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Protein co-products and by-products of the biodiesel industry for ruminants feeding

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ABSTRACT - The objective of the experiment was to classify 20 protein co-products and by-products of the biodiesel industry with potential to use in ruminant feeding. The meals evaluated were: cottonseed, canudo-de-pito, crambe, sunflower, castor-oil seeds detoxified with calcium, non-detoxified castor-oil seeds and soybean; and the cakes were: cottonseed, peanut, babassu, crambe, palm oil, sunflower, licuri, macauba seeds, non-detoxified castor-oil seeds, turnip and jatropha. The samples were quantified to determine dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), neutral detergent fiber corrected for ash and protein (NDFap), non-fiber carbohydrates (NFC), acid detergent fiber corrected for ash and protein (ADFap), lignin, cutin and starch levels. The CP profile was characterized in fractions A, B1, B2, B3 and C. The in vitro dry matter digestibility (IVDMD), in vitro neutral detergent fiber digestibility (IVNDFD), rumen degradable and undegradable protein, intestinal digestibility, indigestible neutral detergent fiber and undegradable neutral detergent insoluble protein were evaluated. The OM, CP, EE, NDFap, NFC, ADFap, lignin, cutin and starch contents varied from 81.95 to 95.41%, 18.92 to 57.75%, 0.56 to 18.40%, 10.13 to 62.30%, 3.89 to 27.88%, 6.15 to 36.86%, 1.19 to 5.04%, 0 to 17.87% and 0.68 to 14.50%, respectively. The values of fractions A, B1, B2, B3 and C ranged from 5.40 to 43.31%, 0.08 to 37.63%, 16.75 to 79.39%, 1.86 to 59.15% and 0.60 to 11.47%, respectively. Concentrations of IVDMD, IVNDFD, rumen-degradable and undegradable protein, intestinal digestibility, indigestible NDF and undegradable neutral detergent insoluble protein ranged from 31.00 to 95.92%, 55.04 to 97.74%, 41.06 to 97.61%, 2.39 to 58.94, 9.27 to 94.26%, 1.05 to 40.80% and 0.29 to 2.92%, respectively. Some of these products can replace soybean meal, specially the Macauba seeds cake, cottonseed meal and peanut and turnip cakes based on digestive characteristics.

Key Words: bromatology, chemical composition, digestive traits, *in vitro* digestibility

Introduction

The total world demand for primary energy reaches 11.4 billion tons of oil equivalents per year (IEA, 2006). The increasing demand for fuels, associated to the growing environmental care, has been stimulating the search for alternative energy sources in Brazil and the whole world. Among these options, it is important to point out liquid biofuels, which represent 1.9% of the whole bioenergy produced; also, in the transport sector in the year 2005, biofuels supplied 0.9% of the entire fuel consumption (FAO, 2008).

The stimulation of biodiesel production, also, constitutes a governmental goal to reduce the dependency on external non-renewable fuel sources in Brazil. The use of renewable sources is not only appreciated through the environmental point of view, but it also plays an essential role in the establishing of family agricultural programs.

Extraction makes it possible to achieve a high number of by-products and co-products, which, without a proper destination, can generate a series of problems related to their accumulation in the environment. The production of oilseed cakes and meals corresponding to the biodiesel produced in 2008 can be estimated in 3.7 million tons; considering the same proportions, Brazil will be able to produce around 8.9 million tons of cakes in 2013 (Abdalla et al., 2008). Their composition varies according to the types of species, cultivation and extraction of the oilseeds. The cakes are obtained through mechanical extraction and the meals through extraction with solvent.

Many of these products can be used as feed for ruminants. Ruminants are capable of turning materials that are not useful for humans into animal origin products of high biological value, due to the microbial fermentative process that takes place in their gastrointestinal tracit. The use of these products can also reduce animal feeding costs.

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Inside this specific context, the objective of this study was to assess chemical and digestive characteristics of protein co-products and by-products in the biodiesel industry with potential use as ruminant feeding.

Material and Methods

The experiment was conducted at the facilities of the Animal Nutrition Laboratory at Universidade Federal de Viçosa, at the Animal Science Department. Twenty cake and seed samples were evaluated, each one corresponding to protein co-products and by-products originated from the biodiesel industry in different parts of the country that presented potential use as ruminant feeding. These co-products and by-products were: cottonseed meal and cake (*Gossypium spp.* L.); two peanut cakes (*Arachis hypogaea*); babassu cake (*Orbignya speciosa*); canudo-de-pito meal (*Mabea fistulifera* Mart); crambe meal and cake (*Crambe abyssinica*); palm oil cake (*Elaeis guineensis*); sunflower meal and cake (*Helianthus annuus*); licuri cake (*Syagrus coronata*); macauba seeds cake (*Acrocomia aculeata)*; castor-oil seeds meal detoxified with calcium and non-detoxified (*Ricinus communis*); non-detoxified castor-oil seeds cake; turnip cake (*Raphanus sativus*); two jatropha cakes (*Jatropha curcas*); and soybean meal (*Glycine max*). The soybean meal sample was used as a reference for the evaluation of the other material used.

