Effect of extrusion, espansion and toasting on the nutritional value of peas, faba beans and lupins

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ABSTRACT

An assessment was made of the effect that different treatments (toasting, expansion, extrusion) have on the nutritional value of protein plants (pea, faba bean, lupin). In a randomized block design, feeds were screened for enzymatic digestibility of starch and protein, N solubility and in vitro protein degradability. Expansion and extrusion cause increased starch enzymatic degradability while toasting produced virtually no effects. In peas this value increased from 11.80% in meal to 39.70% in the extruded product; 85.37% is the percentage for the expanded product, while 10.90% is the starch digestibility value for toasted peas. In faba beans the extrusion process increased starch digestibility from 11.39% to 85.05%, while in extruded lupins a complete starch hydrolysis was obtained, while in the meal the polysaccharide digestion was 54.48%.

The expansion and extrusion processes significantly decreased rumen degradability during the first 8 hours of incubation. Toasted peas had lower degradability if compared with controls but not with the other treatments. The only potentially alternative source to soybean is the extruded faba bean. In spite of its lower protein content, this feed is characterized by a considerably lower in vitro protein degradability than soybean. This implies that the digestible food protein content is comparable (124.90 g/kg DM) to that of soybean (109.78 g/kg DM) and definitely higher than that of all other protein plants.

Key Words: Legumes, Nutritional value, Technological treatments, Digestibility.

RIASSUNTO

EFFETTO DELL'ESTRUSIONE, ESPANSIONE E TOSTATURA SUL VALORE NUTRIZIONALE DI PISELLO, FAVINO E LUPINO

E' stato valutato l'effetto che diversi trattamenti (tostatura, espansione, estrusione) hanno sul valore nutritivo di proteaginose (pisello, favino, lupino). I parametri misurati sono stati la solubilità dell'N, la digeribilità in vitro dell'amido, la degradabilità ruminale e la digeribilità proteica in vitro, il modello sperimentale adottato è stato quello del blocco randomizzato. L'espansione e l'estrusione determinano un aumento nella degradabilità enzimatica dell'amido, mentre sostanzialmente nullo è l'effetto della tostatura. Nel pisello questo parametro passa da 11,80% per la farina a 39,70 % per l'estruso; 85,37 % è il dato riferito all'espanso, mentre 10,90 % è il valore di digeribilità dell'amido nel pisello tostato. Per il favino il processo di estrusione porta la digeribilità dell'amido da 11,39% a 85,05%, mentre nel lupino estruso si ottiene una idrolisi totale del polisaccaride in confronto al valore di 54,48% per la farina.

I trattamenti di espansione ed estrusione riducono significativamente la degradabilità ruminale nelle prime 8 ore d incubazione. Il pisello tostato ha una degradabilità inferiore rispetto al controllo ma non agli altri trattamenti.
Rispetto alla soia l'unica fonte potenzialmente alternativa è il favino sottoposto ad estrusione, infatti pur avendo un minor titolo proteico questo alimento si caratterizza per una degradabilità proteica in vitro notevolmente più bassa di quella della soia. Questo porta ad un contenuto in proteina digeribile intestinale comparabile (124,90 g/kg SS) a quello della soia (109,78 g/kg SS) e decisamente superiore rispetto a tutte le altre proteaginose.

Parole chiave: *Legumi, Valore nutritivo, Trattamenti tecnologici, Digeribilità.*

Introduction

The ban on the use of both meat and bone meal (European Commission, 1994, 1995) poses a challenge to animal nutritionists within the European Community. Moreover, in Italy there is a growing request for the implementation of a GMO-free food chain, especially for the production of organic and typical food types. Since the Italian soybean yield is not sufficient to cover these needs, the challenge is to find homegrown protein-rich feedstuffs, making sure no antinutritional factors like trypsin inhibitors, tannins, and estrogenic substances are present thus interfering with the digestive process and animal performance.

