# Ruminal Behavior of Protein and Starch Free Organic Matter of Lupinus Albus and Vicia Faba in Dairy Cows

**P. Yu*, B. J. Leury[1] and A. R. Egan[1]**

Department of Animal and Poultry Science. University of Saskatchewan. 51 Campus Drive Saskatoon. SK. S7N 5A8. Canada

**ABSTRACT :** Faba beans *(vicia faba)* (FB) and lupin seeds (*Lupinus Albus*) (LS) were dry roasted at three temperatures (110, 130, 150°C) for 15, 30 or 45 min to determine the effects of dry roasting on rumen degradation of crude protein and starch free organic matter ($^{PSF}$OM). Rumen degradation characteristics of $^{PSF}$OM were determined by the nylon bag incubation technique in dairy cows fed 60% hay and 40% concentrate. Measured characteristics of $^{PSF}$OM were undegradable fraction (U), degradable fraction (D), soluble fraction (S), lag time (T0), and the rate of degradation (Kd). Based on the measured characteristics, rumen availability (RA$^{PSF}$OM) and bypass $^{PSF}$OM (B$^{PSF}$OM) were calculated. Dry roasting did not have a greater impact on rumen degradation characteristics of $^{PSF}$OM ($p>0.05$). S varied from 32.1 (raw) to 30.0, 27.8, 30.8% (LS) and 15.4 (raw) to 14.4, 20.8, 20.9% (FB); D varied from 65.4 (raw) to 66.3, 66.9, 55.9% (LS) and 54.9 (raw) to 55.0, 51.0, 64.7% (FB); U varied from 2.6 (raw) to 7.3, 7.0, 7.7% (LS) and 29.7 (raw) to 30.6, 28.2, 14.4% (FB); Kd varied from 6.0 (raw) to 7.3, 7.0, 7.7% (LS) and 22.4 (raw) to 24.4, 21.1, 7.9% (FB); B$^{PSF}$OM varied from 35.5 (raw) to 33.8, 36.6, 38.2% (LS) and 41.3 (raw) to 41.5, 39.7, 47.6% (FB) at 110, 130 and 150°C, respectively. Therefore dry roasting did not significantly affect RA$^{PSF}$OM, which were 353.7, 367.9, 349.6, 336.9 (g/kg DM) (LS) and 12.82, 127.0, 133.7, 117.1 (g/kg DM) (FB) at 110, 130 and 150°C, respectively. These results alone with our previously published reports indicate dry roasting had the differently affected pattern of rumen degradation characteristics of various components in LS and FB. It strongly increased bypass crude protein (BCP) and moderately increased starch (BST) with increasing temperature and time but least affected $^{PSF}$OM. Such desirable degradation patterns in dry roasted LS and FB might be beneficial to the high yielding cows which could use more dry roasted $^{PSF}$OM as an energy source for microbial protein synthesized in the rumen and absorb more amino acids and glucose in the small intestine. ***(Asian-Aust. J. Anim. Sci. 2002. Vol 15, No. 7 : 974-981)***

**Key Words :** Legume Seeds, Dry Roasting, Rumen Degradation, Bypass Protein and Starch Free Organic Matter, Cows

## INTRODUCTION

Lupin seeds (*lupinus albus*) (LS) and Faba beans *(vicia faba)* (FB) are particularly high in crude protein (CP) (Yu et al., 1998a). FB contain high non-structural carbohydrate (Yu et al., 1998b) and is a good source of lysine but deficient in sulfur containing amino acids (S-AA) and tryptophan (Bailey and Boulter, 1970, 1972). They have attracted attention in recent years and appear to be the protein and (or) starch sources best suitable to the ecological and climatic condition of many countries (Yu et al., 1998a).

Despite the fact LS and FB have an attractive protein content. their use in dairy cow feeding is limited because 1) CP is degraded very rapidly in the rumen causing an imbalance between feed breakdown and microbial protein synthesis. resulting in unnecessary N-loss from the rumen (Tamminga and Jansman. 1993) and 2) FB starch is also fermented rapidly to cause little starch escape fermentation. and volatile fatty acids (VFA) are generated sufficiently rapidly to cause a decrease in ruminal pH. to levels at which cell wall degrading bacteria are inhibited (Tamminga. 1990; Yu et al., 2001). Therefore these seeds are not suitable to be used in an unprocessed form in ruminant diets.

Yu et al. (1998a. 1998b. 1999) reported that dry roasting could significantly decrease rumen degradation characteristics of CP and starch. It at 150°C/45 min increased rumen bypass feed protein (BCP) and starch (BST) nearly 4 times and over 2 times, respectively, over the raw FB (RFB). But Yu et al. (1998a, 1998b) did not report the effect of dry roasting on crude protein and starch free organic matter ($^{PSF}$OM). of which structural carbohydrates were quantitatively the predominant forms due to very low content of crude fat (CFat) (1-5%) (Yu et al., 1998b; Yu et al.. 1999).

For the dairy cows. carbohydrates are important precursors of energy yielding nutrients. At the same time. they are the main energy yielding substrates for the microbial population in the rumen. Finally they may play an important role in stabilizing or destablizing rumen fermentation (Tamminga et al.. 1990). The non-structural carbohydrates that escape from rumen degradation may be beneficial because they can be digested in the small intestine. This usually results in a reduced milk fat content and a somewhat enhanced milk protein content (Yu et al., 1998b. 2001). But escape of structural carbohydrates from

* Corresponding Author: P. Yu. Tel: +1-306-966-4150, Fax: +1-306-966-4151, E-mail: yupe@sask.usask.ca

[1] School of Agriculture and Food Systems, Institute of Land and Food Resources, University of Melbourne, Parkville, Victoria 3010, Australia.