The amounts of dry matter (DM), ash, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin (potassium permanganate method) and cutin were quantified according to the methods described by Silva & Queiroz (2002). In order to quantify the amounts of NDF and ADF corrected for ash and protein (NDFap and ADFap, respectively), the concentrations of neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP), neutral detergent insoluble ash (NDIA) and acid detergent insoluble ash (ADIA), were evaluated also according to the methods described by Silva & Queiroz (2002).

In order to evaluate the amount of ether extract (EE), co-products and the by-products were placed into XT4 (Ankom®) bags and subjected to extraction by the AOCS (2009) official high temperature method, using XT15 (Ankom®) extractor.

The formula (Detmann & Valadares Filho, 2010) NFC = OM – (CP + EE + NDFap) was used to calculate non-fiber carbohydrates (NFC).

To quantify the starch levels in the material, the samples were sent to the Animal Nutrition Laboratory of the Veterinary Medicine School in Universidade Federal de Minas Gerais. The quantification of the starch levels by the enzymatic technique was done through modified amyloglucosidase – α-amylase (McCleary et al., 1997).

Samples ground to 1 mm were used for the evaluation of the *in vitro* dry matter digestibility (IVDMD) and the *in vitro* neutral detergent fiber digestibility (IVNDFD). For ruminal incubation and quantification of the rumen degradable protein, rumen undegradable protein, intestinal protein digestibility, indigestible NDF (iNDF) and undegradable neutral detergent insoluble protein, the samples used were ground to 2 mm.

The IVDMD was evaluated according to the methodology proposed by Tilley & Terry (1963), in two different fermentation stages, for 48 hours of incubation. After obtaining the residues of the IVDMD, the residues of NDF were evaluated in order to quantify the IVNDFD. For the inoculation, a ruminal liquid obtained from a non-castrated and fistulated bovine male, fed with grass and supplemented with 2 kg of feed a day (20% CP), was used.

Intestinal digestibility was analyzed through the three stages method according to the method described by Calsamiglia & Stern (1995). Samples in nylon bags were incubated for 16 hours inside a non-castrated male bovine, fed with grass and supplemented with 2 kg of feed a day, keeping the proportions of 20-25 mg of sample/cm^2. After ruminal incubation, the bags were washed in running water up to total cleaning and placed in a forced ventilation oven, under a temperature of 60 ºC, for 48 hours.

Later, the nitrogen (N) present in the residue (Silva & Queiroz, 2002) was quantified. Aliquots containing 15 mg of N were placed in 50 mL centrifugal tubes. The tubes were then incubated with 10 mL of a 0.1-N solution of HCI, containing 1 g/L of pepsin (pH = 1.9), and put under agitation to a speed of 40 rpm, for 1 hour at a temperature of 38 ºC. Next, 0.5 mL of 1 N of a NaOH solution was added, in order to neutralize acidity, and 13.5 mL of pancreatin solution, containing: 0.5 M of KH_2PO_4 (pH = 7.8) solution, 50 ppm of thymol, to prevent microbial development, and 3 g/L of pancreatin. These were kept under agitation for 24 hours at a speed of 40 rpm and temperature of 38 ºC. At the end of the digestion, 3 mL of a trichloroacetic acid (TCA) 100% (weigh/volume) solution was added, in order to stop enzymatic activity and to precipitate non-digested protein. The samples were centrifuged for 15 minutes at 10.000 x *g* and the supernatant of the tubes was used for residual N evaluation through the Kjeldahl method (Silva & Queiroz, 2002). Intestinal digestibility of the rumen-undegradable protein was calculated as the ratio between the amount of

CP digested after pepsin incubation and the amount of incubated protein.

The proportion of rumen-degradable and undegradable protein in the CP was estimated through the relation between the amount of CP incubated in the rumen, and the non-degraded rumen protein after 16 hours of animal incubation. The digestible rumen-undegradable protein was calculated through the multiplication of the rumen-undegradable protein by the protein intestinal digestibility, which is determined by the three-stage method.

The estimate of the indigestible neutral detergent fiber was made through *in situ* incubation procedures for 240 hours, inside a non-castrated fistulated bovine male, fed with grass and supplemented with 2 kg concentrate/day, following the procedures described by Casali et al. (2008) and using non-woven fabric (100 g/m^2) bags as incubation containers. The residue of the indigestible NDF was then used to estimate undegradable neutral detergent insoluble protein, as described by Detmann et al. (2004) and defined as the approximate to the parametrical value of the cellular walls undegradable protein.

For the quantification of non-protein nitrogen (NPN, fraction A) through the trichloroacetic acid method (TCA) and the true soluble protein (fraction B1), obtained by soluble fraction in borate-phosphate tampon (fraction A+B1) minus the TCA soluble fraction (fraction A), the methods followed were the ones described by Licitra et al. (1996).