Protein plants like peas, lupins and faba beans are largely produced in the Mediterranean area and are suitable for use in the nutrition of monogastrics (Salgado *et al.*, 2002), while their high protein degradability and solubility make their use difficult as replacements for soybean meals in the ruminant rations (INRA, 1988).

According to several papers technological treatments such as extrusion, expansion and toasting are effective in the improvement of starch and protein digestibility (Goelema *et al.*, 1999; Aufrere *et al.*, 2001a, 2001b). Proteaginous feeds have a variable content in anti-nutritional factors (ANF) (Cerioli *et al.*, 1988; Gdala *et al.*, 1992; Zdunczyk *et al.*, 1997) and this can reduce their inclusion in monogastric diets.

Jansman *et al.* (1995) reported a reduction of protein digestibility and increase of endogenous N losses in piglets fed a faba bean based diets. These results could be due to the specific features of faba bean protein, but also to the presence of ANF such as tannins, protease inhibitors, and non digestible ∝-galattosides (Lallès and Jansman, 1998).

Extrusion reduced non digestible oligosaccharides, tannins and lectins content; also phytic acid was partially hydrolised and consequently an increase in mineral absorption was observed (Alonso *et al.*, 2001).

High-temperature, high-pressure and high-moisture heat treatments (extrusion, expansion) or dry treatments (toasting) are largely used in the feed industry to improve starch digestibility and reduce the rumen solubility and degradability of plant proteins (Peisker, 1992, 1994; Goelema *et al.*, 1998, 1999; Aufrere *et al.*, 2001a, 2001b).

The aim of the study was to assess the effects of these technological treatments on the nutritional characteristics of pea, faba bean and lupin used in animal nutrition in order to characterize effective alternatives to soybean meal.

Material and methods

Samples of commercially available protein peas, faba beans and lupins were exposed to extrusion while expansion and toasting processes were applied to protein peas only. The following industrial equipments were used: Buhler expander with conditioning temperature of 70°C, internal temperature of 130°C, head pressure of 30 atm and 180-200 A power absorption available at Consorzio Agrario (Cremona, Italy); Anderson single-screw wet extruder with 300-350 Kg/h capacity and 120 A power absorption available at Cortal Extrasoy (Vicenza, Italy); Roaster rotating dryer with hot air flow at 130-140°C for 20 min. available at Essiccazione Mais (Sospiro, CR, Italy). The samples of the treated products used in this study were taken from different bags of the same processing batch.

The raw and treated products were ground using a mill of the Whiley (Fritsh) type with a 1 mm grid after being dried at 60°C in a ventilation oven and brought to a constant weight. They were analyzed using the analytical protocol specified in the NRC form (NRC, 2001) (for ruminants) and integrated by the amino acid HPLC assay (Spackman *et al.*, 1958; Moore, 1963) and by the determination of the antinutritional factor content: tannins, polyphenols (Carmona *et al.*, 1991), antitrypsin factor (Kakade *et al.*, 1974) and estrogenic molecules like genistein and daizein (Franke *et al.*,1994).

Starch digestibility was assessed by means of amyloglucosidase (Fluka type 10115 with 70 U/mg from *Aspergillus niger* in an acetate buffer with pH of 4.8, as indicated by Casper *et al.* (1990).

At the same time the starch digestion dynamics was assessed after 30, 90 and 120 minutes of incubation with alpha-amylase (Sigma type A 3176 with 28 U/mg) in a phosphate buffer with pH of 6.9 at 37°C (Mercier, 1974). Starch digestibility and digestion dynamics were performed in duplicate.

The protein HCl-pepsin digestibility was assessed according to the AOAC method (1984) with five replicates for each sample.