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rumen is undesirable, because the rumen is by far the most important compartment where structural carbohydrates can be degraded. For the host animal structural carbohydrates, which are not degraded in the rumen, are largely bulk, which has to be spared from the intestinal tract at the expense of sloughing of intestinal cells, resulting in the loss of considerable amounts of endogenous protein (NRC, 1989).

Therefore, the desirable effects of dry roasting on LS and FB should be a maximum increase of BCP and BST but a minimum increase of $B^{PSF}OM$ (structural carbohydrates). The objective of this study was to investigate the effects of dry roasting on rumen degradation characteristics of $^{PSF}OM$ and rumen availability of $^{PSF}OM$ of LS and FB in order to provide data for determining the optimal dry roasting conditions for the dairy feed industry.

## MATERIAL AND METHODS

### Feedstuffs

Lupin seeds and FB were obtained from a commercial feed company (Peter Gibbs Stock Feeds, Australia). Minor contamination in LS and FB were soybean and peas, in all cases contributing less than 0.3%.

### Treatments of faba beans

Raw LS and RFB were dry roasted at 3 different temperatures (110, 130, 150°C) for 15, 30 and 45 min in a complete block design (LS) as shown in table 1.

The RLS and RFB were used as a control. For each treatment, about 1.5 kg RLS and RFB was roasted in a lab oven (Qualtex Solidstat, Universal Series 2000 designed in Australia by Watson Victor LTD). The conditions of processing are shown in table 1. After roasting, the samples were allowed to cool down to ambient temperature and were ground through a 3 mm screen (Hammer Mill AEG TYP AM80N×2).

### Animal and diet

Six dry Holstein Friesian cows, of average weight 620 kg, previously equipped with a rumen cannula with an internal diameter of 10 cm (Silicon rubbers, handmade, Kyabram Dairy Center, Victoria, Australia) for measuring rumen degradation characteristics, were kept at Kyabram Dairy Center (Victoria, Australia) in the feedlot.

All cows received a diet consisting of 3.5 kg/day commercial pelleted concentrate (Barastoc Hi-Lac-Hi-E Dairy Pellets, Ridley Agriproducts PTY. LTD. Australia), chemical analysis of which are 87.6% of DM, 12.0% of CP, 1.3% of non-protein N, 0.5% of urea, 2.0% of crude fat, 15.0% of crude fibre, 1.0% of salt, 0.02% of fluorine, 6,000 IU/kg of vitamin A and 500 IU/kg of vitamin D3, and 5.4 kg/day (83.7% DM) sub-clover hay purchased locally from Goulburn Valley (Victoria, Australia). Water was always available. The cows were individually fed twice daily at 08:00 and 16:00, 2.7 kg sub-clover and 1.75 kg pellets each time. The feeding level was according to the dairy cow requirements calculated by Rumnut 3.3 (Dept. of Agriculture, Reading University, UK). A 12 day period of adaptation was allowed.

### *In sacco* rumen incubation

Rumen degradation characteristics of $^{PSF}OM$ were determined by Dutch standard *in sacco* method (CVB, 1996). For all treatment, incubation in the rumen was with 5 g DM in nylon bags (10 cm×17 cm) with the pore size of approximately 44 μm (Switzerland 1807710014-I-044 Nytal ASTM 325-44) as described by Tamminga et al. (1990). The rumen incubations were performed according to the 'gradual addition/all out' schedule. Incubations were carried out for 24, 12, 8, 4 and 2 h; bags were inserted at 21:00, (next day) 09:00, 13:00, 17:00 and 19:00 and removed at 21:00 h respectively. The 48 h rumen incubation was carried out from 21:00 till 21:00 two days later. All treatments were randomly allocated over all cows and the whole incubation period.

**Table 1.** Treatments and the dry roasting conditions of faba beans (*Vicia faba*) and lupin seeds (*Lupinus albus*)

| Treatment | | Vicia faba | | Lupinus albus (A) | | Lupinus albus (B) | |
|---|---|---|---|---|---|---|---|
| Temp. (°C) | Time (min) | Temp. (°C) | SD | Temp. (°C) | SD | Temp. (°C) | SD |
| | | Raw (control) | | Raw (control A) | | Raw (control B) | |
| 110 | 15 | 110.0 | 0.0 | 110.0 | 1.0 | 111.0 | 1.0 |
| 110 | 30 | 111.3 | 1.2 | 109.5 | 0.5 | 111.0 | 0.0 |
| 110 | 45 | 110.9 | 1.6 | 109.5 | 0.5 | 111.0 | 1.0 |
| 130 | 15 | 130.0 | 0.0 | 129.5 | 0.5 | 130.0 | 0.0 |
| 130 | 30 | 129.8 | 0.5 | 130.0 | 0.0 | 130.5 | 0.5 |
| 130 | 45 | 130.0 | 0.0 | 131.0 | 1.0 | 130.5 | 0.5 |
| 150 | 15 | 149.5 | 0.7 | 150.0 | 0.0 | 150.0 | 0.0 |
| 150 | 30 | 150.0 | 0.0 | 149.5 | 0.5 | 150.0 | 0.0 |
| 150 | 45 | 150.0 | 0.0 | 149.5 | 0.5 | 150.0 | 0.0 |

SD: Standard deviation.

After incubation, the bags containing the residues were rinsed under a cold stream of tap water to remove excess ruminal contents and microbes on the surface to stop microbial activity, washed with cool water without detergent in a commercial washing machine (Fisher and Paykel, Smart Drive 500) for 55 min without spinning and subsequently dried at 60°C for 24 h in an oven, air equilibrated and weighed. The 0 h incubation samples were only put in the washing machine under the same conditions. Residues from the bags were pooled within time and treatment. Samples were stored in a cool room (4°C) until analysis. The residue was ground through a 1 mm screen and analyzed for chemical composition.

