Influence of Pressure Toasting on Starch Ruminal Degradative Kinetics and Fermentation Characteristics and Gelatinization of Whole Horse Beans *(Vicia faba)* in Lactating Dairy Cows

P. Yu*, J. O. Goelema and S. Tamminga
Department of Animal Nutrition, Wageningen Agricultural University,
Zodiac, Marijkeweg 40, 6709 PG, Wageningen, The Netherlands

ABSTRACT : Whole horse beans *(Vicia faba cv. Alfred)* (WHB) were pressure toasted at different temperatures of 100, 118 and 136°C for 3, 7, 15 and 30 minutes in order to determine an optimal heating conditions to increase bypass starch (BPSt) as glucose source which is usually limiting nutrient in highly producing dairy cows in the Netherlands. Starch (St) Ruminal Degradative Kinetics and Fermentation Characteristics of (SRDC) of WHB were determined using *in sacco* technique in 4 lactating dairy cows fed 47% hay and 53% concentrate according to Dutch dairy cow requirements. Measured characteristics of St were soluble fraction (S), potentially degradable fraction (D) and rate of degradation (Kd) of insoluble but degradable fraction. Based on measured characteristics, percentage bypass starch (BPSt) was calculated according to the Dutch new feed evaluation system: the DVE/OEB system. Pressure toasting temperatures significantly affected starch gelatinization ($p<0.01$). Degradability of Starch in the rumen was highly reduced by pressure toasting ($p<0.01$). S varied from 58.2% in the raw WHB (RWHB as a control) to 19.6% in 136°C/15 min. S was reduced rapidly with increasing time and temperature ($p<0.01$). D varied from 41.8% in RWHB to 80.5% in 136°C/15 min. D fraction was enormously increased with increasing time and temperature ($p<0.01$). Kd varied from 4.9%/h in RWHB to 3.4%/h in 136°C/15 min. All these effects resulted in increasing %BPSt from 29.0% in RWHB to 53.1% in 136°C/15 min. Therefore BPSt increased from 93.5 g/kg in RWHB to 173.5 g/kg in 136°C/15 min. The effects of pressure toasting on %BPSt and BPSt seemed to be linear up to the highest values tested. Therefore no optimal pressure toasting conditions could be determined at this stage. But among 10 treatments, The treatment of 136°C/15 min was the best with the highest BPSt content. It was concluded that pressure toasting was effective in shifting starch degradation from rumen to small intestine to increase bypass starch. *(Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 4 : 537-543)*

Key Words : *In Sacco*, Starch Gelatinization, Ruminal Starch Degradative Kinetics and Fermentation Characteristics, Bypass Rumen Starch

INTRODUCTION

Though ruminants have advantages in comparison with monogastric animals, which are of the capacity of degradation of structural carbohydrates, resulting in the formation of easily absorbable and highly utilizable volatile fatty acids (VFA), the synthesis of microbial protein, the elimination of many anti-nutritional factors, and the synthesis of B-vitamins, they also have disadvantages, one of which is the degradation of non-structural carbohydrates of which the storage polysaccharide starch is quantitatively the predominant form (Yu et al., 1998b).

Yu et al. (1998b) reported that glucose is a limiting nutrient particularly in highly producing dairy cattle. If the non-structural dietary carbohydrates (starch) are quantitatively degraded in the reticulo-rumen, the animal has to rely for its glucose supply mainly on glucogenic precursors such as propionic acid and glucogenic amino acids. Under such conditions productivity increases if a part of the dietary non-structural carbohydrates bypasses reticulo-rumen fermentation (Bruchem, 1991). It is advantageous under such conditions to have more starch escape degradation in the rumen which is of special value as a source of glucose in the small intestine (Noeck and Tamminga, 1991) to achieve a higher milk production.

Starch escaping ruminal degradation will not only supply the animal with more glucose, an important precursor for lactose, and save amino acids being used for other purposes (oxidation, precursors for gluconeogensis) than the production of milk protein, it may also prevent fermentation losses in the rumen (Tamminga and Jansman, 1993) and it usually results in a reduced milk fat content and somewhat enhanced milk protein content (Tamminga and Goelema, 1993). Performance data from growing cattle fed processed corn and sorghum grains indicate that starch was used 42% more efficiently if it was digested in the small intestine rather than in the rumen (Owens, 1986).