The organic matter fermentability was assessed using the gas-test technique as indicated by Menke and Steigass (1979) using the ruminal fluid taken from fistulated cows three hours after the morning meal as the inoculum. The cows had been fed on a grass hay diet (60 % DM), corn silage (20 % DM) and concentrate (20 % DM) in order to meet the maintenance requirements and ensure a 13% protein content on dry matter. The ration was administered in two meals (6.00 h and 17.30 h), 8 replicates were obtained for each feed (four replicates for two fermentations).

The gas production data obtained after 4, 8, 24, 32 e 48 hours of fermentation were compared to those of barley which had been included in each fermentation as an internal standard and used to determine the fermentation curve parameters according to the exponential model proposed by Ørskov and McDonald (1979).

The same animals were used as ruminal inoculum donors to determine *in vitro* dry matter digestibility according to the Daisy method (Ankom, NY, USA) using 3 replicates (bags) for each item and for 3 incubations. The incubation times were 8, 24 and 48 hours.

The bags were incubated separately for each vessel. The residual content of the bags was used to determine the nitrogen residue and, therefore, to calculate the protein rumen degradation.

Protein degradability was also assessed in vitro by incubating four replicates for each samples at 39°C for 18 hours (Sigma Type XIV) with *Streptomyces griseus* protease in a borate-phosphate buffer at a pH of 8.0 as suggested by Krishnammoorty *et al.* (1983).

Results and discussion

Chemical composition and anti-nutritional factors (ANFs) content

The analytical composition is reported in Table 1, while Table 2 shows the ANFs content.

The extrusion and expansion treatment lead to a reduction of NDF and ADF content in peas and faba. These results are in agreement with findings of Kiczorowska *et al.* (2003) in lupins and Gonzalez e Perez (2002) in lentils. These differences could be based on the decrease of hemicellulose and cellulose as a consequence of heating. On the contrary of Kiczorowska *et al.* (2003), no effect of treatments on fibre content in lupins were detected.

The analytical data do not show any significant anti-trypsin activity. The values for both tannins and polyphenols are less than 1%. Concerning estrogenic factors (genistein and daidzein) both the peas, the faba beans and the lupins have lower values than soybean.

Effect of treatments on protein solubility

The heat expansion and extrusion treatments act by reducing protein solubility even if this differs according to the various protein sources (Table 3).

Extrusion is highly efficient in that – both in pea and faba bean - it causes a solubility reduction from values greater than 70% down to approximately 19-20%, similar to the samples of soybean meal commonly available in our markets.

The effect of the extrusion treatment is much less in the case of lupin where solubility was reduced by about one third (87.18% vs 60.84%). Remond *et al.* (2003) also observed a reduction in the *in vivo* soluble amount which is comparable to our results. The different behaviour observed in

Table 1. Analytical feedstuff composition in % DM.

Sample	Treatment type	DM %	CP	Fat	ADF	NDF	ADFIP	NDFIP	Total starch	Sugar	Ash
Pea	Meal	88.01	24.15	1.40	9.94	18.50	0.18	1.67	49.61	4.36	3.70
	Extruded	89.17	24.00	1.67	7.12	15.69	0.27	3.79	47.20	4.09	5.55
	Expanded	86.18	24.40	3.66	6.68	12.27	0.20	2.08	47.92	5.23	3.93
	Toasted	95.91	24.99	1.84	4.01	26.08	0.00	1.91	52.25	6.67	2.90
Faba bean	Meal	88.31	29.33	1.82	12.93	31.30	0.46	1.47	37.05	4.56	3.83
	Extruded	87.26	29.18	2.01	14.71	22.97	0.74	1.73	38.24	6.60	3.86
Lupin	Meal	91.12	38.47	8.49	12.95	20.16	0.23	0.61	12.52	7.20	4.18
	Extruded	91.23	38.85	10.94	13.22	21.09	0.16	1.66	8.93	7.41	4.09
Soybean	Meal	88.59	50.91	1.47	7.53	20.24	0.45	4.09	-	10.45	6.85

ADFIP = acid detergent insoluble protein
NDFIP = neutral detergent insoluble protein

Table 2. Antinutritional factors content.