The division of the protein fractions was related to the speed at which protein is degraded by enzymes. The borate-phosphate soluble protein is known as fraction A (NPN) + B1 (true soluble protein). Fraction B1 is calculated by the subtraction of the NPN fraction, from fraction A+B1 (Licitra et al., 1996). B1 is easily degraded and converted into ammonia in the rumen (Sniffen et al., 1992).

Fraction C (indigestible fraction) was quantified as the undegradable neutral detergent insoluble protein. Fraction B3 is represented by the extensins, which are linking proteins from the cellular walls that present a slow degradation rate and, because of that, are mainly digested in the intestines (Cabral et al., 2004). The value of fraction B3 was obtained by the difference between neutral detergent insoluble protein and undegradable neutral detergent insoluble protein.

Fraction B2 presents variable fermentation. One of its parts is fermented in the rumen and the other part escapes to the small intestines. The destination of fraction B2 depends on the rates of digestion and passage (Sniffen et al., 1992). Fraction B2 was calculated by the difference between the total CP levels minus fractions A, B1, B3 and C.

The difference in nutritional value, based on discriminatory variables between the groups, was estimated by grouping analysis, using the average euclidian distance along with standardized variables and the grouping methods by optimization (Tocher method). All statistical analyses were according to the software SAEG (Sistema para Análises Estatísticas, version 9.1).

Results and Discussion

The concentrations of DM are considered excellent for storage and likely to be conserved for a long period of time since the lower water level decreases microbial activity (Gomes, 2007).

It is possible to observe that the OM in the feedstuff ranged from 81.95 to 95.41% in the detoxified castor-oil seeds meal and the licuri cake, respectively. Concentrations similar to the ones found in this research were observed by Silva et al. (2008b) in soybean meal and jatropha cakes (92.90 and 93.60%, respectively).

The concentrations of CP ranged from 18.92 to 57.75%, for the licuri cake and the canudo-de-pito meal, respectively. The concentrations of CP in the detoxified castor-oil seeds meal, turnip cake, jatropha cake I, palm oil cake, soybean meal, crambe cake and turnip cake II are similar to the ones observed in literature by Oliveira et al. (2004), Neiva Júnior et al. (2007), Arieta et al. (2009), Menezes et al. (2009) and Souza et al. (2009). The concentrations of CP in sunflower, cottonseed and non-detoxified castor-oil seeds cakes, and in the cottonseed meal differed from the ones obtained by Neiva Júnior et al. (2007), Silva et al. (2008b) and Arieta et al. (2009), respectively. They observed respective levels of 31.26; 35.00; 26.50 and 27.58%. This variation in the results seem to be due to the difference in oil extraction methods in the industry and consequently in the non-standardized meal and cake production, available for cattle raising.

The concentrations of EE ranged from 0.56 to 18.40% for crambe meal and cake, respectively. Similar levels to some co-products and by-products are obtained in the literature: Arieta et al. (2009) found EE levels of 5.73 and 13.24% in the turnip and palm oil cakes, respectively.

The concentrations of NDFap were 10.13 and 62.30% in canudo-de-pito meal and the babassu cake, respectively. The level of NDFap in cottonseed cake is similar to the one mentioned by Silva et al. (2008b); this level was 46.30%. The sunflower meal level of 21.8% presented in the research of Marcondes et al. (2009) is rather lower than the one observed in Table 1. Neutral detergent fiber directly influences voluntary consumption and nutritional value, as a result of

