Potential protein degradation balance and total metabolizable protein supply to dairy cows from heat-treated faba beans

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Abstract: The effects of pressure toasting (100, 118 and 136 °C for 3, 7, 15 and 30 min) on potential protein nutritional value of faba beans were evaluated with the NRC 2001 dairy model, by determining undegraded (RUP) and degraded rumen protein (RDP), undegraded (RUST) and degraded rumen starch (RDST), truly absorbed undegraded protein (ARUP), microbial protein (MCP) synthesized in the rumen from rumen-available protein, truly absorbed rumen synthesized microbial protein (AMCP), truly absorbed rumen endogenous protein (AECP), total metabolizable protein (MP) in the small intestine, and the protein degradation balance (PDB). The treatments increased RUP, RUST, ARUP and MP (p < 0.001), and decreased RDP, RDST, MCP and PDB (p < 0.001), the effects increasing with increasing temperature and time. The treatments increased (p < 0.001) ARUP without affecting AECP and AMCP, so that the net absorbable total MP in the small intestine was increased. The PDB was reduced (p < 0.001) but never became negative. These results indicated that potential microbial protein synthesis would not be impaired due to sufficient nitrogen in the rumen, but the high positive PDB values with most treatments, except 136 °C for 15 min (PDB 2.0 g kg⁻¹ DM) indicated that there were large potential losses of nitrogen in the rumen, particularly for the control with a value of 88.9 g kg⁻¹ dry matter. It is concluded that predicted potential protein degradation balance and total metabolizable protein supply from faba beans were improved by the treatments.

Keywords: faba bean; protein degradation balance; metabolizable protein; NRC 2001 model

INTRODUCTION

Ground faba beans (Vicia faba) exhibit a high rate and extent of rumen degradation,¹,² resulting in an imbalance between feed breakdown and microbial protein synthesis, making them inefficient for use in dairy diets. Pressure toasting reduced the rumen degradation of protein and starch (RDP and RDST) and increased rumen bypass protein and starch (RUP and RUST).¹ However, no quantitative evaluation of nutrient supply to dairy cows, predicted with the National Research Council-2001 model (which is widely used in the world) has been reported in terms of the potential protein degradation balance (PDB) and total metabolizable protein (MP).

The PDB value is the balance between microbial protein synthesis from rumen-degradable protein and that from the energy extracted during anaerobic fermentation in the rumen. When PDB is positive, it indicates the potential loss of nitrogen from the rumen. When negative, microbial protein synthesis may be impaired because of a shortage of nitrogen in the rumen. The optimal PDB value in a ration is therefore zero to slightly positive.⁴

The objectives of this study were to use the National Research Council-2001 model² to predict the potential nutrient supply to dairy cows when faba beans were pressure toasted, to measure how pressure toasting affected the nutritional value and to give information for dairy ration formulation.

MATERIALS AND METHODS

Raw material and treatments

Faba beans were pressure-toasted at three different temperatures (100, 118 and 136 °C) for 3, 7, 15 and 30 min, resulting in 11 treatments (control, raw; T₁, 100 °C for 7 min; T₂, 100 °C for 15 min; T₃, 100 °C for 30 min; T₄, 118 °C for 3 min; T₅, 118 °C for 7 min; T₆, 118 °C for 15 min; T₇, 118 °C for 30 min; T₈, 136 °C for 3 min; T₉, 136 °C for 7 min; T₁₀, 136 °C for 15 min). All treatments were carried out in duplicate (A and B series). Treatments at 100 °C for 3 min and 136 °C for 30 min were excluded due to no expected significant difference between the raw beans and beans heated at 100 °C for 3 min and the risk of overheating, respectively. The treatments...
were carried out at the Wageningen Feed Processing Center, The Netherlands, using a laboratory scale pressure toaster as described by Van der Poel. After toasting, the beans were dried at 35 °C for 18 h in an oven, allowed to cool to ambient temperature and then ground through a 3 mm screen (Hammer Mill TYP AM80N°2, AEG, Wageningen).

**In situ rumen incubation and mobile nylon bag technique**

Four lactating cows, each fitted with a rumen cannula and housed in tie stalls at the experimental station at Wageningen University, were used for *in situ* rumen incubations. Four lactating Dutch dairy cows, each fitted with a T-piece cannula in the proximal duodenum and housed in tie stalls at the Research Institute of Animal Husbandry, Lelystad, The Netherlands, were used for mobile nylon bag work. All the cows were fed pelleted commercial concentrate and hay according to Dutch feeding standards. Ethics approval for these studies was given by Wageningen University and the Research Institute of Animal Husbandry (Lelystad) Animal Ethics Committees.