Sample	Treatment type	Tannins mg/g	Poliphenols mg/g	Genistein ppm	Daizein ppm	Antitrypsin activity-TIA mg/g
Pea	Meal	0.14	11.19	0	0.10	0.89
	Extruded	0.12	8.08	0.20	0.40	0.24
	Expanded	0.34	7.54	0	0.10	0.40
	Toasted	0.39	2.27	0	0.10	0.92
Faba bean	Meal	0.47	2.49	0	0.10	0.78
	Extruded	0.42	1.07	0	0.20	0.30
Lupin	Meal	0.61	6.39	0	0.00	0.72
	Extruded	0.81	2.68	0.10	0.20	1.40
Soybean	Meal	0.39	2.09	0.70	1.60	1.30

Table 3. Effect of treatments on in vitro AOAC digestibility, enzymatic CP degradation[1] and N solubility (Data in % of initial N).

Feed	Treatment	AOAC	Enzymatic CP degradation	Solubile N
Pea	Meal	93.04^{De}	87.19^{G}	74.53^{F}
	Extruded	88.41^{Bb}	74.97^{B}	20.00^{B}
	Expanded	88.90^{Bc}	85.70^{F}	28.07^{C}
	Toasted	94.49^{Ef}	77.78^{Dd}	29.49^{C}
Faba bean	Meal	90.71^{Cd}	81.76^{E}	71.12^{E}
	Extruded	87.37^{Aa}	51.01^{A}	19.39^{B}
Lupin	Meal	96.22^{Hi}	95.01^{I}	87.18^{G}
	Extruded	95.26^{Fg}	91.06^{H}	60.84^{D}
Soybean meal		90.53^{Cd}	76.18^{C}	12.71^{A}
	SE	0.16	0.20	0.19

$^{A, B, C, D, E, F}$: $P < 0.01$; $^{a, b, c, d, e, f}$: $P < 0.05$

[1] *Protease from* Streptomyces griseus.

lupins may be due to the fact that their 7S protein fraction is made up of β-conglutin which is more soluble than vicilin and convicilin found in peas (Aufrère *et al.*, 2001a). In any case the solubility of N is much higher than in soybean which shows the lowest nitrogen solubility values (12.71%). The soybean-lupin comparison is a particularly interesting one since lupin is the protein plant with the highest protein content which is comparable with that of soybean.

It is also interesting to observe the intermediate effect of the expansion treatment on peas which have solubility values of approximately 28%, similar to what can be obtained with toasting which is characterized by the absence of the wet phase during the heat treatment.

Effect of treatments on the enzymatic degradability obtained with Streptomyces griseus

Similar to what can be observed in soluble proteins, in peas extrusion causes improved resistance to enzymatic attack (87.19% vs approx. 74.97%) while expansion induces a slight reduction (85.70%) (Table 3).

Toasting decreases protein degradation as well (77.78%) though to a slightly lower degree than the extrusion treatment.

Extrusion proved to be highly effective in faba bean increasing the by-pass value by 37%, with a two-fold increase if compared with peas. Faba beans and peas have similar protein content (20.18 % vs 24.00%), but NDF and ADF content are higher in extruded faba than in extruded peas (Table 1); the major fibre content could be the reason of higher by-pass value in faba bean when compared to peas.

Degradability increases from the extruded peas to soybean and toasted peas which showed a similar degradability to that of soybean (Table 6). Extrusion only moderately decreases lupin degradability (95.01 vs 91.06%) which is nevertheless the highest among all the investigated feedstuffs.

However, the treatments caused a slight decrease in the pepsin digestibility of the proteins as compared to the untreated products because of the increase in NDFIP which is approximately 4 percentage points in peas and faba bean. The same cannot be said for lupins where the poor effect of treatment on enzymatic solubility and degradability is accompanied by a slight drop in HCl-pepsin digestibility (Table 3).