Table 1 - Chemical composition of feedstuffs

Feedstuffs	DM (%)	Item[1]								
		OM	CP	EE	NDFap	NFC	ADFap	Lignin	Cutin	Starch
Cottonseed meal	87.61	91.92	54.14	2.10	23.27	12.40	13.05	2.75	1.46	1.83
Cottonseed cake	91.58	94.86	31.37	9.31	46.96	7.22	28.69	3.39	5.17	0.87
Peanut cake I	88.71	94.87	52.02	5.18	15.26	22.41	10.05	1.38	2.00	2.78
Peanut, cake II	92.17	92.00	42.97	15.14	12.75	21.14	6.15	2.56	2.55	5.80
Babassu cake	93.20	94.45	19.06	9.20	62.30	3.89	33.91	4.22	7.04	1.03
Canudo-de-pito meal	89.02	92.30	57.75	3.15	10.13	21.27	6.60	2.11	2.56	0.70
Crambe meal	84.59	91.56	43.11	0.56	35.77	12.12	24.04	3.12	6.69	2.13
Crambe cake	86.37	92.06	32.61	18.40	27.64	13.40	18.61	3.06	3.94	0.76
Palm oil cake	89.41	92.44	19.60	5.37	60.10	7.36	36.86	5.04	8.89	1.61
Sunflower meal	89.81	93.78	27.77	1.06	48.59	16.36	31.49	3.61	4.71	2.59
Sunflower cake	88.41	93.41	28.78	2.11	39.00	23.52	24.78	3.74	5.46	0.85
Licuri cake	93.30	95.41	18.92	16.59	52.18	7.72	30.05	3.78	13.93	1.89
Macauba, seeds cake	89.65	94.85	37.31	8.66	44.91	3.97	28.59	3.51	7.56	1.93
Castor-oil seed detoxified meal	88.67	81.95	35.32	2.66	32.62	11.35	24.68	1.97	17.87	2.45
Castor-oil seeds non-detoxified meal	88.82	89.53	55.83	2.16	27.21	4.33	23.38	1.56	12.30	2.20
Castor-oil seeds non-detoxified cake	90.34	91.60	48.21	10.36	24.30	8.72	18.84	1.89	14.26	0.68
Turnip cake	91.72	93.03	37.45	13.89	15.37	26.32	14.27	3.35	3.34	1.96
Jatropha cake I	91.91	93.22	25.32	13.38	42.22	12.29	33.10	4.09	17.53	0.99
Jatropha cake II	91.92	93.02	28.35	8.67	43.31	12.69	36.21	4.32	16.66	1.09
Soybean meal	88.90	93.15	49.20	1.00	15.07	27.88	7.73	1.19	0.00	14.50

[1] % in dry matter (DM); OM - organic matter; CP - crude protein; EE - ether extract; NDFap - neutral detergent fiber corrected for ash and protein; NFC - non-fiber carbohydrates; ADFap - acid detergent fiber corrected for ash and protein.

its insolubility in neutral conditions, as the rumen, and in general, due to its slow utilization by ruminal microorganisms, in comparison with the components of the other feedstuffs (Detmann et al., 2008b).

Regarding NFC, concentrations ranged from 3.89 to 27.88%, for babassu cake and soybean meal, respectively. In the literature, different concentrations were found in sunflower cake and soybean meal: 47.01 and 36.14%, respectively, reported by Marcondes et al. (2009).

The concentrations of ADF corrected for nitrogen and protein (ADFap) ranged from 6.15 to 36.86% for peanut cake II and palm oil cake, respectively. Concentrations of ADFap different from the observed in this research were reported by Marcondes et al. (2009), who obtained levels of 15.64 and 4.29% in sunflower and soybean meals, respectively.

Lignin concentrations ranged from 1.19 to 5.04% in soybean meal and babassu cake, respectively. In palm oil and babassu cakes and in the detoxified castor-oil seeds meal, the levels obtained by Moreira et al. (2003), Gomes (2007) and Silva et al. (2008a) were 24.60, 17.90% and 12.24%, respectively. This suggests that the feedstuffs analyzed by these authors were contaminated by cutin, possibly because of the lignin analysis method.

Cutin concentrations ranged from 0 to 17.87% in soybean and detoxified castor-oil seeds meals, respectively. Cutin is presented as a barrier to ruminal microorganisms (Van Soest, 1994).

Starch levels ranged from 0.68 to 14.50% in the non-detoxified castor-oil seeds cake and soybean meal, respectively. The level of starch in soybean meal was a different number from that reported by Valadares Filho et al. (2006), of 8.89%. The difference between the starch level numbers could be due to the variation in the results to which the enzymatic methods can be subjected (Saliba, 2009).

The first group (GI) was formed by 14 feedstuffs; the second group (GII) by four feedstuffs; and the groups three (GIII) and four (GIV) by one feedstuff each (Table 2). The Tocher method, adopted in this research, leads to group establishment so that there is homogeneity inside the group and heterogeneity between them. The variable of greatest contribution for the proposed grouping was CP (27.40%), followed by EE (14.20%), NDFap (13.70%), NFC (12.10%), lignin (11.60%), OM (11.10%), cutin (4.74%), starch (3.16%) and, lastly, ADFap (2.11%).

The concentration of CP was found to be the main characteristic separating the groups, basically in: GI and GIII, they presented the lowest levels of CP, around 34%. The ones with the highest CP levels were GII and GIV, around 50%. It was verified that GI and GIII, still containing a similar amount of CP, were separated due to the fact that GIII presents lower OM levels than GI (81.95 and 93.26%, respectively).