**Chemical analysis and calculations**

*Analysis procedures* : Feed and rumen residues were analyzed for DM, ash, N, starch. DM was determined by drying at 105°C to constant weight. Ash was determined by ashing at 550°C to constant weight. N was analyzed by NCS instruments (NA 1500 NCS FISONS), and CP content was deduced by N×6.25. Starch in FB was determined according to the AGS-DG method (Brunt, 1992). No starch in LS was determined due to little starch content (<1%). Crude fat (CFat) of feed was analyzed according to the AOAC (1984). $^{PSF}$OM was calculated as: $^{PSF}$OM=OM-CP-starch (g/kg DM).

*Treatments of results* : For analysis of rumen degradation characteristics of $^{PSF}$OM, the important degradation characteristics in the rumen were:

1. The fraction which was not degraded (U) irrespective of time it was incubated in the rumen;
2. The soluble (washable) fraction (S);
3. The degradable fraction (D);
4. The fractional rate of degradation (Kd) of the fraction D (Tamminga et al., 1990).
5. The lag time (T0 in h) in which no degradation takes place.

From the nylon bag incubation studies it become apparent that part of $^{PSF}$OM did not disappear from the bags. The proportion (S) was considered to be degraded instantaneously and completely. The proportion (U) was considered to be undegradable, which was estimated from the degradation curve. The remaining proportion was termed D and can be calculated as 100-U-D. The fractional rate of degradation of D was called Kd. Results of nylon bags incubations were therefore fitted though iterative least square regression by Gauess-Newton method (SAS, 1991) by the following equations (Tamminga et al., 1990): For $^{PSF}$OM: $R(t)=U+D\times\exp^{-Kd\times(t-T0)}$, where, R(t)=residue at time t; T0=lag phase in h in which no degradation took place.

Based on the residues after rumen incubation the rumen availability (RA$^{PSF}$OM) and bypass (B$^{PSF}$OM) amount of $^{PSF}$OM were calculated using the method of Ørskov and McDonald (1979) and the new Dutch protein evaluation system (Tamminga et al., 1994). Percentages of B$^{PSF}$OM (%B$^{PSF}$OM) and %RA$^{PSF}$OM were calculated as: %B$^{PSF}$OM=U+D×Kp/(Kp+Kd); %RA$^{PSF}$OM=100-%B$^{PSF}$OM. B$^{PSF}$OM and RA$^{PSF}$OM in g/kg DM were calculated as: B$^{PSF}$OM=1.11×$^{PSF}$OM×%B$^{PSF}$OM/100; RA$^{PSF}$OM=$^{PSF}$OM-B$^{PSF}$OM, where, passage rates (Kp) of 2.5% /h was adopted; The factor 1.11 in the formula was taken from the French PDI-system, the regression coefficient of *in vivo* on *in sacco* degradation data.

The Ratios of BDM, BCP, BST and B$^{PSF}$OM were calculated as:

1. BDM Ratio=dry roasted treatment %BDM/raw %BDM;
1. BCP Ratio=dry roasted treatment %BCP/raw %BCP;
2. BST Ratio=dry roasted treatment %BST/raw %BST and
3. B$^{PSF}$OM Ratio=dry roasted treatment %B$^{PSF}$OM/raw % %B$^{PSF}$OM.

**Statistical analysis**

Statistical analysis was carried out using the statistical package SAS (1991). Analysis of variance was carried out using Proc GLM (SAS, 1991) using following model:

$$Y_{ij}=m+Temp_i+Time_j+Temp\times Time_{ij}+e_{ij}$$

where: Y=degraded fraction; i=1,2,3,4; j=1,2,3,4

Comparison of temperature effect or time effect on degradation characteristics were carried out by Tukey's Studentized Range Test (HSD or Tukey Test).

Due to the limited research sources available at the beginning of the study, rumen degradation characteristics of FB were determined only on one series of dry roasted FB. Therefore, using NLIN procedure by SAS (1991) of iterative least squares regression to run the first order kinetic degradation model, each treatment had only yielded one estimated NLIN parameter of rumen degradation characteristics (U, D, S, T0, Kd etc.). Statistical analysis was determined only on the effect of temperature and time on rumen degradation characteristics.

## RESULTS

**Chemical composition**

The chemical compositions of raw and dry roasted LS and FB are presented in table 2. Both RLS and RFB were particularly high in CP content: 386.5 vs. 317.3 g/kg DM, respectively. RFB were also very high in starch content at 411.0 g/kg DM. LS had a higher content of CFat (53.9 vs. 20.4 g/kg DM) and a lower ash content (27.3 vs. 34.7 g/kg DM) than RFB. It is obvious that dry roasting increased DM (LS: 921.3 to 933.7 g/kg DM; FB: 885.9 to 941.0 g/kg DM) and decreased CFat contents (LS: 53.9 to 41.7 g/kg