Effect of treatments on starch enzymatic digestibility

The effects of heat treatments on starch digestibility are extremely clear both with the alpha-amylase and the amyloglucosidase treatments (Table 4).

Table 4. Starch digestibility (% of starch).

Sample	Treatment type	Alfa-Amylase Hydrolysis time 30'	 90'	 120'	Amyloglucosidase
Pea	Meal	5.94	11.89	11.96	11.80
	Extruded	26.90	38.16	39.02	39.70
	Expanded	66.98	82.56	86.85	85.37
	Toasted	7.85	12.19	13.96	10.90
Faba bean	Meal	4.70	8.94	10.42	11.39
	Extruded	53.72	96.80	91.50	85.05
Lupin	Meal	23.32	41.98	48.51	54.48
	Extruded	79.83	93.28	100.00	100.00

In peas extrusion causes an 87% digestion after 120 min, with a very marked effect already at the first detection after 30 min. of incubation (67%). This shows that heat treatment combined with a vapour-induced moisture increase induces a much stronger and faster starch gelatinization process than that obtained with an expansion treatment. Indeed the expansion process, which is less strong than the extrusion treatment, causes a less marked gelatinization effect with values of starch digestibility of only 39% (after 120 min. of incubation). Similar data are observed for extruded faba beans and lupins which show considerable starch digestion already after 30 minutes of incubation.

It is possible to identify a clear trend in the selection of the treatments to be used for monogastrics or ruminants. Wet technologies (extrusion or expansion) are clearly preferable for monogastrics in that they change the digestibility characteristics of both components, i.e. starch and protein, while toasting seems to be more interesting for ruminants in that it does not change starch degradability which is already very high in these feedstuffs.

In vitro dry matter and protein rumen degradability

Toasting, expansion and extrusion treatments significantly reduce rumen degradability during the first 8 hours of incubation (Table 5). In faba bean and pea, wet treatments cause less degradability than in soybean. Toasted peas have less degradability than the controls and the other treatments. This trend is most likely caused by the lower amount of soluble N obtained after heating as was also reported by Goelema *et al.*, (1999). As is the case for solubility, in lupin extrusion significantly reduces degradability which is, however, still higher than in soybean. After 24 hours the situation is still unchanged even if rumen degradability of course increases, while after 48 hours of incubation there is an overall flattening out and only the extrusion process can reduce N disappearance from the bags if compared to soybean or the untreated sample.

In the first 24 hours the lupin degradation values were always higher than the soybean degradation values, thus confirming what had been previously observed in relation to the effects of treatment on solubility and enzymatic degradability (*Streptomyces griseus*). This highlights that there is a problem in adapting the lupin extrusion technology to peas and faba beans which could depend on the too high starch content of these two plants when compared to lupins.

The effect of heat treatment in the presence of starch and the formation of Maillard's compounds probably further enhance protein protection against rumen degradation while in the case of lupins a similar heat treatment is not sufficient to obtain the required protein denaturation.

This shows the need to evaluate stronger treatment processes (times and temperatures) for lupin. These observations are in agreement with the data obtained by Grela *et al.* (1998).

Effect of treatments on rumen fermentability

In faba beans and peas the extrusion process increased the initial rate of rumen degradation (Table 6). Indeed up to 8 hours gas production was greater than that obtained with the meal. Over the same period of time pea toasting caused exactly the opposite behaviour which persisted until the end of the trial. Cooking reduces rumen starch degradability (Goelema *et al.*, 1998) and this could be the reason for low gas production observed in toasted pea. The absence of an effect induced by expansion in peas and extrusion in lupin may be explained by the sharp NDFIP increase induced by both treatments (Table 1). Furthermore, lupin has a low total starch content (less than 10 %) and probably draws less benefit from the extrusion process than the other feedstuffs. However, the extrusion process does not change the hydrolysable starch content (2.92 vs 2.93 % for the meal and the extruded product respectively).