Whole horse beans (WHB), legume seeds, which are particularly high in crude protein (Yu et al., 1998a), also a good source of lysine, and high starch content (Cerning-Beroard, 1977), have attracted attention in recent years as possible homegrown feeds in a large area (temperate and subtropical zone) and appear to be the protein source and starch source best suitable to the ecological and climatic condition of many countries (Yu et al., 1998b).

But the fast fermentation of starch in the rumen limits their use in ruminant nutrition, resulting in little starch being escaping fermentation (only 22% to 24% horse beans bypassed rumen into intestines (Tamminga, 1989; Yu et al., 1998b), but also volatile fatty acids

* Corresponding Author: P. Yu. Dept. of Animal Production, Institute of Land and Food Resources, University of Melbourne, Parkville, Vic. 3052, Australia.
Received July 15, 1998; Accepted November 2, 1998

(VFA) being generated rapidly with a concomitant decrease in ruminal pH, to which cell wall degrading bacteria are sensitive, large enough to disturb rumen fermentation (Cone, 1990), inhibit the degradation of cell walls and causing an imbalance between feed breakdown and microbial synthesis. High contents of easily degradable concentrates in the diet may also lead to the production of lactate, a substance that is less easily absorbed from the rumen. Hence a rumen acidosis may develop, possibly eventually resulting in the so-called off-feed syndrome and a concurrent atony of the rumen. Therefore these seeds are not suitable to be used in large amounts in an unprocessed form in ruminant diets.

One of the possibilities to reduce rumen degradation is heat treatment. The intensity of the effect is a function of time of exposure and temperature reached (Stern et al., 1985; Pene et al., 1986; Annexstad et al., 1987; Waltz and Stern, 1989), while also particle size and moisture during processing are influencing the possible effects of processing. The decrease in rumen starch degradation may lead to an increasing intestinal availability of starch. Under conditions of high concentrate intake, treatments that would lead to even a small improvement in the nutritive value of legume seeds could be of significant economic consequence. A number of publications (Arieli et al., 1989, Walhain et al., 1992) indicated that heat treatment does effect rumen degradation. But optimal heating conditions have not been found for each legume seed till now. Heating above the optimal temperature may overprotect starch so that starch is neither fermented in the rumen nor digested in the small intestines (Stern et al., 1985). Also prolonged treatment with high temperature could lead to reactions (Maillard reaction) between carbohydrate and amino acid.

Pressure toasting is a technology to improve the nutritive value of legume seeds. Literature on the nutritive value of pressure toasted WHB for ruminants is scarce. The aim of the present experiment was to determine the effect of pressure toasting of faba beans on starch ruminal degradative kinetics and fermentation characteristics for high yielding dairy cows in order to decrease rumen degradation, increase the amount of bypass starch and optimize fermentation in the rumen by shifting of starch digestion from rumen to intestines and therefore reduce unnecessary starch losses from the rumen. Effects of pressure toasting on starch gelatinization of whole horse beans were investigated too.

MATERIALS AND METHODS

Feedstuffs

WHB (Vicia faba cv Alfred) were obtained from the commercial company. The chemical composition of raw whole horse beans (RWHB) are showed in table 1.

Treatment of WHB

RWHB were pressure toasted at 3 different temperatures (100, 118 and 136°C) for 3, 7, 15 and 30 minutes in an incomplete block design. All treatment were carried out in duplicate resulting in 22 treatments in total divided into A and B series as shown in the table 2. The treatment of 100°C/3 min and 136°C/30 min were dropped due to no expected significant difference between RWHB and 100°C/3 and the risk of overheating, respectively. Processing was carried out at Wageningen Feed Processing Center (WFPC) using a laboratory scale pressure toaster as described by van der Poel (1990). The conditions of processing are shown in table 2. After toasting, the toasted feedstuffs were dried at 35°C for 18 h in the oven and then allowed to cool down to ambient temperature and were ground through a 3 mm screen (Hemmer Mill AEG TYP AM80N*2)

Table 1. Dry matter and chemical composition (g/kg) of RWHB

Chemical composition	Content (g/kg)
Dry matter	887.9 ± 0.28
Starch	322.6 ± 7.69
Crude protein	245.8 ± 0.08
Organic matter	755.1 ± 0.62
Ash	35.8 ± 0.14

Note: analysis method see the section of chemical analysis.