**Table 2.** Chemical composition of raw and dry roasted lupin seeds (*Lupinus albus*) and faba beans (*Vicia faba*)

| Temp (°C) | Raw | 110 | | | 130 | | | 150 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (Min) | | 15 | 30 | 45 | 15 | 30 | 45 | 15 | 30 | 45 |
| Lupins (*Lupinus albus*) | | | | | | | | | | |
| DM (g/kg) | 921.26 | 920.95 | 930.40 | 933.15 | 928.77 | 927.78 | 931.92 | 932.98 | 935.06 | 933.72 |
| Ash (g/kg DM) | 27.25 | 28.32 | 26.21 | 27.53 | 29.40 | 26.78 | 26.88 | 28.30 | 26.15 | 25.84 |
| OM (g/kg DM) | 972.75 | 971.69 | 973.79 | 972.48 | 970.61 | 973.22 | 973.13 | 971.70 | 973.86 | 974.16 |
| CP (g/kg DM) | 386.53 | 387.88 | 380.69 | 377.25 | 379.76 | 384.97 | 380.07 | 392.35 | 384.97 | 386.04 |
| CFat (g/kg DM) | 53.88 | 53.21 | 53.13 | 50.68 | 49.68 | 48.43 | 45.33 | 44.06 | 43.90 | 41.68 |
| Faba beans (*Vicia faba*) | | | | | | | | | | |
| DM (g/kg) | 885.90 | 895.60 | 900.70 | 910.20 | 919.00 | 920.60 | 923.40 | 924.10 | 935.30 | 941.00 |
| Ash (g/kg DM) | 34.77 | 34.17 | 33.75 | 33.40 | 33.73 | 34.22 | 34.33 | 35.28 | 34.00 | 34.22 |
| OM (g/kg DM) | 965.23 | 965.83 | 966.25 | 966.60 | 966.27 | 965.78 | 965.67 | 964.72 | 966.00 | 965.78 |
| CP (g/kg DM) | 317.33 | 317.45 | 319.89 | 318.82 | 323.04 | 324.25 | 318.19 | 322.00 | 320.35 | 310.37 |
| CFat (g/kg DM) | 20.42 | 19.87 | 18.67 | 17.12 | 18.20 | 16.34 | 15.98 | 16.24 | 14.57 | 13.98 |
| Starch (g/kg DM) | 410.99 | 415.14 | 412.12 | 420.46 | 404.46 | 402.13 | 407.73 | 401.15 | 395.06 | 400.74 |

Note: No starch analysis for LS due to very little starch content in LS (<1%).

DM; FB: 20.4 to 14.0 g/kg DM) with increasing temperature and time. However, it did not alter CP, ash and starch content on the basis of dry matter.

### Rumen degradation characteristics of $^{PSF}$OM

The effects of dry roasting on rumen degradation characteristics of $^{PSF}$OM in LS are presented in table 3. The $^{PSF}$OM degradation characteristics of RLS were 32.1% of S, 65.4% of D, 6.0%/h of Kd, 2.6% of U, which resulted in 64.5% of $^{PSF}$OM rumen availability thus 35.5% of B $^{PSF}$OM. There is no significant effects of roasting temperature and time interaction on all rumen degradation characteristics of $^{PSF}$OM (S, D, U, To, Kd, B$^{PSF}$OM, RA$^{PSF}$OM) (table 3). Dry roasting time also had no significant effect on any of parameters of rumen degradation characteristics of $^{PSF}$OM ($p>0.05$). Dry roasting temperature had no significant effects on S, T0, Kd and %B $^{PSF}$OM ($p>0.05$) but not on D and U ($p<0.05$). U varied from 2.6 (raw) to 3.8, 5.4 and 13.4%; D varied from 65.4 (raw) to 66.3, 66.9 and 55.9, at 110, 130 and 150°C, respectively. Dry roasting did not significantly affect the estimate of RA$^{PSF}$OM ($p>0.05$) with averaging 353.7, 367.9, 349.6, 336.9 g/kg DM for raw, 110, 130 and 150°C group, respectively.

The effects of dry roasting on rumen degradation characteristics of $^{PSF}$OM in FB are presented in table 4. The $^{PSF}$OM degradation characteristics of RFB were low value for S (15.4 %), high value for D (54.9%), Kd (22.4%/h) and U (29.7%), which resulted in an estimated 58.7% of RA $^{PSF}$OM. Dry roasting temperature had no significant effects on S, D, U and B$^{PSF}$OM ($p>0.05$) except Kd value, which was decreased ($p<0.05$) from 22.4 (raw), 24.4, 21.1 to 7.9%/h at 110, 130 and 150°C, respectively. Dry roasting time had no significant effects on all parameters of rumen degradation characteristics of $^{PSF}$OM ($p>0.05$). RA$^{PSF}$OM as an energy source for microbial protein synthesis in the rumen varied from 128.2 in the raw to 127.0, 133.7, 117.1 g/kg DM at 110, 130 and 150°C, respectively. Generally dry roasting had little effects on rumen degradation characteristics of $^{PSF}$OM for both LS and FB.

### Ratio of BDM, BCP, BST and B$^{PSF}$OM

Results of effects of dry roasting on the amounts and the ratios of BDM, BCP, BST and B$^{PSF}$OM are presented in table 5. It is obvious that dry roasting had different effects on different components (CP, starch and $^{PSF}$OM) in LS and FB. It had strong effects on CP, moderate effects on starch and least effects on $^{PSF}$OM. Compared with the raw, the treatment of 150°C/45 min increased BCP, BST and B$^{PSF}$OM in FB nearly 3.8, 2.1 and 1.5 times, respectively, and increase BCP, B$^{PSF}$OM in LS nearly 2.3 and 1.1 times, respectively.

## DISCUSSION

### Rumen degradation model of structural carbohydrate

There are various models to describe rumen degradation characteristics of feed components such as biological or mathematical models. The mathematical models (Sauvant et al., 1985) are less popular because their biological interpretation is often difficult although they may be more accurate in fitting the data. The most widely used model is a first order kinetics equation. Methods used to solve such an equation include non-linear iterative least square regression, least square regression of logarithmic-transformed residuals with or without correction for an estimated or measured ruminally undegraded residue, curve peeling (Tamminga et al., 1990).