Soybean has a good initial fermentation rate, probably due to the high content of simple sugars. Once this fraction is metabolized gas production slows down as shown by the data at 24 hours and later. It should be noted that in soybean and extruded peas almost two thirds of the gas production are concentrated in the first 8 hours of fermentation.

After 48 hours of fermentation the largest gas productions were obtained from peas (raw, extruded or expanded peas), followed by toasted faba beans and peas. The lowest fermentability values were found in soybean and lupin.

Table 5. In vitro dry matter and protein rumen degradation (%).

Dry matter

		Hours of incubation		
Sample	Treatment type	8	24	48
Pea	Meal	55.64^{Dd}	88.84^{Ce}	97.06^{CDde}
	Extruded	56.78^{Dd}	79.34^{Bc}	91.15^{Bb}
	Expanded	46.13^{Bb}	75.15^{Bb}	93.63^{BCcd}
	Toasted	41.71^{Aa}	79.06^{Bbc}	95.74^{CDde}
Faba bean	Meal	50.00^{BCc}	77.57^{Bbc}	86.26^{Aa}
	Extruded	47.31^{Bbc}	68.60^{Aa}	87.99^{Aa}
Lupin	Meal	66.06^{Ee}	84.89^{Cd}	92.66^{Bbc}
	Extruded	56.36^{Dd}	79.14^{Bc}	86.61^{Aa}
Soybean	Meal	53.81^{CDd}	78.40^{Bbc}	96.35^{CDe}
	SE	1.07	1.52	0.81

Crude protein

		Hours of incubation		
Sample	Treatment type	8	24	48
Pea	Meal	51.53^{Cc}	82.06^{DcE}	99.74^{Bd}
	Extruded	12.32^{Aa}	58.73^{Aa}	89.58^{Aa}
	Expanded	17.81^{Aa}	59.39^{AaB}	94.03^{AabB}
	Toasted	30.70^{Bb}	60.10^{AaB}	90.70^{Aab}
Faba bean	Meal	58.80^{Ccd}	73.64^{CbD}	89.86^{Aab}
	Extruded	13.49^{Aa}	55.37^{Aa}	92.91^{AabB}
Lupin	Meal	70.82^{De}	90.03^{Ed}	98.52^{Bcd}
	Extruded	59.91^{Cd}	81.14^{Dc}	94.28^{AabB}
Soybean	Meal	37.66^{Bb}	68.60^{BbC}	95.63^{AbB}
	SE	1.34	0.68	0.49

$^{A, B, C, D, E}$: *$P < 0.01$*; $^{a, b, c, d, e}$: *$P < 0.05$*

Table 6. Organic matter (OM) fermentability and (a+b) coefficient according to Ørskov's kinetic exponential model found in protein plants exposed to different treatments.

		ml gas / mg OM / hours of incubation					Ørskov
Sample	Treatment type	4	8	24	32	48	(a+b) %
Pea	Meal	101.25^{Cb}	183.75^{CdD}	293.75^{De}	312.50^{Ce}	331.25^{Cc}	98.23^{D}
	Extruded	135.00^{Ed}	212.50^{Ee}	288.75^{Dde}	306.25^{Ce}	326.25^{Cc}	96.10^{D}
	Expanded	101.25^{Cb}	190.00^{Dd}	291.25^{Dde}	306.50^{Ce}	323.75^{BcC}	995.68^{CbD}
	Toasted	82.50^{Aa}	170.00B^{bcC}	272.50^{CcDd}	296.25^{Bde}	316.25^{Bb}	993.27^{BCD}
Faba bean	Meal	87.50^{AaB}	167.50^{AbBc}	262.50^{BcC}	280.00^{Bcd}	300.00^{Bb}	88.23^{B}
	Extruded	111.25^{Dc}	178.75^{BcCdD}	261.25^{BbcC}	275.00^{Bbc}	298.75^{Bb}	88.80^{BCa}
Lupin	Meal	83.75^{Aa}	153.75^{Aa}	245.00^{AaBb}	257.50^{AaBb}	267.50^{Aa}	79.2^{A}
	Extruded	86.25^{Aa}	153.75^{Aa}	232.50^{Aa}	245.00^{Aa}	257.50^{Aa}	76.13^{A}
Soybean	Meal	96.25^{BbC}	166.25^{AbB}	237.50^{Aa}	251.25^{Aa}	262.50^{Aa}	76.69^{A}
	SE	2.59	4.07	5.82	6.22	6.72	1.86