Another difference between these two groups was that GI presented an 8.55% concentration of EE, compared with

Table 2 - Feedstuff groups based on chemical composition

Group	Feedstuff	Item[1]								
		OM	CP	EE	NDFap	NFC	ADFap	Lignin	Cutin	Starch
I	Cottonseed meal Cottonseed cake Babassu cake Crambe meal Crambe cake Palm oil cake Sunflower meal Sunflower cake Licuri cake Macauba seeds cake Castor-oil seeds non-detoxified cake Turnip cake Jatropha cake I Jatropha cake II	93.26	32.29	8.55	40.42	12.00	26.61	3.56	8.33	1.44
II	Peanut cake I Peanut cake II Canudo-de-pito meal Castor-oil seeds non-detoxified meal	92.18	52.14	6.41	16.34	17.29	11.55	1.90	4.85	2.87
III	Castor-oil seeds detoxified meal	81.95	35.32	2.66	32.62	11.35	24.68	1.97	17.87	2.45
IV	Soybean meal	93.15	49.20	1.00	15.07	27.88	7.73	1.19	0.00	14.50
Contribution for discrimination (%)		11,10	27.40	14.20	13.70	12.10	2.11	11.60	4.74	3.16

[1] % mean values based on organic matter; OM - organic matter; CP - crude protein; EE - ether extract; NDFap - neutral detergent fiber corrected for ash and protein; NFC - non-fiber carbohydrates; ADFap - acid detergent fiber corrected for ash and protein.

2.66% in GIII. In GII and GIV, the average concentrations of EE were 6.41 and 1.00%, respectively.

The concentration of NDFap was an important characteristic for feedstuffs clustering. GI and GIII presented elevated NDFap levels of 40.42 and 32.62%, respectively. On the other hand, GII and GIV presented NDFap levels of 16.34 and 15.07%, respectively.

The concentration of NFC, like the one observed for CP, was smaller than the ones in GI and GIII, which were 12.00 and 11.35%, respectively. GII and GIV presented more elevated NFC levels: 17.29 and 27.88%, respectively.

Another significant difference between GI and GIII was the amount of cutin. The former had 8.33 and the latter, 17.87%. GIII was the group that presented the highest cutin level; this high cutin level separates GIII and GI completely, although they remain similar in other items. GII and GIV presented largely different cutin levels although they had similar levels of some of the components. GIV, which was exclusively formed by soybean meal, did not present cutin and GIII presented an average level of 4.85%.

Regarding lignin levels, the highest level was observed in GI (3.56%); groups II, III and IV presented lignin levels that were below 2%. Regarding starch levels, the highest mark was in GIV (14.50%). This number separates GIV from the other three groups.

Soybean meal (GIV) presented the best chemical composition; however, GII presented similar chemical characteristics, with higher EE levels and lower starch levels than GIV.

The division of protein levels (Table 3) was done according to the Cornell Net Carbohydrate and Protein System (Fox et al., 2004), and according to suggestion of Detmann et al. (2004), fraction C was modified.

The heating of the material generates a general reduction in cytoplasmatic protein through denaturing. The degree of the solubility reduction depends on circumstances, more specifically temperature and or, the time of heating applied to the material (Van Soest, 1994). Therefore, protein fractioning allows a more precise use of nutrients in animal feeding, which also enables a prediction regarding protein digestibility on the feedstuff with predictive models and equations.

Fraction A, or NPN, ranged from 5.40 to 43.31% for soybean meal and crambe cake, respectively. Levels of fraction B1 ranged from 0.08 to 37.63% in non-detoxified castor-oil seeds meal and in peanut cake I, respectively. Levels of fraction B2 were between 16.75 and 79.39% for palm oil cake and soybean meal, respectively. Levels of fraction B3 ranged from 1.86 to 59.15%, corresponding to turnip and palm oil cake, respectively. Protein supplements have low levels of fraction B3, but, on the other hand, co-

Table 3 - Crude protein chemical profile

Feedstuff	Fraction[1]				
	NPN	B1	B2	B3	C
Cottonseed meal	9.61	1.61	76.40	11.23	1.15
Cottonseed cake	12.01	1.39	77.97	5.31	3.32
Peanut cake I	24.63	37.63	34.62	2.38	0.74
Peanut cake II	20.74	36.04	38.04	4.32	0.87
Babassu cake	9.02	0.19	41.32	41.51	7.96
Canudo-de-pito meal	8.11	13.76	74.26	2.00	1.88
Crambe meal	30.01	1.92	55.47	9.20	3.40
Crambe cake	43.31	3.60	46.72	3.14	3.22
Palm oil cake	8.53	4.10	16.75	59.15	11.47
Sunflower meal	11.65	23.83	50.73	11.04	2.76
Sunflower cake	9.18	1.36	65.70	20.77	2.98
Licuri cake	18.68	3.48	61.57	11.53	4.74
Macauba seeds cake	13.68	15.89	65.17	2.90	2.37
Castor-oil seeds detoxified meal	21.42	0.20	65.56	4.56	8.26
Castor-oil seeds non-detoxified meal	18.13	0.08	71.65	7.01	3.12
Castor-oil seeds non-detoxified cake	26.78	3.36	64.11	2.93	2.81
Turnip cake	40.08	3.40	50.81	1.86	3.84
Jatropha cake I	12.97	1.38	76.70	4.06	4.89
Jatropha cake II	12.71	12.49	64.02	5.39	5.39
Soybean meal	5.40	0.15	79.39	14.47	0.60

[1] % of crude protein.NPN - non-protein nitrogen. The NPN quantification (fraction A) was determined by the trichloroacetic acid (TCA) method and fraction B was obtained by the soluble in a borate-phosphate tampon fraction (fraction A+B1) minus soluble in TCA fraction (fraction A). Fraction C was quantified as the undegradable neutral detergent insoluble protein (UNDIP). Fraction B3 value was obtained by the difference between NDIP and UNDIP. Fraction B2 was calculated by the difference between total CP minus fractions A, B1, B3 and C.

products and by-products have a significant amount of this fraction (Krishnamoorthy et al., 1982).