In models used to describe the rumen degradation of structural carbohydrate in a biological sense, the number of pools usually varies between 1 and 3. Rate of degradation

**Table 3.** Effect of dry roasting on rumen degradation characteristics of PSFOM in lupin seeds (*Lupinus albus*)

| Temp. (°C) | Raw | 110 | | | 130 | | | 150 | | | SEM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time (min) | | 15 | 30 | 45 | 15 | 30 | 45 | 15 | 30 | 45 | |
| Chemical composition | | | | | | | | | | | |
| $^{PSF}$OM (g/kg DM) | 583.89 | 581.39 | 591.14 | 593.26 | 588.60 | 586.17 | 591.10 | 577.33 | 589.99 | 586.30 | 5.89 |
| S (%) | 32.06 | 24.93 | 31.69 | 33.29 | 31.81 | 29.03 | 22.50 | 31.21 | 30.67 | 30.37 | 3.00 |
| D (%) | 65.39 | 69.82 | 63.63 | 65.04 | 63.71 | 67.59 | 69.29 | 51.73 | 58.41 | 57.48 | 4.50 |
| Kd (%/h) | 5.99 | 7.33 | 7.17 | 7.04 | 7.83 | 5.25 | 7.97 | 8.66 | 6.61 | 7.95 | 0.74 |
| U (%) | $2.55^{ab}$ | $5.26^{ab}$ | $4.69^{ab}$ | $1.32^{ab}$ | $4.49^{ab}$ | $3.39^{ab}$ | $8.21^{ab}$ | $17.07^{a}$ | $10.92^{ab}$ | $12.15^{ab}$ | 2.79 |
| T0 (h) | 1.81 | 0.81 | 1.52 | 1.81 | 2.18 | 0.36 | 0.67 | 3.28 | 1.66 | 1.98 | 0.71 |
| %B$^{PSF}$OM | 35.48 | 36.65 | 33.70 | 31.05 | 32.31 | 39.45 | 38.04 | 38.50 | 39.06 | 39.95 | 1.64 |
| %RA$^{PSF}$OM | 64.52 | 63.35 | 66.30 | 68.95 | 67.69 | 60.55 | 61.96 | 61.50 | 60.94 | 60.05 | 1.64 |
| B$^{PSF}$OM (g/kg DM) | 230.16 | 236.46 | 221.32 | 204.42 | 211.05 | 256.56 | 249.34 | 246.70 | 255.78 | 240.45 | 10.9 |
| RA$^{PSF}$OM (g/kg DM) | 353.73 | 344.93 | 369.82 | 388.84 | 377.55 | 329.61 | 341.76 | 330.63 | 334.21 | 345.85 | 13.1 |
| Dry roasting temperature effect | | | 110°C | | | 130°C | | | 150°C | | |
| Mean S (SD) | | | 29.97 (±5.05) | | | 27.78 (±5.08) | | | 30.75 (±4.33) | | |
| Mean D (SD) | | | 66.28 (±4.82) | | | 66.86 (±3.68) | | | 55.87 (±8.26) | | |
| Mean Kd (SD) | | | 7.25 (±0.48) | | | 7.01 (±1.54) | | | 7.74 (±1.38) | | |
| Mean U (SD) | | | 3.75 (±2.40) | | | 5.36 (±3.66) | | | 13.38 (±5.37) | | |
| Mean T0 (SD) | | | 1.38 (±0.71) | | | 1.07 (±1.03) | | | 2.30 (±1.40) | | |
| Mean % B$^{PSF}$OM (SD) | | | 33.80 (±3.03) | | | 36.60 (±3.78) | | | 38.17 (±1.02) | | |
| Mean %RA$^{PSF}$OM (SD) | | | 66.20 (±3.03) | | | 63.40 (±3.78) | | | 60.83 (±1.02) | | |
| Mean B$^{PSF}$OM (SD) | | | 220.73 (±16.03) | | | 238.98 (±24.46) | | | 247.64 (±7.71) | | |
| Mean RA$^{PSF}$OM (SD) | | | 367.86 (±22.02) | | | 349.64 (±24.92) | | | 336.90 (±7.96) | | |
| Dry roasting time effect | | | 15 min | | | 30 min | | | 45 min | | |
| Mean S (SD) | | | 29.32 (±5.95) | | | 30.46 (±2.69) | | | 28.72 (±5.59) | | |
| Mean D (SD) | | | 61.75 (±11.79) | | | 63.21 (±4.61) | | | 64.06 (±5.78) | | |
| Mean Kd (SD) | | | 7.94 (±0.90) | | | 6.34 (±1.32) | | | 7.72 (±0.70) | | |
| Mean U (SD) | | | 8.94 (±7.43) | | | 6.33 (±4.39) | | | 7.23 (±5.76) | | |
| Mean T0 (SD) | | | 2.09 (±1.72) | | | 1.18 (±0.70) | | | 1.48 (±0.75) | | |
| Mean % B$^{PSF}$OM (SD) | | | 35.82 (±3.07) | | | 37.40 (±3.22) | | | 63.65 (±4.69) | | |
| Mean %RA$^{SF}$OM (SD) | | | 64.18 (±3.18) | | | 62.60 (±3.21) | | | 35.34 (±3.86) | | |
| Mean B$^{PSF}$OM (SD) | | | 231.40 (±17.79) | | | 244.55 (±21.22) | | | 231.39 (±23.67) | | |
| Mean RA$^{SF}$OM (SD) | | | 351.04 (±24.05) | | | 344.55 (±22.01) | | | 358.82 (±26.08) | | |

| Statistical analysis | S | Kd | U | T0 | % B$^{PSF}$OM | %RA$^{SF}$OM | B$^{PSF}$OM | RA$^{SF}$OM |
|---|---|---|---|---|---|---|---|---|
| Series | 0.34 | 0.71 | 0.26 | 0.11 | 0.87 | 0.87 | 0.57 | 0.61 |
| Temp. | 0.48 | 0.54 | 0.004 | 0.10 | 0.07 | 0.07 | 0.06 | 0.08 |
| Time | 0.78 | 0.07 | 0.52 | 0.27 | 0.36 | 0.36 | 0.30 | 0.45 |
| Temp×Time | 0.15 | 0.47 | 0.42 | 0.27 | 0.06 | 0.06 | 0.08 | 0.11 |