In *in situ* rumen incubation procedure

*In situ* ruminal degradation characteristics were determined using the Dutch standard method. Incubation of all treatments in the rumen was conducted with 5.5 g dry matter (DM) in each coded nylon bag (10 × 17 cm) with a pore size of approximately 40 µm (Nylot, Zurich, Switzerland). The rumen incubations were performed according to the 'gradual addition/all out' schedule. Incubations were carried out for 2, 4, 8, 12 and 48 h. All treatments were randomly allocated over all cows and the whole incubation period. After incubation, the bags were removed from the rumen and rinsed under a stream of cold tap water to remove excess ruminal contents and microbes on the surface. The bags were then washed with cold water without detergent in a commercial washing machine for 55 min without spinning and subsequently dried at 35 °C for 24 h. The 0 h incubation samples were put in the washing machine under the same conditions without preliminary washing. Dry samples were stored in a cool room (4 °C) until analysis. The residues were pooled according to feed treatment and incubation time and then ground through a 1 mm screen for chemical analysis.

Mobile nylon bag procedure

For intestinal digestion, the four intestinally cannulated lactating dairy cows were used for the mobile nylon bag technique. Extra bags were incubated in the rumen for 12 h to provide sufficient material for the intestinal studies. After rumen incubation, the bags were removed and handled as described above. However, the residues were freeze-dried and pooled according to feed treatments. Approximately 0.5 g (DM) of rumen residue was then weighed into each coded nylon bag (5 × 3 cm, pore size 40 µm), 24 bags per treatment. Prior to incubation in the intestine the bags were incubated in a solution of pepsin–HCl solution [1 g pepsin (2000 FIP u g⁻¹, product no. 7190, Merck, Whitehouse Station, NJ, USA) in 11 0.1 M HCl] at 39 °C for 1 h. Every 20 min, four bags were taken at random and inserted into the intestine through the duodenal cannula. The bags were retrieved from the faeces. Checks were made every 2 h after bag introduction, and the collection time was recorded for each bag. The retrieved bags were stored at −20 °C until all the bags had been recovered, and were then thawed and washed in a washing machine for 2 h at 40 °C without spinning. The residues were freeze-dried, weighed and pooled according to feed treatments and analysed for chemical contents after the pooled residues were ground using a 1 mm mesh.

In situ rumen degradation characteristics

In general, the important *in situ* rumen degradation characteristics described by the first-order kinetics degradation model, modified by Robinson *et al.* and Tamminga *et al.* are: (1) the soluble (washable) fraction (A) which is assumed to be degraded rapidly and completely; (2) fraction C, which is not degraded irrespective of the time it is incubated in the rumen; (3) fraction B, which is not soluble, but potentially degradable; (4) the fractional rate of degradation (Kd), at which fraction B becomes degraded; and (5) the lag time (T0), in which no degradation of B takes place.

Rumen degradation of crude protein (CP) and starch (ST) were calculated using iterative least squares regression (Gauss–Newton method) by the following first-order kinetics equations:

\[
R(t) = C + B \times e^{-K_d (t-T_0)} \quad \text{for CP} \tag{1}
\]

\[
R(t) = B \times e^{-K_d t} \quad \text{for ST} \tag{2}
\]

where \(R(t)\) stands for residue of the incubated material after \(t\) h of rumen incubation (g kg⁻¹); \(C\) and \(B\) stand for undegradable and potentially degradable fractions, respectively (g kg⁻¹); lag time \((T_0)\), in which no degradation of \(B\) takes place.

