consequence, postruminal starch digestion in the small intestine may have increased (Wood et al., 2008), causing differences in fat deposition.

**Effects of Grain Type and Processing on Stress and Temperament of Beef Cattle**

There was an effect of the grain type on stress and temperament of feedlot steers. Others have also shown that feeding acidogenic diets such as WH increases the incidence of liver abscesses (Nagaraja and Chengappa, 1998), acute phase proteins (Gozho et al., 2005; Khafipour et al., 2009), and the stereotypic behaviors (Petherick et al., 2009b; Faleiro et al., 2011), all indicators of reduced animal welfare.

Poor welfare and stress are closely associated concepts (Veissier and Boissy, 2007), and previous studies (Lindström et al., 2001; Bristow and Holmes, 2007) have reported that cows that spend less time ruminating have greater levels of cortisol. However, low ruminal pH has not been previously linked with an increase in cortisol levels in either saliva (González et al., 2009) or serum (Brown et al., 2000). The explanation, as suggested by Mormède et al. (2007), may be that cortisol levels measured in plasma or saliva are not suitable indicators of chronic stress such as when beef cattle maybe suffering from prolonged subacute ruminal acidosis. This lack of suitability may be due to difficulties in differentiating slight elevations in basal levels from spontaneous variation or the effect of sampling itself (Barnett et al., 1988). Furthermore, the effect of stress is not constant over the day, and increased cortisol levels may occur later in the day when levels are usually low (Janssens et al., 1995; de Jong et al., 2000). Mormène et al. (2007) proposed that measuring cortisol levels in other biological matrices, such as urine, feces, or hair, may be more sensitive for detecting small, long-term changes in cortisol secretion.

In this regard, we have recently validated cattle hair as a sample matrix for measuring cortisol levels in beef cattle (Moya et al., 2013). Compared with blood, saliva, or feces, hair provides long-term average levels of cortisol and is therefore more suitable for assessing chronic stress. One thing to consider when analyzing cortisol levels over long periods of time in cattle fed different diets is that blood glucose levels may alter stress responses and/or secretion of cortisol. However, Mudroň et al. (2005) reported that different blood plasma glucose levels do not have any effect on cortisol and metabolite responses in stressed dairy cows. Therefore, it can be concluded that mechanisms regulating peripheral cortisol concentrations, and thus the animal’s stress response, are more dependent on the intensity of the stressful stimulus than on the energetic status of animal.

Under the conditions of this study, steers fed WH with LO showed a trend for lower saliva cortisol compared with steers fed the other diets. This effect is quite different from that observed in hair cortisol or flight speed, resulting in a lack of correlation of saliva cortisol with hair cortisol or flight speed, whereas hair cortisol and flight speed were positively correlated. This result suggests that the predictive and explanatory value of saliva cortisol with regard to stress assessment is limited to short periods of time, leading to the possibility that handling of the animal itself during sample collection
may influence the experimental outcome (Moberg and Mench, 2000). In contrast, hair cortisol likely represents a long-term average of plasma cortisol levels and, unlike saliva, provides information on stress responses over long periods of time (Moya et al., 2013). Likewise, flight speed is largely a measure of general agitation and not of a response to immediate stress or handling (Petherick et al., 2009a). Previous studies (Curley et al., 2006; Petherick et al., 2009b) have found significant correlations between serum cortisol and flight speed. However, Curley et al. (2008) found that following adrenal stimulation with exogenous adrenocorticotrope hormone (ACTH), peak cortisol concentrations and amplitude of the adrenal response did not differ between cattle with high or low flight speed. Such an apparent discrepancy in results may be due to differences in the environment, genotype, and the particular challenge in question (Cabib, 2006). Van Reenen et al. (2013) showed that measures of hypothalamus-pituitary-adrenal axis (HPA) reactivity to immediate or chronic stress, as well as adrenocortical and behavioral responses to novelty, were largely uncorrelated and concluded that stress responses in cattle are mediated by multiple independent underlying traits.

The reason why steers fed WH-LO had a lower saliva cortisol concentration than those fed other diets may be due to a reduction in their HPA axis sensitivity. There is evidence that chronic stress decreases the sensitivity of the adrenal cortex in cattle (Redbo, 1998), as well as in other species (Dallman and Jones, 1973; Rivier and Vale, 1987). For example, in a study with growing bulls (Ladewig and Smidt, 1989), individuals exposed to long-term tethering showed a lower plasma cortisol concentration after an ACTH challenge than those loosely housed on deep straw. A decreased response to ACTH was also found in heifers exposed to crowding (Beneke et al., 1983) and dairy heifers exposed to heat stress (Gwazdauskas et al., 1975). A similar suppression of pituitary-adrenal response to pharmacological stimuli was observed in Holstein heifers when the stress challenge was preceded by transportation stress (Knights and Smith, 2007). Therefore, we hypothesize that the WH-LO diet caused stress to a greater extent than other diets, reducing the sensitivity of the HPA axis to handling and thereby lowering levels of salivary cortisol. Nevertheless, cattle fed the WH-LO treatment had the greatest incidence of total and severe liver abscesses. Although there was no statistical difference in the incidence of liver abscesses between treatments, there may be biological relevance to such differences at the adrenal level.

Flight speed is a measurement of handling temperament and general agitation in cattle (Petherick et al., 2009b; MacKay et al., 2013), with greater flight speeds being associated with an increased stress response (Curley et al., 2008; Burdick et al., 2011). Although temperament of farm animals is part of the enduring biological makeup of each individual (Van Reenen et al., 2013), prolonged chronic stress may alter brain function and, as a consequence, temperament (Cabib, 2006). For example, adaptations to long-term or uncontrollable stress involve mainly the areas within the brain receiving dopamine projections from the mesencephalon (midbrain), where an imbalance toward the mesoaccumbens dopamine transmission favors active coping responses under stressful conditions, such as escape, struggling, and fighting (Alcaro et al., 2002; Cabib et al., 2002). Experiments with beef cattle (Petherick et al., 2009a) and grazing bulls (Holroyd et al., 2004) have also shown an increase in the flight speed of individuals exposed to chronic stressful conditions caused by poor handling and a high-energy grain-based diet, respectively.

Conclusions

The use of WH as a replacement for BA resulted in a reduced DMI, along with changes in the feeding behavior, such as lower frequency of visits to the feed bunk, intake per meal, and time spent at the feed bunk per meal and per day. Although these differences did not have any effect on the growth performance or carcass quality of steers, the increased hair cortisol and flight speed suggested that WH increased stress in finishing cattle. A lower processing index increased DMI but reduced feed efficiency and adversely impacted carcass quality parameters, including saleable meat yield, back fat thickness, and rib eye area.

LITERATURE CITED