Table 2. Treatments and the pressure toasting conditions of WHB

Treatments	Series A			Series B		
	Temperature		Steam toaster	Temperature		Steam toaster
	Temp (°C)	sd	P (bar)	Temp (°C)	sd	P (bar)
RWHB						
100°C/7min	100.9	0.6	0.10	101.1	0.4	0.11
100°C/15min	100.0	0.1	0.10	100.2	2.6	0.10
100°C/30min	100.8	0.4	0.10	101.1	0.8	0.10
118°C/3min	118.0	0.2	0.90	118.4	0.1	0.90
118°C/7min	118.2	0.2	0.90	118.5	0.3	0.90
118°C/15min	117.8	0.4	0.89	118.6	0.2	0.90
118°C/30min	118.3	0.2	0.90	118.5	0.2	0.90
136°C/3min	136.0	0.2	2.21	136.4	0.2	2.25
136°C/7min	136.2	0.2	2.24	136.4	0.2	2.30
136°C/15min	136.0	0.2	2.24	136.4	0.3	2.30

Notes: each treatment was measured at least 6 times; sd: standard deviation.

Animals and diets

Four lactating Holstein Friesian cows were previously equipped with a large rumen cannula with an internal diameter of 10 cm (Bar Diamond Inc., Parma, Idaho, USA) for measuring rumen degradability were kept in tie stalls.

All cows received a diet consisting of a commercial pelleted concentrate (940 VEM (energy), 120 g DVE (true protein digested in the small intestine) and hay

(666 VEM, 53 DVE) according to Dutch lactating dairy cow requirement. The cows were individually fed twice daily at 08:00 and 16:00. Water was always available. A 14 days period of adaptation was allowed. The animal used in these experiments were cared for in accordance with the guidelines Dutch Animal Care and Use.

In sacco method

Ruminal degradative kinetics and fermentation characteristics of starch of WHB in the rumen of 4 lactating dairy cows were determined using the in sacco method. Incubations of all treatments in the rumen were with 5.5 g dry matter in nylon bags (10*17 cm) with the pore size of approximately 40 μm (Swiss Silk Bolting Cloth Mfg. Co. Ltd, Zurich, Switzerland) 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 17:00, (next day) 05:00, 09:00, 13:00, 15:00 and removed at 17:00 h, respectively. The 48 h rumen incubations were carried out from 20:00 till 20:00 two days later. All treatments were randomly allocated over all cows and the whole incubation period.

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 for 55 minutes without spinning and subsequently dried at 60°C for 24 h. The 0 h incubation samples were only put in the washing machine under the same conditions. Dry samples were stored in a cool room (4°C) until analysis. The residues were ground through a 1 mm screen and analyzed for chemical composition.

Chemical analysis

Analyses of DM, ash, N and starch (St) for feed and rumen residues of 0, 2, 4, 8, 12 and 24 h of all treatments were performed. 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 Kjeldahl digestion and distillation apparatus (Gerhardt Vadopest 6, Germany) and CP content was obtained by N multiplication by 6.25. Starch and starch gelatinization were determined according to the AGS-DG method (Yu, 1995), of which the analysis principle was a). Removal of dextrin and lower sugars by extraction with ethanol, gelatinization of the starch, hydrolysation of starch by the enzyme amyloglucosidase (AGS) to glucose at pH 4.8; b) Glucose is phosphorylated to glucose -6-phosphate (G-6-P) by adenosine -5-triphosphate (ATP) in the presence of the enzyme hexokinase at pH 7.6; c) In the presence of the enzyme glucose-6-phosphate dehydrogenase (G6P-DH), glucose-6-phosphate is oxidized by nicotinamide-adenine-dinucleotide-phosphate (NADP+) to gluconate -6- phosphate under formation of NADPH; d). The amount of NADPH formed is stoichiometric with the amount of glucose. NADPH is determined by means of its absorbency at 334, 340 or 365 nm.

Calculation and statistical analysis

The effect of pressure toasting on starch of WHB was estimated by measuring degree of genatilization. Degree of gelatinization (DG)=C-(A-B)*100/B, where, A= parameter starch, sugar included (g/kg DM); B = parameter starch after extraction (g/kg DM); C = parameter degradable starch (g/kg DM).

Important degradative kinetics and fermentation characteristics of starch are: the soluble fraction (S) which is assumed to be degraded rapidly and completely; the fraction which is not soluble, but potentially degradable (D); the fractional rate of degradation (Kd) of the fraction D (Van Straalen and Tamminga, 1990). Part of starch could be washed out of the bags without incubation in the rumen. This proportion (S) was considered to be degraded very rapidly and completely. The remaining proportion (D) was degradable but insoluble and can be calculated as 100-S. The fractional rate of degradation of this proportion was called Kd. Lag time (T0) and undegradable fraction (U) (irrespective of time in the rumen) in starch were neglected (Tamminga, 1989) due to the fast and complete starch degradation.