Notes: SD: Standard deviation; Means with different letters in the same row are significantly different by Tukey's Studentized Range (HSD) Test, Alpha=0.05.

may be assumed constant per pool or variable and the model may or may not contain a discrete lag phase (Tamminga et al., 1990). In a comparison of a number of biological models, Robinson et al. (1986) showed the degradation of structural carbohydrates can often be described quite adequately by a first order kinetics equation with two fractions, one degradable and one undegradable. They also showed that for some ingredients rumen degradation of structural carbohydrates could be described more accurately by assuming 3 discrete fractions, one rapidly degradable, one slowly degradable and one undegradable. In present study, degradation of $^{PSF}$OM, of which structural carbohydrates were predominant, was described by a first order kinetics equation with three fractions of rapidly degradable, slowly degradable and undegradable fractions due to that the measuring number was high enough to make a distinction of three fractions, one rapidly degradable, one slowly degradable and undegradable fraction in the model.

**Table 4.** Effect of dry roasting on rumen degradation characteristics of $^{PSF}$OM in faba beans (*Vicia faba*)

| Temp. (°C) | Raw | 110 | | | 130 | | | 150 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (min) | | 15 | 30 | 45 | 15 | 30 | 45 | 15 | 30 | 45 |
| Chemical composition | | | | | | | | | | |
| $^{PSF}$OM (g/kg DM) | 236.93 | 233.25 | 234.26 | 227.31 | 238.74 | 239.41 | 239.77 | 241.64 | 250.61 | 254.62 |
| Rumen degradation characteristics of $^{PSF}$OM | | | | | | | | | | |
| S (%) | 15.38 | 16.23 | 14.98 | 11.95 | 21.73 | 24.80 | 15.99 | 23.48 | 14.62 | 24.68 |
| D (%) | 54.90 | 53.42 | 53.64 | 58.02 | 49.57 | 45.30 | 58.16 | 51.88 | 66.85 | 75.32 |
| Kd (%/h) | 22.37 | 22.76 | 24.69 | 25.78 | 23.53 | 23.10 | 16.62 | 13.12 | 8.28 | 2.18 |
| U (%) | 29.72 | 30.35 | 31.38 | 30.03 | 28.70 | 29.90 | 25.85 | 24.64 | 18.53 | 0.00 |
| T0 (h) | 2.67 | 2.64 | 2.20 | 3.02 | 3.75 | 3.71 | 1.98 | 1.94 | 1.29 | 0.00 |
| %B$^{PSF}$OM | 41.33 | 41.49 | 41.87 | 40.99 | 38.44 | 39.24 | 41.28 | 40.92 | 46.72 | 55.25 |
| RA$^{SF}$OM (%) | 58.67 | 58.51 | 58.13 | 59.01 | 61.56 | 60.76 | 58.72 | 59.08 | 53.28 | 44.75 |
| B$^{PSF}$OM (kg/kg DM) | 108.70 | 107.45 | 108.87 | 103.42 | 102.75 | 104.28 | 109.85 | 109.76 | 129.68 | 156.16 |
| RA$^{SF}$OM (g/kg DM) | 128.23 | 125.80 | 125.39 | 129.89 | 135.99 | 135.13 | 129.92 | 131.88 | 120.93 | 98.46 |
| Dry roasting temperature effect | | 110°C | | | 130°C | | | 150°C | | |
| Mean S (SD) | | 14.39 (±2.20) | | | 20.84 (±4.47) | | | 20.93 (±5.49) | | |
| Mean D (SD) | | 55.03 (±2.59) | | | 51.01 (±6.55) | | | 64.68 (±11.87) | | |
| Mean Kd (SD) | | 24.41 (±1.53) | | | 21.08 (±3.87) | | | 7.86 (±5.48) | | |
| Mean U (SD) | | 30.58 (±0.71) | | | 28.15 (±2.08) | | | 14.39 (±12.83) | | |
| Mean T0 (SD) | | 2.62 (±0.41) | | | 3.15 (±1.01) | | | 1.08 (±0.99) | | |
| Mean % B$^{PSF}$OM (SD) | | 41.45 (±0.44) | | | 39.65 (±1.46) | | | 47.63 (±7.21) | | |
| Mean %RA$^{SF}$OM (SD) | | 58.55 (±0.44) | | | 60.35 (±1.46) | | | 52.37 (±7.21) | | |
| Mean B$^{PSF}$OM (SD) | | 106.58 (±2.83) | | | 105.63 (±3.74) | | | 131.87 (±23.28) | | |
| Mean RA$^{SF}$OM (SD) | | 127.03 (±2.49) | | | 133.68 (±3.28) | | | 117.09 (±17.04) | | |
| Dry roasting time effect | | 15 min | | | 30 min | | | 45 min | | |
| Mean S (SD) | | 20.48 (±3.78) | | | 18.13 (±5.78) | | | 17.54 (±6.51) | | |
| Mean D (SD) | | 51.62 (±1.94) | | | 55.26 (±10.87) | | | 63.83 (±9.95) | | |
| Mean Kd (SD) | | 19.80 (±5.80) | | | 18.69 (±9.05) | | | 14.86 (±11.90) | | |
| Mean U (SD) | | 27.90 (±2.94) | | | 26.60 (±7.03) | | | 18.63 (±16.27) | | |
| Mean T0 (SD) | | 2.78 (±0.91) | | | 2.40 (±1.22) | | | 1.67 (±1.53) | | |
| Mean % B$^{PSF}$OM (SD) | | 40.28 (±1.62) | | | 42.61 (±3.79) | | | 45.84 (±8.15) | | |
| Mean %RA$^{SF}$OM (SD) | | 59.72 (±1.62) | | | 57.39 (±3.79) | | | 54.16 (±8.15) | | |
| Mean B$^{PSF}$OM (SD) | | 106.65 (±3.57) | | | 114.28 (±13.54) | | | 123.14 (±28.77) | | |
| Mean RA$^{SF}$OM (SD) | | 131.22 (±5.13) | | | 127.15 (±7.26) | | | 119.42 (±18.15) | | |