Using the estimated values of \(A\), \(B\), \(C\) and \(K_d\) for both CP and ST, the respective rumen-degradable values were calculated as:

For rumen-degradable CP (RDP, g kg⁻¹ DM)

\[
RDP = CP[A + B \times K_d/(K_p + K_d)] \tag{3}
\]

For rumen-degradable ST (RDST, g kg⁻¹ DM)

\[
RDST = ST[A + B \times K_d/(K_p + K_d)] \tag{4}
\]

For rumen-undegraded CP (RUP, g kg⁻¹ DM)

\[
RUP = 1.11 \times CP[C + B \times K_p/(K_p + K_d)] \tag{5}
\]

For rumen-undegraded ST (RUST, g kg⁻¹ DM)

\[
RUST = ST[B \times K_p/(K_p + K_d) + 0.1 \times A] \tag{6}
\]
where, in each case, a passage rate, $K_o$ of 0.06 h$^{-1}$ was adopted. The factor 1.11 in equation (5) is the regression coefficient of in vivo on in situ degradation data. For the factor 0.1 in equation (6), it was assumed that for starch, 100 g kg$^{-1}$ of soluble $A$ fraction escapes rumen fermentation.

### Chemical analysis
Laboratory samples of the feeds, rumen residues and mobile bag residues for all treatments were prepared by grinding to pass a 1 mm mesh. DM was determined by drying at 105 °C to constant weight. Ash was determined by heating at 550 °C to constant weight. Starch was determined according to the NIKO method, nitrogen by Kjeldahl digestion and distillation (Gerhardt Vadopest 6, Germany) and CP content was calculated as $N \times 6.25$.

### Estimation of energy values
The energy values of TDN$_{1X}$ (total digestible nutrient for the estimated maintenance level), DE$_{3X}$, ME$_{3X}$ and NE$_{L3X}$ (standing for digestible energy, metabolizable energy and net energy for lactation at production level of intake, $3 \times$) were estimated using the summative approach from the NRC model.

### Using the NRC 2001 dairy model to predict potential nutrient supply
The detailed concepts and formulas were obtained from the NRC model. The following is a brief explanation.

**Microbial protein synthesis in the rumen**
When RDP exceeded $1.18 \times$ TDN-predicted MCP (MCPRDP), potential ruminally synthesized microbial CP was calculated as:

$$MCP(g \text{ kg}^{-1} \text{DM}) = 0.13 \text{ TDN (discounted)} \quad (7)$$

where TDN (discounted) was calculated according to the formula in NRC model. When RDP was less than $1.18 \times$ TDN-predicted MCP (MCPTDN), then MCP was calculated as:

$$MCP(g \text{ kg}^{-1} \text{DM}) = 0.85 \text{ RDP (MCPRDP)} \quad (8)$$

**Intestinal digestion of feed and microbial protein**
In the NRC model, true protein of ruminally synthesized microbial CP is assumed to be 800 g kg$^{-1}$ and the digestibility of ruminally synthesized microbial CP is assumed to be 800 g kg$^{-1}$; therefore the amount of truly absorbed MCP (AMCP) in the small intestine was estimated as:

$$\text{AMCP} = 0.80 \times 0.80 \text{ MCP} = 0.64 \text{ MCP} \quad (9)$$

where AMCP is in g kg$^{-1}$ DM.

Truly absorbed rumen undegraded protein in the small intestine (ARUP) was calculated as:

$$\text{ARUP} = \text{RUP} \times d\text{RUP} \quad (10)$$

where $d\text{RUP}$ (digestibility of RUP) was determined using the mobile nylon bag technique, calculated as:

$$ECP(g \text{ kg}^{-1} \text{DM}) = 6.25 \times 1.9 \text{ DM}/1000 = 0.12 \text{ DM} \quad (11)$$

where DM is in g kg$^{-1}$.

Assuming that 500 g kg$^{-1}$ of rumen endogenous CP passes to the duodenum and 800 g kg$^{-1}$ of rumen endogenous CP is true protein, the truly absorbed rumen endogenous protein in the small intestine (AECP) was estimated as:

$$\text{AECP} = 0.50 \times 0.80 \text{ ECP} = 0.4 \text{ ECP} \quad (12)$$

where AECP and ECP are in g kg$^{-1}$ DM.

**Total metabolizable protein**
Total metabolizable protein (MP) is the sum of the truly absorbed ruminally undegraded feed CP (ARUP), the ruminally synthesized microbial CP (AMCP) and rumen endogenous CP (AECP).

**Protein degradation balance**
The protein degradation balance (PDB) reflects the difference (g kg$^{-1}$ DM) between potential microbial protein synthesis based on ruminally degraded feed protein (RDP) and that based on energy (discounted TDN) available for microbial fermentation in the rumen, which was calculated as:

$$\text{PDB} = \text{RDP} - 1.18 \text{MCPTDN} \quad (13)$$

### Statistical analysis
Statistical analyses were carried out according to SAS. Comparison of means was carried out by using the Student–Newman–Keuls test, when the effect of temperature and time interaction was significant ($p < 0.05$).