Results of *in sacco* incubations were calculated using the NLIN procedure of the statistical package SAS (SAS, 1991) using iterative least squares regression (Gauess-Newton method) by the following equation Ørskov and McDonald, 1979): $R(t) = U+D*\exp^{-Kd*(t)}$, Where, R(t) stands for residue (in %) of the amount of incubated material after t h of rumen incubation. Percentage of bypass starch (%BPSt) was calculated according the following formula (Tamminga, 1994): % BPSt = D * Kp / (Kp+Kd) + 0.1 * S. Bypass starch was calculated as: BPSt = Starch (g/kg) * %BPSt /100, Where, passage rates (kp) of 0.06 /h was adopted based on international data (Tamminga et al, 1994); BPSt and Starch in g/kg DM.

Statistical analysis of differences among treatments were carried out using the SAS (1991). Analysis of variance was carried out using Proc GLM of SAS (1991). The following linear model was used for data analysis: Yhij = m+Blockh+Tempi+Timej+Temp*Time ij +e hij, where: Y = degraded fraction and starch gelatinization; block = series effect; h =1. 2; i = 1,2,3,4; j = 1,2,3,4,5. Comparison of means of treatments for degree of starch gelatinization, degradation characteristics (S, D and Kd) and %BPSt and BPSt were carried out by Tukeyís studentized Range Test (HSD) (SAS, 1991)

RESULTS

Chemical compositions

The chemical composition of DM and total starch (St) contents of raw and each treatments are presented in table 3. There were no significant series ($p>0.05$), temperatures ($p>0.05$) and times ($p>0.05$) effects on

Table 3. Starch disappearance (%) of WHB pressure toasting at different time and temperature, as a function of time of incubation in nylon bags incubated in the rumen of lactating dairy cows

Temp. (°C)	Raw	100			118				136		
Time (Min.)	Raw	7	15	30	3	7	15	30	3	7	15
DM (%)	887.0	902.1	903.2	902.4	906.3	902.4	901.3	901.5	904.1	900.5	893.4
Starch (g/kg DM)	322.6	335.4	334.9	346.0	336.4	333.8	338.9	333.1	332.8	339.1	326.5
Starch rumen disappearance (RD %)											
Series A											
Incubation time (h)											
0	57.24	53.81	48.49	52.11	45.88	41.87	35.85	34.66	33.97	24.61	20.27
2	55.09	54.52	54.96	58.35	50.12	46.44	39.87	38.36	35.44	28.47	25.53
4	61.66	58.47	55.21	58.67	52.23	51.75	42.13	39.28	39.18	30.86	25.30
8	68.97	64.92	63.51	66.70	57.06	52.66	49.67	46.23	45.03	41.52	33.63
12	78.74	70.06	71.50	74.58	69.04	64.27	55.71	56.65	58.10	51.40	42.30
24	95.79	90.93	89.85	85.07	84.08	87.31	76.55	83.72	78.46	77.55	69.42
Series B											
Incubation time (h)											
0	59.20	53.44	52.65	49.24	42.25	36.86	40.40	30.12	26.26	24.71	18.92
2	56.09	53.71	52.59	55.24	43.54	45.22	40.61	34.92	31.09	26.34	20.29
4	53.08	53.90	53.27	60.74	56.40	46.78	43.64	35.52	36.90	28.69	25.15
8	68.59	60.60	69.13	56.94	61.39	54.25	47.37	40.89	44.26	38.08	31.08
12	73.26	72.33	75.56	67.23	69.98	60.28	64.48	50.78	51.81	50.53	43.71
24	89.63	93.13	89.20	88.34	83.85	86.79	79.90	80.75	82.11	76.86	77.25
Average											
Incubation time (h)											
0	58.22^{a}	53.63^{a}	50.70^{ab}	50.68^{ab}	44.07^{bc}	39.37^{dc}	38.13^{dc}	32.39^{dc}	30.12^{dcf}	24.66^{cf}	19.60^{f}
2	55.59^{ab}	54.12^{abc}	53.78^{anc}	56.80^{a}	46.83^{bcd}	45.83^{cdc}	40.24^{cdf}	36.64^{cfg}	33.27^{gf}	27.41^{gh}	22.91^{h}
4	57.37^{a}	56.19^{a}	54.24^{a}	59.71^{a}	54.32^{a}	49.27^{ab}	42.89^{bc}	37.40^{cd}	38.04^{cd}	29.78^{dc}	25.23^{e}
8	68.78^{a}	62.76^{ab}	66.32^{a}	61.82^{ab}	59.23^{abc}	53.46^{bcd}	48.52^{cdc}	43.56^{dcf}	44.65^{dcf}	39.80^{cf}	32.36^{f}
12	76.00^{a}	71.20^{ab}	73.53^{ab}	70.91^{ab}	69.51^{ab}	62.28^{abc}	60.10^{bc}	53.72^{cd}	54.96^{cd}	50.97^{cd}	43.01^{d}
24	92.91^{a}	92.03^{ab}	89.53^{abc}	86.71^{abcd}	83.97^{abcd}	87.05^{abcd}	78.23^{dc}	82.24^{bcde}	80.29^{cde}	77.21^{de}	73.34^{e}