| Statistical analysis | P values | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | S | D | Kd | U | T0 | %B$^{PSF}$OM | %RA$^{F}$OM | B$^{PSF}$OM | RA$^{F}$OM |
| Temp. | 0.28 | 0.11 | 0.01 | 0.08 | 0.07 | 0.14 | 0.14 | 0.13 | 0.19 |
| Time | 0.75 | 0.15 | 0.33 | 0.31 | 0.31 | 0.32 | 0.32 | 0.32 | 0.46 |

Notes: SD: Standard deviation.

**Degradation characteristics of structural carbohydrates**

Rumen availability of $^{PSF}$OM, (of which structural carbohydrates were predominant with the monomers linked together by β-1, 6 glycosidic linkages), the important component of LS and FB's nutrition values in dairy cow, was a function of Kd and D or U fractions. RLS had a low degradation rate (6.0%/h), 1.8 h lag time, low undegradable fraction (2.6%), high rapidly degradable (32.1%) and slowly degradable fraction (65.4%), which all contributed to 64.5% or 353.7 g/kg DM of $^{PSF}$OM fermented in the rumen and 35.5% or 230.2 g/kg DM of $^{PSF}$OM bypassed into the small intestines. RFB had a very high degradation rate (22.4%/h), 2.7 h lag time, high undegradable fraction (29.7%), low rapidly degradable (15.4%) and slowly degradable fraction (54.9%), which all contributed to 58.6% or 128.3 g/kg DM of $^{PSF}$OM fermented in the rumen and 41.3% or 108.7 g/kg DM of $^{PSF}$OM bypassed into the small intestines. Tamminga et al. (1990) reported that rumen degradation characteristics of cell walls in raw beans were 20% undegradable, 4.0 h lag phase, 15%/h degradation rate and 80% degradable fractions, which resulted in 62% structural carbohydrates fermented in the rumen. Those

**Table 5.** The contents and ratios of BDM, BCP, BST and $B^{PSF}OM$ of lupin seeds (*Lupinus albus*) and faba beans (*Vicia faba*)

| Temp. (°C) | Raw | 110 | | | 130 | | | 150 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time (min) | | 15 | 30 | 45 | 15 | 30 | 45 | 15 | 30 | 45 |
| Lupin seeds (*Lupinus albus*) | | | | | | | | | | |
| Rumen bypass fraction of feed components | | | | | | | | | | |
| %BDM | 32.11 | 32.09 | 30.91 | 28.76 | 30.32 | 36.53 | 35.19 | 37.95 | 44.44 | 47.21 |
| %BCP | 25.90 | 26.70 | 27.49 | 25.44 | 27.54 | 33.03 | 31.76 | 37.83 | 52.74 | 60.96 |
| %$B^{PSF}OM$ | 35.48 | 36.65 | 33.70 | 31.05 | 32.31 | 39.45 | 38.04 | 38.50 | 39.06 | 39.95 |
| Ratios of BDM, BCP and $B^{PSF}OM$ | | | | | | | | | | |
| BDM ratio | 1.00 | 1.00 | 0.96 | 0.90 | 0.94 | 1.14 | 1.10 | 1.18 | 1.38 | 1.47 |
| BCP ratio | 1.00 | 1.03 | 1.06 | 0.98 | 1.03 | 1.24 | 1.18 | 1.42 | 1.98 | 2.28 |
| $B^{PSF}OM$ ratio | 1.00 | 1.03 | 0.95 | 0.88 | 0.91 | 1.11 | 1.07 | 1.09 | 1.10 | 1.13 |
| Faba beans (*Vicia faba*) | | | | | | | | | | |
| Rumen bypass fraction of feed components | | | | | | | | | | |
| %BDM | 18.56 | 18.35 | 18.26 | 18.30 | 20.78 | 21.09 | 23.70 | 24.91 | 30.76 | 43.06 |
| %BCP | 11.33 | 8.88 | 9.16 | 9.91 | 12.53 | 12.76 | 15.91 | 16.93 | 23.50 | 43.08 |
| %BST | 23.94 | 22.86 | 22.18 | 22.07 | 25.65 | 26.32 | 29.11 | 31.63 | 36.79 | 49.90 |
| %$B^{PSF}OM$ | 41.33 | 41.49 | 41.87 | 40.99 | 38.44 | 39.24 | 41.28 | 40.92 | 46.72 | 55.25 |
| Ratios of BDM, BCP, BST and $B^{PSF}OM$ | | | | | | | | | | |
| BDM ratio | 1.00 | 0.99 | 0.98 | 0.99 | 1.12 | 1.14 | 1.28 | 1.34 | 1.66 | 2.32 |
| BCP ratio | 1.00 | 0.78 | 0.81 | 0.87 | 1.11 | 1.13 | 1.40 | 1.49 | 2.07 | 3.80 |
| BST ratio | 1.00 | 0.95 | 0.93 | 0.92 | 1.07 | 1.10 | 1.22 | 1.32 | 1.54 | 2.08 |
| $B^{PSF}OM$ ratio | 1.00 | 1.00 | 1.01 | 0.99 | 0.94 | 0.95 | 1.00 | 0.99 | 1.13 | 1.34 |

Notes: a: Yu et al., 1998a; b: Yu et al., 1998b; Yu et al., 1999; Yu et al., 2001. BDM ratio=Treatment %BDM/ raw %BDM; BCP ratio= Treatment %BCP/raw %BCP; BST ratio=Treatment %BST/raw BST; $B^{PSF}OM$ ratio=Treatment %$B^{PSF}OM$/raw %$B^{PSF}OM$.

results were quite close to those of FB obtained in the present study.