### RESULTS
**Chemical composition, total digestible nutrients and energy value**
The chemical composition, total digestible nutrient and predicted energy values of the beans are given in Table 1. Raw beans contain high concentrations of protein and starch. Total digestible nutrient (TDN) was 811 g kg$^{-1}$ DM. The predicted values of DE$_{3X}$,
### Table 1. Chemical composition, total digestible nutrients and energy values of faba beans

<table>
<thead>
<tr>
<th>Item</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical composition</strong></td>
<td></td>
</tr>
<tr>
<td>Dry matter (DM, g kg⁻¹)</td>
<td>887.3</td>
</tr>
<tr>
<td>Organic matter (OM, g kg⁻¹)</td>
<td>964.3</td>
</tr>
<tr>
<td>Ash (g kg⁻¹ DM)</td>
<td>35.7</td>
</tr>
<tr>
<td>Crude protein (CP, g kg⁻¹ DM)</td>
<td>245.8</td>
</tr>
<tr>
<td>Total carbohydrate (CHO, g kg⁻¹ DM)</td>
<td>707.0</td>
</tr>
<tr>
<td>Starch (ST, g kg⁻¹ DM)</td>
<td>322.6</td>
</tr>
<tr>
<td>Crude fat (CF, g kg⁻¹ DM)</td>
<td>11.6</td>
</tr>
<tr>
<td>Neutral detergent fibre (NDF, g kg⁻¹ DM)</td>
<td>119.9</td>
</tr>
<tr>
<td>Acid detergent fibre (ADF, g kg⁻¹ DM)</td>
<td>116.7</td>
</tr>
<tr>
<td>Acid detergent lignin (ADL, g kg⁻¹ DM)</td>
<td>13.9</td>
</tr>
<tr>
<td><strong>Total digestible nutrient</strong></td>
<td></td>
</tr>
<tr>
<td>TDN₁X (g kg⁻¹ DM)</td>
<td>811.3</td>
</tr>
<tr>
<td>TDN₃X₃ (g kg⁻¹ DM)</td>
<td>745.1</td>
</tr>
<tr>
<td><strong>Predicted energy value</strong></td>
<td></td>
</tr>
<tr>
<td>DE₃X (NRC-2001 Dairy)</td>
<td>3.42</td>
</tr>
<tr>
<td>ME₃X (NRC-2001 Dairy)</td>
<td>3.01</td>
</tr>
<tr>
<td>NE₃X (NRC-2001 Dairy)</td>
<td>1.92</td>
</tr>
</tbody>
</table>

ME₃X and NE₃X₃ were 14.3, 12.6 and 8.0 MJ kg⁻¹ DM, respectively.

### Quantitative evaluation of faba beans

**In situ rumen degradation**

In situ rumen degradation characteristics of starch and protein are presented in Tables 2 and 3. For starch, the treatments decreased the A fraction (p < 0.05) and increased the B fraction without increasing the C fraction. The treatments also decreased K₃ (p < 0.05). This would have increased rumen undegradable protein (RUP) and reduced rumen degradable protein (RDP) (Table 3).

For protein, the treatments decreased the A fraction (p < 0.05) and increased the B fraction without increasing the C fraction. The treatments also decreased K₃ (p < 0.05). This would have increased rumen undegradable protein (RUP) and reduced rumen degradable protein (RDP) (Table 3).

### Ruminally synthesized microbial protein

Since the rumen-degradable protein (Table 4) exceeded 1.18 TDN-predicted MCP (MCP₃X₃), potential ruminally synthesized microbial protein was calculated as: 0.13 TDN (discounted).³ The treatments had little effect on truly absorbed rumen synthesized microbial protein in the small intestine (AMCP) because they did not affect the chemical composition of faba beans used to predict TDN.

### Intestinal digestion of rumen undegradable protein

Intestinal digestibility of rumen-undegradable protein, measured by the mobile nylon bag technique, was unaffected by the treatments, therefore truly absorbed ARUP increased from 40.1 in the control to 138.9 g kg⁻¹ DM in T10 (136 °C for 15 min; p < 0.05; Table 5).