Notes: Treatment temperatures and time had significantly effects on starch rumen disappearance ($p<0.01$). Means with the same letter in the same row are not significantly different (=0.05).

Table 4. The effect of pressure toasting on starch gelatinization, starch rumen degradative kinetics and fermentation characteristics (SRDC) and bypass starch (BPSt) in WHB

Temp. (°C)	Raw	100			118				136		
Time (Min.)	Raw	7	15	30	3	7	15	30	3	7	15
DM (g/kg)	887.0	902.1	903.2	902.4	906.3	902.4	901.3	901.5	904.1	900.5	893.4
Starch (g/kg DM)	322.6	335.4	334.9	346.0	336.4	333.8	338.9	333.1	332.8	339.1	326.5
Series A											
Starch rumen degradative kinetics and Fermentation characteristics (SRDC, %) and bypass starch (BPSt)											
S	57.24	53.81	48.49	52.11	45.88	41.87	35.85	34.66	33.97	24.61	20.27
D	42.76	46.19	51.51	47.89	54.12	58.13	64.15	65.34	66.03	75.39	79.73
Kd	5.71	4.51	5.28	4.88	4.35	4.57	3.56	4.02	3.73	4.02	3.20
%BPSt	27.63	31.75	32.25	31.62	35.96	37.18	43.85	42.59	44.11	47.60	54.02
BPSt(g/kg)	90.65	107.01	110.33	112.08	120.00	123.30	146.75	144.36	150.96	161.68	179.91
Series B											
Starch rumen degradative kinetics and Fermentation characteristics(SRDC, %) and bypass starch (BPSt)											
S	59.20	53.44	52.65	49.24	42.25	36.86	40.40	30.12	26.26	24.71	18.92
D	40.80	46.56	47.35	50.76	57.75	63.14	59.60	69.88	73.74	75.29	81.08
Kd	4.01	4.50	5.08	4.43	5.32	4.89	3.63	3.72	4.42	3.72	3.68
%BPSt	30.38	31.95	30.91	34.12	34.83	38.47	41.17	46.15	45.09	48.95	52.15
BPSt(g/kg)	96.34	106.66	101.27	115.10	118.11	129.25	141.26	151.01	145.82	165.80	167.00
Average											
Starch rumen degradative kinetics and Fermentation characteristics(SRDC, %) and bypass starch (BPSt)											
S	58.22^{a}	53.63^{ab}	50.57^{ab}	50.68^{ab}	44.07^{bc}	39.37^{dc}	38.13^{dc}	32.39^{dc}	30.12^{dcf}	24.66^{cf}	19.60^{f}
D	41.78^{f}	46.38^{cf}	49.43^{cf}	49.33^{cf}	55.94^{cd}	60.64^{dc}	61.88^{dc}	67.61^{bc}	69.89^{abc}	75.34^{ab}	80.51^{a}
Kd	4.86^{a}	4.51^{a}	5.18^{a}	4.66^{a}	4.84^{a}	4.73^{a}	3.60^{a}	3.87^{a}	4.08^{a}	3.87^{a}	3.44^{a}
%BPSt	29.01^{g}	31.85^{fg}	31.58^{fg}	32.87^{cfg}	35.40^{cf}	37.83^{dc}	42.51^{dc}	44.37^{bc}	44.60^{bc}	48.28^{ab}	53.09^{a}
BPSt(g/kg)	93.50^{g}	106.84^{fg}	105.80^{fg}	113.59^{cf}	119.06^{cf}	126.28^{dc}	144.01^{cd}	147.69^{bc}	148.38^{bc}	163.74^{ab}	173.46^{a}
Degree of starch gelatinization (DG)											
DG	-11.89^{ab}	-25.00^{ab}	-17.86^{ab}	-25.58^{ab}	-22.28^{ab}	-27.80^{b}	-12.92^{ab}	-20.03^{ab}	-2.41^{an}	-0.89^{ab}	2.50^{a}