Fraction C presented soybean meal level of 0.60 and palm oil cake, of 11.47%. This fraction represents the indigestible part of crude protein, therefore, not available for the animal.

Fractioning CP is important because the consideration of CP in feedstuff, as a homogeneous entity, could lead to distortions on the estimates of the fraction that is apparently digestible regarding chemical composition of feedstuffs produced in tropical conditions. This way, partitioning total CP would lead to a more accurate estimate of the dietetic levels of apparently digestible CP (Detmann et al., 2008a).

Four groups were formed and the variable of greater contribution in discrimination was fraction B1 (28.90%), followed by B2 (22.60%), B3 (20.00%), NPN (18.40%) and fraction C (10.00%). The first group (GI) was formed by 14 feedstuffs, the second group (GII) by three feedstuffs, the third group (GIII) by two feedstuffs, and the fourth group (GIV) by one feedstuff (Table 4). It is possible to observe that GIV levels of fraction B2 and NPN were similar to the ones in GI; however, the levels of fraction B1 were largely different between the two groups and that brought them apart. Also, GI presented lower and higher fraction C and fraction B3 levels than GIV, respectively. These numbers were 3.12 and 7.27% in GI and 8.26 and 4.56% in GIV, respectively.

GII presented NPN levels similar to the ones found in GI; however, fraction B1 was different, with 32.50% in GII and 4.56% in GI. There was also difference between the levels of fractions B2, B3 and C for both groups, these values were 66.42, 7.27 and 3.12% in GI, respectively, and 41.13, 5.91 and 1.45% in GII, respectively.

GIII presented more protein associated to the fiber, corresponding to fraction B3. Feedstuffs from this group presented the highest levels of NDFap (Table 1).

Excluding babassu and palm oil cake, cakes presented good CP chemical profiles due to the low level of fractions B3 and C and, especially, to high proportions of fractions B1 and B2, allowing part of this protein to be fermented in the rumen and part to escape to small intestines, resulting in better uses of CP.

In vitro dry matter digestibility ranged from 31.00 to 95.92% for detoxified castor-oil seeds and soybean meal, respectively (Table 5). Regarding the percentage of IVNDFD, they were between 55.04 and 97.74% for licuri cake and soybean meal, respectively. Inferior values of IVNDFD are related to higher proportions of indigestible NDF and can be due to higher proportions of peel in some feedstuffs.

The concentration of rumen-degradable protein ranged from 41.06 to 97.61% for palm oil cake and peanut cake I, respectively. The concentration of rumen-degradable protein in soybean and cottonseed meals differed from the ones reported by Cabral et al. (2001), which were 50.86 and 64.71%, respectively. The CP of peanut cakes I and

Table 4 - Feedstuff groups based on crude protein profile

Group	Feedstuff	Average concentration[1]				
		NPN	B1	B2	B3	C
I	Cottonseed cake Cottonseed meal Canudo-de-pito meal Crambe meal Crambe cake Sunflower cake Licuri cake Macauba seeds cake Castor-oil seeds non-detoxified meal Castor-oil seeds non-detoxified meal Turnip cake Jatropha cake I Jatropha cake II Soybean meal	18.62	4.56	66.42	7.27	3.12
II	Peanut cake I Peanut cake II Sunflower meal	19.01	32.50	41.13	5.91	1.45
III	Babassu cake Palm oil cake	8.77	2.15	29.03	50.33	9.71
IV	Castor-oil seeds detoxified meal	21.42	0.20	65.56	4.56	8.26
Contribution to discrimination (%)		18,40	28.90	22.60	20.00	10.00

[1]% of crude protein.NPN - non-protein nitrogen.

II, turnip, crambe and non-detoxified castor-oil seeds cakes, in a similar way to the one in cottonseed and canudo-de-pito meals, presented high rumen degradation; this fact deserves special attention when those elements are added to animal feeding. This is because great nitrogen loss can take place in the rumen so there is the necessity of including energy sources of high availability, since microbial synthesis greater efficiency happens when the rates of degradation of protein and carbohydrates are similar (Lana, 2005).

The concentration of rumen-undegradable protein is inversely proportional to the concentration of rumen-degradable protein in feedstuffs. As examples of feedstuffs with high concentration of rumen-undegradable protein, one can point out babassu, palm oil, sunflower and licuri cakes and macauba seeds cake.