### Rumen endogenous protein

The treatments did not affect DM, so AECP was not changed by the treatments (data not shown).

### Total metabolizable protein (MP)

Total metabolizable protein was increased 1.9 times (from 106.3 in the control to 205.1 g kg⁻¹ DM in the 136 °C for 15 min) by the treatments (Table 6).

### Protein degraded balance (PDB)

The PDB was reduced from 88.9 g kg⁻¹ DM (raw) to 2.0 g kg⁻¹ DM at 136 °C for 15 min with increasing temperature and length of pressure toasting as shown in Table 6, but never became negative.

### Table 2. In situ rumen degradation of starch from faba beans

<table>
<thead>
<tr>
<th>Treatment</th>
<th>A (g kg⁻¹)</th>
<th>B (g kg⁻¹)</th>
<th>K₄ (g kg⁻¹ h⁻¹)</th>
<th>RUST Fraction (g kg⁻¹)</th>
<th>RDST Fraction (g kg⁻¹)</th>
<th>RUST (g kg⁻¹ DM)</th>
<th>RDST (g kg⁻¹ DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>582 a</td>
<td>442 g</td>
<td>48.6</td>
<td>2901</td>
<td>710 a</td>
<td>93.5 e</td>
<td>229.1 a</td>
</tr>
<tr>
<td>T₁ (100 °C for 7 min)</td>
<td>536 a</td>
<td>464 g</td>
<td>45.1</td>
<td>319 ef</td>
<td>662 ab</td>
<td>106.8 d</td>
<td>228.6 a</td>
</tr>
<tr>
<td>T₂ (100 °C for 15 min)</td>
<td>506 ab</td>
<td>493 fg</td>
<td>51.8</td>
<td>316 ef</td>
<td>684 ab</td>
<td>105.8 d</td>
<td>229.1 a</td>
</tr>
<tr>
<td>T₃ (100 °C for 30 min)</td>
<td>507 ab</td>
<td>493 fg</td>
<td>46.6</td>
<td>329 ef</td>
<td>671 ab</td>
<td>113.6 d</td>
<td>232.3 a</td>
</tr>
<tr>
<td>T₄ (118 °C for 3 min)</td>
<td>441 bc</td>
<td>559 ef</td>
<td>48.4</td>
<td>354 ed</td>
<td>646 bc</td>
<td>119.1 cd</td>
<td>217.3 a</td>
</tr>
<tr>
<td>T₅ (118 °C for 7 min)</td>
<td>394 cd</td>
<td>606 de</td>
<td>47.3</td>
<td>378 d</td>
<td>622 c</td>
<td>126.3 c</td>
<td>207.5 ab</td>
</tr>
<tr>
<td>T₆ (118 °C for 15 min)</td>
<td>166 cd</td>
<td>619 de</td>
<td>36.0</td>
<td>425 c</td>
<td>575 d</td>
<td>144.0 b</td>
<td>194.9 bc</td>
</tr>
<tr>
<td>T₇ (118 °C for 30 min)</td>
<td>324 de</td>
<td>676 cd</td>
<td>38.7</td>
<td>444 c</td>
<td>556 d</td>
<td>147.7 b</td>
<td>185.4 bc</td>
</tr>
<tr>
<td>T₈ (136 °C for 3 min)</td>
<td>301 ef</td>
<td>699 bc</td>
<td>40.8</td>
<td>446 c</td>
<td>554 d</td>
<td>148.4 b</td>
<td>184.4 bc</td>
</tr>
<tr>
<td>T₉ (136 °C for 7 min)</td>
<td>247 fg</td>
<td>753 ab</td>
<td>38.7</td>
<td>483 b</td>
<td>517 e</td>
<td>163.7 a</td>
<td>175.4 c</td>
</tr>
<tr>
<td>T₁₀ (136 °C for 15 min)</td>
<td>196 g</td>
<td>804 a</td>
<td>34.4</td>
<td>531 a</td>
<td>469 f</td>
<td>173.5 a</td>
<td>153.2 d</td>
</tr>
<tr>
<td>SEM</td>
<td>19.7</td>
<td>19.7</td>
<td>3.4</td>
<td>10.1</td>
<td>10.1</td>
<td>3.19</td>
<td>5.87</td>
</tr>
</tbody>
</table>

Means with the same letter in the same column are not significantly different (p > 0.05) by Student–Newman–Keuls test; SEM = standard error of mean.
the small intestine with faba beans