Notes: %BPSt=D*Kp/(kp+Kd) +0.1 S; BPSt (g/kg)=St (g/kg) * % BPSt/100 (Kp = 0.06/h); Means with the same letter in the same row are not significantly different (=0.05).

chemical compositions of DM and starch among the treatments.

Rumen starch disappearance

Rumen starch disappearance (%) of each treatment of WHB are presented in table 3. Pressure toasting decreased rumen starch disappearance at all incubation time of 0, 2, 4, 8, 12 and 24 h with increasing time and temperature ($p<0.01$ for both time and temperature). At the short time incubations, pressure toasting had strong effects on rumen disappearance but after the long rumen incubations, the effects tended to reduce. Compared with RWHB, rumen disappearance at 0, 2, 4, 8, 12 and 24 h of WHB treated at 136°C/15 min was reduced by 3, 2.4, 2.3, 2, 1.8 and 1.3 times, respectively.

Rumen starch degradative kinetics and fermentation characteristics

Table 4 presents ruminal degradative kinetics and fermentation characteristics in WHB as described by means of the exponential equation and based on the best fit of data to the model. RWHB showed a high soluble fraction (58.2%), high degradation rate (4.9%/h) and less escaping starch to small intestine (29.0%). Pressure toasting significantly changed WHB soluble fraction, degradation fraction and bypass starch with increasing time and temperature. S was significantly decreased with increasing pressure toasting time and temperature ($p<0.01$) and varied from 58.2% in RWHB to 19.6% in 136°C/15 min. D varied from 41.8% in RWHB to 80.5% in 136°C/15 min. The effects of treatment time and temperature were highly significant ($p<0.01$)on D. Kd fraction was decreased and varied from 4.9% /h in RWHB to 3.4%/h in 136°C/15 min. Percentage of BSt varied from 29.0% in RWHB to 53.1% in 136°C/15 min. Compared with control, %BSt of 136°C/15 min was increased nearly two times. The effects of temperature and time were both highly significant ($p<0.01$) on %BSt. The changes of bypass starch in g/kg had the same pattern as %BSt. It varied from 93.5 g/kg in RWHB to 173.5 g/kg in 136°C/15 min as shown in figure 1. The effects of temperature and time were significant ($p<0.01$) on bypass starch.

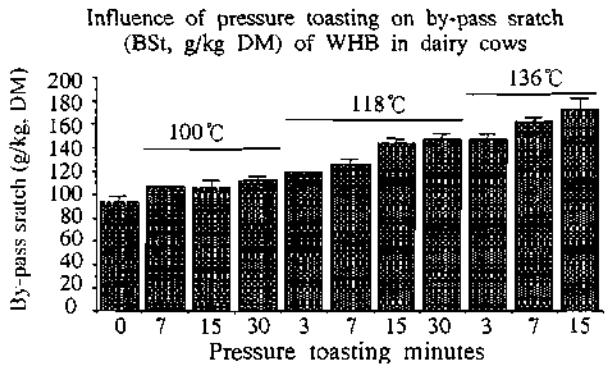

Figure 1. The effect of pressure toasting on bypass sratch of whole horse beans (WHB) in lactating dairy cows

Degree of gelatinization of starch

The effects of pressure toasting on rumen degradation of starch gelatinization of WHB are present in table 4. Though the effects of series, time and interaction between time and temperature on starch gelatinization were not significant ($p>0.05$), the pressure temperatures did have a highly significant effects on starch gelatinization ($p<0.01$).Therefore pressure temperature was important element for starch gelatinization.

DISCUSSION

The results indicate that pressure toasting did not significantly change chemical composition of DM and starch of raw and each treatment. This results were smilar to the results obtained by Yu et al. (1998a) that pressure toasting did not change crude protein content in raw and treatments of whole horse beans.