Dry roasting at 110, 130 and 150°C for 15, 30 and 45 min had no significant effect ($p>0.05$) on rumen degradation characteristics of $^{PSF}OM$ in terms of $B^{PSF}OM$ and $RA^{PSF}OM$. This means that the amount of energy, which could be extracted by rumen microbes, was similar between treatments. These results were desirable because the rumen is by far the most important compartment where structural carbohydrate can be degraded. If not degraded in the rumen, structural carbohydrates are largely bulk which results the considerable loss of amounts of endogenous protein (NRC, 1989).

The ratios results showed that CP, starch and $^{PSF}OM$ had different susceptibility to dry roasting (Yu et al., 1999; Yu et al., 2001). CP and starch had more sensitivity to heating than $^{PSF}OM$. For example, dry roasting at 150° for 45 min increased BCP in FB nearly 4 times, starch over 2 times and $B^{PSF}OM$ only nearly 1.5 times (table 5). The results indicated that dry roasting had the differently affected patterns of rumen degradation characteristics with regard to different components in seeds. It strongly increased BCP and moderately increased BST with increasing temperature and time but least affected $^{PSF}OM$. Such results confirmed the report by De Visser (1980) that ruminal behaviour between non-structural carbohydrates like starch and sugars and structural carbohydrates like crude fibre are different. Such rumen degradation pattern of increasing more BST as glucose source and more BCP as amino acids source in the small intestines and little affecting $^{PSF}OM$ were quite desirable and might be beneficial to highly yielding dairy cows which both amino acids and glucose are usually limiting nutrients in the small intestines.

## REFERENCES

AOAC. 1984. Association of official analytical chemists, Official Methods of Analysis. Washington DC.

Bailey, C. J. and D. Boulter. 1970. The structure of legumine, a storage protein of broad beans (*Vicia faba*) seed. Eur. J. Biochem. 17:460.

Bailey, C. J. and D. Boulter. 1972. The structure of vicilin of Vicia faba. PhytoChemistry 11:59.

Brunt, K. 1992. Enzymatische bepaling van het gahalte aan zetmeel in veevoeder en veevoedergrondstoffen (concept). Netherlands Instituut Voor Koolhydraten Onderzoek (NIKO), memo, pp. 92-115.

CVB. 1996. Centraal Veevoeder Bureau. 1996. Voorlopig protocol voor *in sacco* pensincubatie voor het meten van eiwitbestendigheid.

De Visser, H. 1980. Effect of the percentage of starch and sugars in cattle feeds on feed consumption and its consequences for milk production. Bedrijfsontwikkeling. Den Haag, Ministerie van Landbouw en Visserij. 11(11):1041-1047.

NRC. 1989. Nutrient requirements of dairy cattle. National Research Council. Washington. USA. p. 157.

Ørskov, E. R. and I. McDonald. 1979 The estimation of protein degradability in the rumen from incubation measurements weighted according to the rate of passage. J. Agric. Sci. Cambridge. 92:499-503.

Robinson, P. H., J. G. Fadel and S. Tamminga. 1986. Evaluation of mathematical models to describe neutral detergent residue in terms of its susceptibility to degredation in the rumen. Anim. Feed Sci. Technol. 15:249-271.

SAS. 1991. User's Guide: Statistics, Version 6 Edition. SAS Inst., Inc., Cary, NC.

Sauvant, D., D. Bettrand and S. Giger. 1985. Variations and precision of the *in sacco* dry matter digestion of concentrates and by-products. Anim. Feed Sci. Technol. 13:7-23.

Tamminga, S. and A. J. M. Jansman. 1993. Animal nutrition (Ed. B. A. Williams). Dept. of Animal Nutrition, Wageningan Agriculture University, The Netherlands.

Tamminga, S., A. M. van Vuuren, C. J. van der Koelen, R. S. Ketelaar and P. L. van der Togt. 1990. Ruminal behavior of structural carbohydrates, non-structural carbohydrates and crude protein from concentrate ingredients in dairy cows. Netherlands J. Agric. Sci. 38:513-526.

Tamminga, S., W. M. Van Straalen, A. P. J. Subnel, R. G. M. Meijer, A. Steg, C. J. G. Wever and M. C. Block. 1994. The Dutch Protein Evaluation System: the DVE/OEB-system. Livestock Prod. Sci. 40:139-155.

Yu, P., J. H. G. Holmes, B. J. Leury and A. R. Egan. 1998a. Influence of dry roasting on rumen protein degradation characteristics of whole faba beans *(Vicia faba)* in dairy cows. Asian-Aus. J. Anim Sci. 11:35-42.

Yu, P., A. R. Egan, J. H. G. Holmes and B. J. Leury. 1998b. Influence of dry roasting on rumen degradation characteristics of whole faba beans *(Vicia faba)* in dairy cows, II: starch. Asian-Aus. J. Anim Sci. 11:503-509.

Yu, P., A. R. Egan and B. J. Leury. 1999. Protein Evaluation of Dry Roasted Whole Faba Beans (*Vicia faba*) and Whole Lupin Seeds (*Lupinus Albus*) by the New Dutch Protein Evaluation System: the DVE/OEB System. Asian-Aus. J. Anim. Sci. 12:871-880.

Yu, P., B. J. Leury, M. Sprague and A. R. Egan. 2001. Effect of the DVE and OEB value changes of grain legumes (Lupin and faba beans) after roasting on the performance of lambs fed a roughage-based diet. Anim. Feed Sci. Technol. 94:89-102.