$^{A, B, C, D, E:}$ $P < 0.01$; $^{a, b, c, d, e:}$ $P < 0.05$

Table 7. Correlation between analytical parameters and gas production at different times.

	Digestible starch (%DM)	Digestible starch (% starch)	Starch	NDF	ADF
Gas - 4 h	0.91**	0.42	0.45	-0.67	-0.37
Gas - 8 h	0.78*	0.06	0.75*	-0.63	-0.71*
Gas - 24 h	0.41	-0.44	0.91**	-0.43	-0.86**
Gas - 32 h	0.35	-0.51	0.94**	-0.36	-0.90**
Gas - 48 h	0.41	-0.48	0.97**	-0.29	-0.91**
(a+b)	0.42	-0.48	0.97**	-0.30	-0.90**

** P<0.05; **P<0.01*

Table 7 shows the correlation coefficients between some analytical parameters and gas production. It also shows some useful information for interpretation of the fermentability data. Gas production in the first 4 hours shows a positive relationship only to the amount of starch which is hydrolyzed by amyloglucosidase ($r = 0.914$; $P<0.01$). In the following incubation periods starch plays an important role while the role of ADF is negative.

It is therefore reasonable that the extruded pea produces more gas in the first 4 hours of fermentation since this feedstuff has a greater amount of hydrolysable starch if compared to the other bean types (Table 4).

The investigated treatments do not induce any significant changes in the (a+b) parameter of the kinetic model developed by Ørskow e McDonald (1979). This is explained by the fact that the only analytical data related to this kinetic parameter are starch and ADF content which do not show any substantial changes in peas. The lower starch content and the higher amount of fiber are most likely the cause for the lower "a+b" values found in faba beans, lupin and soybean as compared to peas. The difference between toasted pea and faba bean, however, is not significant. Faba bean show greater "a+b" values than lupin and soybean.

Conclusions

The investigated treatments reduce nitrogen solubility and, as a consequence, protein rumen degradability. Extrusion increases starch gelatinization which translates into greater gas production during the first 8 hours.

The only potentially alternative source to soybean is the extruded faba bean. In fact, even if this feedstuff has less protein content it is characterized by a considerably lower *in vitro* degradability than soybean. The results are summarized in Table 8 which shows that the soybean digestible feed protein content is comparable to that of faba beans and certainly higher than that of all other protein plants.

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Table 8. Theoretical calculation of digestible by-pass protein supply of plant source protein feeds.

Feed	Treatment	CP (% DM)	CP enzymatic degradation (%)	By-pass CP (g/kg DM)	AOAC digestibility (%)	Intestinal available CP (g/kg DM)
Pea	Meal	24.15	87.19	30.94	93.04	28.78
	Extruded	24.00	85.7	34.32	88.9	30.51
	Expanded	24.40	74.97	61.07	88.41	53.99
	Toasted	24.99	77.78	55.53	94.49	52.47
Faba	Meal	29.33	81.76	5.5	90.71	48.53
	Extruded	29.18	51.01	142.95	87.37	124.90
Lupin	Meal	38.47	95.01	19.20	96.22	18.47
	Extruded	38.85	91.06	34.37	95.26	33.09
Soybean meal		50.91	76.18	121.27	90.53	109.78

By-pass CP = CP x CP enzymatic degradation;
Intestinal available CP = By-pass CP x AOAC digestibility.

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