The results indicated that though raw whole horse beans were of potentially special value as source of glucose in the small intestines for high yielding dairy cows with rich starch content (322.6 g/kg), raw starch had the rate of degradation of 4.9%/h, very high soluble fraction (58.2%) and low potentially degradable fraction (41.8%), which all contributed to very high degradability (71.0%) after being incubated in the rumen. Only 29.0% of starch entered the intestines as a glucose source. The portion of starch of horse beans escaping from reticulo-ruminal degradation was estimated by Tamminga (1989) as 22%, water solubility as 44% and rate of degradation (Kd, %/h) of the non-soluble fraction of starch was 8.0%/h. Yu et al. (1998b) reported the raw whole faba beans had rapid rumen degradability (76.1%) with rate of degradation of 9.8%/h, soluble fraction of 50.0%, potentially degraded fraction of 49.9% and bypass starch of 23.9%. These results are very close to the results obtained in the present experiment except the values of degradation rate which were higher than our values (4.9%/h). Excessive amounts of soluble or rapidly degradable carbohydrates may give rise to an excessive VFA production resulting in a low pH, which will slow down the degradation of structural carbohydrates and also result in excessive NH_3 production followed by urea excretion (Yu et al., 1998b).

Heat treatment had a variable effect on starch degradation, the reasons for this is not clear. But during the heat treatment not only the physical form of the feed may have been changed, but also its chemical structure may have been affected. When the temperature and pressure are high enough, starch granules are disrupted and starch gelatinizes (amylose and amylopectin molecules are irreversibly changed in structure) (Tamminga, 1993). Whether it increased or decreased starch fermentation is depended on not only temperature and time but also heating methods, feed type and species. Using laboratory scale pressurized toaster in this experiment increased the bypass starch dramatically from 27.6 to 31.7, 40.0, 48.7% at pressure temperature of 100, 118, 136°C. Yu et al. (1998b)

reported the dry roasting increased the bypass starch with increasing roasting times and temperatures. But Hung (1995) reported that rumen starch degradabilities were higher for diets with autoclaved than raw maize in Taiwan native goat. Benchaar (1992) reported that faba beans extrusion at 195°C increased the apparent ruminal degradation of starch from 58 to 72% and total tract apparent digestibility of starch were not effected. Walhain et al (1992) reported that degradation of starch of peas increased after extrusion. Research by Tamminga et al. (unpublished) showed that pelleting different concentrates decreased amount of starch escaping rumen degradation (%BPSt). The decreased bypass starch varied from 15 to 43%. Goelema (personal communication) found that grinding method didn't affect %BPSt, but technological treatments (such as pressure toasting, pelleting) affected bypass starch. Compared with the control sample (concentrate meal), cold pelleting increased kd by 3.2% and decreased %BPSt by 3.9%; Steam pelleting increased the rate of degradation by 3.1% and decreased %BPSt by 4.3%; expander treatment increased degradation rate by 3.6 and reduced %BPSt by 7.9%; expander/pelleting treatment had the largest effects on Kd and %BPSt, increase

Therefore starch degradability in the rumen differs among feed in response to processing. Such a heterogeneity may be related to a divergence in the crystallinity of the starch source and/or the association between starch and the protein matrix surrounding the starch granules (Theurer, 1986). Differences in degradative behavior of starches can also be caused by several other factors such as their amylose and amylopectin content, crystallinity, particle size and the presence of enzyme inhibitors (Cone & wolters, 1990). Starches may be locked in granules, in size varying between 0.010 (maize, rice, wheat) to 0.050 mm (field bean, potato, pea), surrounded by a proteinous layer (Cone, 1991). The maylose / amylopectin ratio may also influence its susceptibility to enzymatic degradation. The later ratio ranges from 1 to 4 (Cone & Wolters, 1990).

Whether the total tract disappearance, rumen and intestinal digestibility of undegraded rumen starch of horse beans were different among treatments, or whether there was the overprotection effect, need further investigation of intestinal digestibility using mobile bags technique in the next trial.

CONCLUSIONS

Pressure toasting of whole horse beans had potential for increasing supply of escaping starch and improves the nutritional quality by reducing degradation in the rumen and thus increasing the amount of starch supplied to the small intestine, which could be a benefit to high yielding dairy cows. In our experiment, although bypass starch was increased with increasing time and temperature, no optimal combination of time and temperature was found at these stage. But among the 10 treatments, the treatment of 136°C/15 min seems the best with twice bypass starch increase compared with raw whole horse beans. To determine the optimal treatment, the intestinal digestibility of rumen undegraded starch for all treatments should be measured.