Table 4. In situ rumen degradation characteristics of crude protein

<table>
<thead>
<tr>
<th>Treatment</th>
<th>A (g kg(^{-1}))</th>
<th>B (g kg(^{-1}))</th>
<th>C (g kg(^{-1}))</th>
<th>K(_d) (g kg(^{-1}) h(^{-1}))</th>
<th>RUP fraction (g kg(^{-1}))</th>
<th>RDP fraction (g kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>642 a</td>
<td>340 d</td>
<td>18</td>
<td>74 ab</td>
<td>173 g</td>
<td>827 a</td>
</tr>
<tr>
<td>T(_1) (100 °C for 7 min)</td>
<td>614 b</td>
<td>357 d</td>
<td>29</td>
<td>88 a</td>
<td>175 g</td>
<td>825 a</td>
</tr>
<tr>
<td>T(_2) (100 °C for 15 min)</td>
<td>582 c</td>
<td>374 d</td>
<td>44</td>
<td>87 a</td>
<td>200 g</td>
<td>800 ab</td>
</tr>
<tr>
<td>T(_3) (100 °C for 30 min)</td>
<td>544 d</td>
<td>444 c</td>
<td>13</td>
<td>61 abc</td>
<td>233 ef</td>
<td>767 bc</td>
</tr>
<tr>
<td>T(_4) (118 °C for 3 min)</td>
<td>518 e</td>
<td>431 c</td>
<td>51</td>
<td>62 abc</td>
<td>263 e</td>
<td>737 c</td>
</tr>
<tr>
<td>T(_5) (118 °C for 7 min)</td>
<td>486 f</td>
<td>473 c</td>
<td>42</td>
<td>74 ab</td>
<td>254 e</td>
<td>746 c</td>
</tr>
<tr>
<td>T(_6) (118 °C for 15 min)</td>
<td>412 g</td>
<td>588 b</td>
<td>0</td>
<td>44 abc</td>
<td>340 d</td>
<td>660 d</td>
</tr>
<tr>
<td>T(_7) (118 °C for 30 min)</td>
<td>381 h</td>
<td>614 b</td>
<td>5</td>
<td>45 abc</td>
<td>357 d</td>
<td>643 d</td>
</tr>
<tr>
<td>T(_8) (136 °C for 3 min)</td>
<td>342 l</td>
<td>632 b</td>
<td>26</td>
<td>40 abc</td>
<td>406 c</td>
<td>594 e</td>
</tr>
<tr>
<td>T(_9) (136 °C for 7 min)</td>
<td>309 j</td>
<td>690 a</td>
<td>0</td>
<td>29 bc</td>
<td>467 b</td>
<td>461 f</td>
</tr>
<tr>
<td>T(_10) (136 °C for 15 min)</td>
<td>313 l</td>
<td>687 a</td>
<td>0</td>
<td>17 c</td>
<td>534 a</td>
<td>466 g</td>
</tr>
<tr>
<td>SEM</td>
<td>5.9</td>
<td>12.2</td>
<td>12.2</td>
<td>9.1</td>
<td>10.9</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Means with the same letter in the same column are not significantly different (p > 0.05) by Student–Newman–Keuls test; SEM = standard error of mean.

Table 5. Rumen undegraded protein and rumen endogenous protein truly absorbed from the small intestine with faba beans