Regarding the values observed in the intestinal digestibility of the rumen-undegradable protein, the numbers ranged from 9.27 to 94.26%, in canudo-de-pito and soybean meals, respectively. In soybean meal, this number is in accordance to the ones of 89.9% obtained by Calsamiglia & Stern (1995), and of 91.86%, by Marcondes et al. (2009). For cottonseed meal, intestinal digestibility percentage close to that obtained in this research was reported by Cabral et al. (2001), which was 53.66%.

Macauba seeds cake also presented high intestinal digestibility, close to the one obtained in soybean meal. This fact can be attributed to the good quality of protein that was retained in the rumen-undegradable protein portion. Peanut cake II, sunflower, licuri and non-detoxified castor-oil seeds cakes presented intestinal digestibility superior to 80%.

Concentrations of digestible rumen-undegradable protein between 0.33 and 53.32% were obtained in canudo-de-pito meal and macauba seeds cake, respectively. It is possible to notice that babassu, palm oil, sunflower, licuri and macauba seeds cakes presented digestible rumen-undegradable protein concentration superior to the one presented by soybean meal. Rumen-degradable protein and digestible rumen-undegradable protein fractions are of great importance, since diets in which there is excessive CP or rumen-degradable protein might present a certain asynchrony between protein degradation and energy availability in the rumen. On the other hand, diets presenting inadequate amounts of ammonia and rumen-degradable protein limit microbial development and impair the digestion for carbohydrates fiber fraction (Santos, 1999).

Among ruminants, the greatest part of the capacity in providing the energy necessary for animal maintenance or production refers to the way NDF interacts with microbial enzymatic systems which are responsible for NDF

Table 5 - Digestive characteristics of the feedstuffs

Feedstuff	IVDMD	IVNDFD	RDP[1]	RUP[1]	ID	$_{D}$RUP [1]	iNDF[2]	UNDIP[2]
Cottonseed meal	79.36	89.10	90.86	9.14	47.78	4.37	18.85	0.62
Cottonseed cake	66.16	73.21	79.87	20.13	43.30	8.72	23.48	1.04
Peanut cake I	90.03	93.28	97.61	2.39	46.09	1.10	6.05	0.38
Peanut cake II	93.39	95.65	91.78	8.22	81.73	6.72	4.64	0.37
Babassu cake	62.66	66.71	46.17	53.83	65.69	35.37	40.71	1.52
Canudo-de-pito meal	88.85	94.66	96.44	3.56	9.27	0.33	5.11	1.08
Crambe meal	65.72	72.52	70.40	29.60	50.29	14.88	21.87	1.46
Crambe cake	64.16	78.45	92.44	7.56	15.49	1.17	18.95	1.05
Palm oil cake	66.44	70.69	41.06	58.94	53.71	31.66	22.75	2.25
Sunflower meal	61.03	64.44	84.81	15.19	43.99	6.68	28.61	0.77
Sunflower cake	60.87	66.43	41.42	58.58	81.94	48.00	24.75	0.86
Licuri cake	47.97	55.04	56.61	43.39	81.26	35.25	35.06	0.90
Macauba seeds cake	82.74	85.61	42.89	57.11	93.35	53.32	12.13	0.88
Castor-oil seeds detoxified cake	31.00	60.13	62.67	37.33	64.82	24.20	31.98	2.92
Castor-oil seeds non-detoxified meal	74.88	78.86	67.92	32.08	56.59	18.15	36.90	1.74
Castor-oil seeds non-detoxified cake	70.91	77.42	85.21	14.79	80.53	11.91	32.08	1.36
Turnip cake	84.65	88.35	94.16	5.84	12.76	0.75	9.87	1.44
Jatropha cake I	57.14	62.66	70.92	29.08	65.11	18.93	34.71	1.24
Jatropha cake II	57.13	62.40	72.61	27.39	56.38	15.44	40.80	1.53
Soybean meal	95.92	97.74	67.95	32.05	94.26	30.21	1.05	0.29

[1] % in CP.
[2] % in dry matter (DM).IVDMD - *in vitro* DM digestibility; IVNDFD - *in vitro* neutral detergent fiber digestibility; RDP - rumen degradable protein; RUP - rumen undegradable protein; ID - intestinal digestibility of RUP; $_{D}$RUP - digestible RUP; iNDF - indigestible neutral detergent fiber; UNDIP - undegradable neutral detergent insoluble protein.

degradation and use (Detmann et al., 2008b). For some times, the digestible NDF fraction constitutes the main energetic fraction in tropical feedstuffs; the indigestible NDF fraction limits consumption due to the gastrointestinal tract-filling factor. The indigestible NDF fraction ranged from 1.05 to 40.80% for soybean meal and jatropha cake II, respectively. High indigestible NDF concentrations in jatropha cakes I and II, babassu, licuri and non-detoxified castor-oil seeds cakes, and in castor-oil seeds detoxified and non-detoxified meals might be due to the elevated amount of peel found in these feedstuffs. Indigestible NDF concentration in soybean meal was inferior to the one presented by Valadares Filho et al. (2006), who reported a total number of 2.11%.