ACKNOWLEDGMENTS

The authors wish to thank Dr. H. Boer, Jane-Martine, Marian and Truus (Dept. of Animal Nutrition, Wageningen Agricultural University, The Netherlands) for helpful assistance in the chemical analysis.

REFERENCES

Annexstad, R. J., M. D. Stern, D. E. Otterby, J. G. Linn and W. P. Hanaen. 1987. Extruded soybeans and corn gluten meal as supplemental protein sources for lactating dairy cattle. J. Dairy Sci. 70: 814-822.

Arieli, A., A. Ben-Moshe, S. Zamwel and H. Tagari. 1989. In situ evaluation of ruminal and intestinal digestibility of heat-treated whole cottonseeds. J. Dairy Sci. 72: 1228-1233.

Benchaar, C., M. Vernay, C. Bayourthe and R. Moncoulon. 1994. Effects of extrusion of whole horse beans on protein digestion and amino acid absorption in dairy cows. J. Dairy Sci. 77:1360-1371

Bruchem, J. van. 1991. Physiology of the Gastrointestinal Tract. Wageningen Agricultural University, The Netherlands. pp. 6-17

Cerning-Beroard, J. and A. Filiatre. 1977. Characterization and distribution of soluble and insoluble carbohydrates in legume seeds: horse beans, peas, lupines. p. 65. In: Protein Quality from Leguminous Crops. Com. Eur. Commun. Brussels, Belgium.

Cone, J. W. 1991. Degradation of starch in feed concentrates by enzymes, rumen fluid and rumen enzymes. J. Scientific Food & Agric. 54: 23-34.

Cone, J. W. and M. G. E. Wolters. 1990. Some properties and degradability of isolated starch granules. Starch/Starke. 42: 298-301.

Hung, Y., Y. Li, J. Hsu, Y. C. Hung, Y. T. Li and J. Hsu. 1995. Effect of protein and starch degradation rates on rumen metabolism in Taiwan native goat. Proceedings of the National Science Council, Part B Life Science. 19: 2, 99-104.

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

Owens, F. N., R. A. Zinn and Y. K. Kim. 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63: 1634-1648.

Pena, F., H. Tagari and L. D. Satter. 1986. The effect of heat treatment of whole cottonseed on site and extent of protein digestion in dairy cows. J. Anim. Sci. 55: 395

Poel, A. F. B. van der. 1990. Effects of processing on bean (phaseolus vulgaris L.) protein quality. J. Agric. Sci. 38: 513-526.

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

Stern, M. D., K. A. Santos and L. D. Satter. 1985. Protein Degradation in rumen and Amino Acids absorption in the small intestine of lactating dairy cattle fed heat-treated whole soybeans. J. Dairy Sci. 68: 45-56

Tamminga, S. 1989. In: Physiology of the Gastrointestinal Tract. 1991. edited by J. van. Bruchem. Wageningen Agricultural University. The Netherlands. pp. 6-20.

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. and A. J. M. Jansman. 1993. Animal Nutrition. Wageningen Agricultural University. The Netherlands. pp. 30.

Tamminga, S. and J. O. Goelema. 1993. Feed processing as a means to improve feed utilization by ruminants. WIAS course at Wageningen Agricultural University, The Netherlands.

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 Production Sci. 40: 139-155.

Theurer, C. B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63: 1649-1662.

Van Straalen, W. M and S. Tamminga. 1990. Protein degradation in ruminant diets. In: Feed Evaluation (Wiseman, J. and Cole, D. J. A, Eds.), Butterworth, London, pp. 55 - 72

Walhain, P., M. Foucart and A. Thewis. 1992. Influence of extrusion on ruminal and intestinal disappearance in sacco of pea proteins and starch. Anim. Feed Sci. & Tech. 38: 43-55

Waltz, D. M. and M. D. Stern. 1989. Evaluation methods for protecting soybean protein from degradation by rumen bacteria. Anim. Feed Sci. & Tech. 25: 11-122.

Yu, P. 1995. Influence of pressure toasting on rumen degradation characteristics of horse beans in lactating dairy cows. M.Sc. Thesis. Wageningen Agricultural University, The Netherlands.

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. Asi.-Aus. J. Anim. Sci. 11 (1): 35-42.

Yu, P., A. R. Egan and B. J. Leury. 1998b. Influence of dry roasting of whole faba beans (vicia faba) on rumen degradation characteristics in dairy cows, II: starch. Asi.-Aus. J. Anim. Sci. 11 (5).