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RUP (g kg(^{-1})DM)</th>
<th>dRUP (g kg(^{-1})DM)</th>
<th>UCP (g kg(^{-1})DM)</th>
<th>ARUP (g kg(^{-1})DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>47.2 f</td>
<td>85.0</td>
<td>7.1 b</td>
<td>41.1 f</td>
</tr>
<tr>
<td>T(_1) (100 °C for 7 min)</td>
<td>48.7 f</td>
<td>87.9</td>
<td>5.9 b</td>
<td>42.7 f</td>
</tr>
<tr>
<td>T(_2) (100 °C for 15 min)</td>
<td>56.3 f</td>
<td>87.5</td>
<td>7.0 b</td>
<td>49.2 f</td>
</tr>
<tr>
<td>T(_3) (100 °C for 30 min)</td>
<td>65.4 e</td>
<td>89.6</td>
<td>6.8 b</td>
<td>58.6 e</td>
</tr>
<tr>
<td>T(_4) (118 °C for 3 min)</td>
<td>73.9 e</td>
<td>89.0</td>
<td>8.1 a</td>
<td>65.7 e</td>
</tr>
<tr>
<td>T(_5) (118 °C for 7 min)</td>
<td>71.2 e</td>
<td>90.4</td>
<td>8.6 a</td>
<td>64.4 e</td>
</tr>
<tr>
<td>T(_6) (118 °C for 15 min)</td>
<td>94.3 d</td>
<td>91.3</td>
<td>8.2 a</td>
<td>86.1 d</td>
</tr>
<tr>
<td>T(_7) (118 °C for 30 min)</td>
<td>99.0 d</td>
<td>91.4</td>
<td>8.5 a</td>
<td>90.4 d</td>
</tr>
<tr>
<td>T(_8) (136 °C for 3 min)</td>
<td>112.5 c</td>
<td>92.4</td>
<td>8.5 a</td>
<td>103.7 c</td>
</tr>
<tr>
<td>T(_9) (136 °C for 7 min)</td>
<td>128.8 b</td>
<td>93.4</td>
<td>8.5 a</td>
<td>120.3 b</td>
</tr>
<tr>
<td>T(_10) (136 °C for 15 min)</td>
<td>147.8 a</td>
<td>94.0</td>
<td>8.7 a</td>
<td>138.9 a</td>
</tr>
<tr>
<td>SEM</td>
<td>2.82</td>
<td>0.27</td>
<td>2.56</td>
<td></td>
</tr>
</tbody>
</table>

Means with the same letter in the same column are not significantly different (p > 0.05) by Student–Newman–Keuls test; SEM = standard error of mean.

DISCUSSION

Starch digestion

Little research has been done on the effect of heat treatment of legume seeds on the digestion of starch.\(^2\) Our data show that starch from faba beans is highly soluble and easily degradable. The purpose of heat treatment of starch in legume seeds is to reduce the degradation rate in the rumen and through this to manipulate the amounts degraded in the rumen and digested in the small intestine, which may benefit animals under certain circumstances. The mechanism for altering the rumen degradative behaviour of starch by heat treatment involves three processes: swelling, gelatinization and retrogradation.\(^15\) Goelema\(^16\) reported that swelling results from the exposure of starch to water when gradually heated to 55 °C. At temperatures below 60–80 °C, swelling is reversible after cooling and drying. Above that irreversible gelatinization takes place and starch granules lose their crystallinity.\(^17\) Retrogradation is the re-association of starch molecules separated after gelatinization, in which hydrogen bonding between amylose and amylopectin is re-established. Retrograded starch does not completely regain the native starch character, but changes can be reversed to some degree by reheating.\(^18\)

Few systematic studies were found on rumen starch degradation characteristics of legume seeds affected by heat treatment.\(^16\) In high-producing dairy cows, glucose can also be a limiting nutrient.\(^15,19\) Under such conditions productivity increases if a part of the dietary non-structural carbohydrate (starch) bypasses the reticulo-rumen. It is advantageous under such conditions to have more starch escape degradation in the rumen and provide a source of glucose in the small
Table 6. Protein degradation balance in the NRC system and total metabolizable protein supply to dairy cows of faba beans

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Protein degradation balance (PDB, g kg(^{-1}) DM)</th>
<th>Total metabolizable protein (MP, g kg(^{-1}) DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>89.9 ab</td>
<td>106.3 f</td>
</tr>
<tr>
<td>T(_1) (100°C for 7 min)</td>
<td>92.4 a</td>
<td>108.9 f</td>
</tr>
<tr>
<td>T(_2) (100°C for 15 min)</td>
<td>88.0 ab</td>
<td>115.5 f</td>
</tr>
<tr>
<td>T(_3) (100°C for 30 min)</td>
<td>80.0 abc</td>
<td>124.8 e</td>
</tr>
<tr>
<td>T(_4) (118°C for 3 min)</td>
<td>71.8 c</td>
<td>132.0 e</td>
</tr>
<tr>
<td>T(_5) (118°C for 7 min)</td>
<td>74.1 bc</td>
<td>130.6 e</td>
</tr>
<tr>
<td>T(_6) (118°C for 15 min)</td>
<td>50.7 d</td>
<td>152.3 d</td>
</tr>
<tr>
<td>T(_7) (118°C for 30 min)</td>
<td>46.7 d</td>
<td>156.7 d</td>
</tr>
<tr>
<td>T(_8) (136°C for 3 min)</td>
<td>33.6 e</td>
<td>169.9 c</td>
</tr>
<tr>
<td>T(_9) (136°C for 7 min)</td>
<td>18.3 f</td>
<td>186.5 b</td>
</tr>
<tr>
<td>T(_{10}) (136°C for 15 min)</td>
<td>2.0 b</td>
<td>205.1 a</td>
</tr>
<tr>
<td>SEM</td>
<td>3.71</td>
<td>2.56</td>
</tr>
</tbody>
</table>

Means with the same letter in the same column are not significantly different (p > 0.05) by Student–Newman–Keuls test; SEM = standard error of mean.

intestine\(^{15}\) to achieve higher milk production. Such an advantage may also apply for growing meat animals.\(^{20}\)

Protein digestion

Many attempts have been made to protect protein in grain legumes against rapid rumen degradation by treatments involving application of heat with or without moisture.\(^{2,16}\) The objective of heat treatment is to reduce rumen degradation of protein and increase RUP without adversely affecting total tract protein digestion. In other words, heat treatment may provide the means of shifting protein digestion to the small intestine to provide more dietary amino acids to the animal. In this way, under certain circumstances, it will benefit the animals. The pressure-toasting of faba beans decreased (p < 0.05) protein A fraction and increased the B fraction without increasing the C fraction. The treatments also decreased (p < 0.05) the degradation rate. Therefore, this would have increased RUP and reduced RDP (Table 3). Intestinal digestibility of RUP measured by the mobile nylon bag technique was unaffected by the treatments; therefore absorbed ARUP was increased (Table 5). However, undesirable effects of heat treatments through increasing rumen protein degradation have also been reported. Goelema et al\(^{21}\) reported that pelleting did not reduce but increased rumen degradation of protein in mixture of peas, lupins and faba beans. In terms of the rumen degradation characteristics identified above, pelleting significantly increased \(K_d\) (0.036 vs 0.1 h\(^{-1}\)) and decreased rumen undegradable fraction (647 vs 280 g kg\(^{-1}\)). Thus, pelleting would be expected to shift the site of digestion to the rumen rather than to the intestines.

Protein-degraded balance

The PDB value shows the balance or imbalance between microbial protein synthesis from available rumen degradable protein and potential energy (TDN) from anaerobic fermentation in the rumen. When the PDB value is positive, it indicates potential nitrogen loss from the rumen. When negative, microbial protein synthesis is likely to be impaired because of a shortage of nitrogen in the rumen. The optimal PDB value in a ration is therefore zero or slightly positive. This principle was described by Tamminga et al.\(^4\) The studies by Goelema\(^{16}\) and Yu et al\(^2\) showed that common legume seeds such as raw lupin seeds, peas and soybeans all had high PDB values (142, 88 and 186 g kg\(^{-1}\) DM, respectively), which indicated a potential imbalance between feed nitrogen degradation and utilization, and indicated a potentially large nitrogen loss from the rumen.

Pressure toasting reduced the PDB value as temperature and length of toasting increased as shown in Table 6. High positive PDB values in most treatments except 136°C for 15 min (PDB = 2.0 g kg\(^{-1}\) DM) for faba beans indicated that there were still large potential losses of nitrogen in the rumen. In other words, the treatments of 100°C for 7, 15 or 30 min, 118°C for 3, 7, 15 or 30 min and 136°C for 3 or 7 min were not sufficient to prevent nitrogen loss in the rumen if the heated faba beans were used as rumen-undegradable protein sources for high production ruminants. Pressure toasting at 136°C for 15 min might represent the optimal treatment range for faba beans in terms of achieving target values for potential high net absorbable protein in the small intestine while holding any nitrogen loss in the rumen to a low level.

CONCLUSIONS

Toasting faba beans was effective in increasing the total metabolizable protein reaching the intestine but did not cause the protein degradation balance to become negative. The increased total MP was due mainly to increased truly absorbed rumen-undegraded protein because the treatments did not impact on truly absorbed rumen endogenous protein and truly absorbed rumen synthesized microbial protein.

REFERENCES

6 CVB, Centraal Veevoeder Bureau (Central Bureau for Livestock Feeding), Voorlopig protocol voor in sacco pensincubatie voor het meten van eiwitbestedigheid, 14 November (1996).