Regarding undegradable neutral detergent insoluble protein concentration, numbers ranged from 0.29 to 2.92% in soybean and non-detoxified castor-oil seeds meals, respectively.

Five groups were formed and variables of greater contribution for discrimination were IVNDFD and rumen-degradable protein, both with contribution values of 23.20% (Table 6). Indigestible NDF came second with 13.70%, followed by rumen-undegradable protein (8.95%), undegradable neutral detergent insoluble protein (8.42%), IVDMD and intestinal digestibility with the same contribution (7.89%) and digestible rumen-undegradable protein (6.84%).

GII and GIV, though with similar values of IVDMD, IVNDFD, indigestible NDF and undegradable neutral detergent insoluble protein, presented different levels of rumen-degradable protein. GII presented higher rumen-degradable protein concentration; unlike GIV, the numbers were 95.00 and 55.42%, respectively. GII presented intestinal digestibility and digestible rumen-undegradable protein concentration a lot inferior to the numbers in GIV: 37.46 and 2.22% in GII and 93.80 and 41.76% in GIV, respectively.

GV, formed by non-detoxified castor-oil seeds meal only, presented the lowest numbers of IVDMD and IVNDFD and the highest numbers of indigestible NDF and rumen-undegradable protein compared with the other groups. GV, however, presented similar IVNDFD to the one presented by GIII, the difference was the fact that intestinal digestibility and digestible rumen-undegradable protein were superior in GIII, these numbers were 64.82 and 24.20% in GV and 70.65 and 37.57% in GIII, respectively.

GI and GIII presented similar indigestible NDF and undegradable neutral detergent insoluble protein, although GI had superior IVDMD, IVNDFD and rumen-degradable protein concentration to the ones in GIII: 66.28; 73.23 and 79.45% in GI, respectively, and 59.49; 64.72 and 46.31% in GIII, respectively. GI presented inferior intestinal digestibility and digestible rumen-undegradable protein numbers compared with GIII: 51.05 and 11.14% in GI, respectively, and 70.65 and 37.57% for GIII, respectively.

It is possible to observe that GIII and GIV presented similar digestible rumen-undegradable protein and rumen digestible protein concentrations. GIV, however presented

Table 6 - Feedstuff groups based on digestive characteristics

Group	Feedstuff	Average concentration							
		IVDMD	IVNDFD	RDP[1]	RUP[1]	ID	$_{D}$ RUP[1]	iNDF[2]	UNDIP[2]
I	Cottonseed meal Cottonseed cake Crambe meal Crambe cake Sunlower meal Castor-oil seeds non-detoxified meal Castor-oil seeds non-detoxified cake Jatropha cake I Jatropha cake II	66.28	73.23	79.45	20.55	51.05	11.14	28.47	1.20
II	Peanut cake I Peanut cake II Canudo-de-pito meal Turnip cake	89.23	92.98	95.00	5.00	37.46	2.22	6.42	0.82
III	Babassu cake Palm oil cake Sunflower cake Licuri cake	59.49	64.72	46.31	53.69	70.65	37.57	30.82	1.38
IV	Macauba seeds cake Soybean meal	89.33	91.67	55.42	44.58	93.80	41.76	6.59	0.59
V	Castor-oil seeds detoxified meal	31.00	60.13	62.67	37.33	64.82	24.20	31.98	2.92
Contribution for discrimination (%)		7,89	23.20	23.20	8.95	7.89	6.84	13.70	8.42

[1] % in crude protein (CP).[2] % in dry matter (DM).IVDMD - *in vitro* DM digestibility; IVNDFD - *in vitro* NDF digestibility; RDP - rumen degradable protein; RUP - rumen undegradable protein; ID - intestinal digestibility of RUP; $_{D}$RUP - digestible RUP; iNDF - indigestible neutral detergent fiber; UNDIP - undegradable neutral detergent insoluble protein.

higher IVDMD and IVNDFD, which were 89.33 and 91.67% in GIV, and 59.49 and 64.72% in GIII, respectively. GIV presented rather inferior indigestible NDF and undegradable neutral detergent insoluble protein concentrations, in GIV the numbers were 6.59 and 0.59%, and in GIII, the numbers were 30.82 and 1.38%, respectively.

According to biological characteristics of the feedstuffs, GIV had the best characteristics due to high IVNDFD and intestinal digestibility and having great proportion of rumen-degradable protein and rumen-undegradable protein and low indigestible NDF and undegradable neutral detergent insoluble protein concentrations. Regarding digestive characteristics, macauba seeds cake was similar to soybean meal.

Conclusions

The different types of co-products and by-products can be part of ruminant animal feeding when used properly; they can also be used as protein feedstuffs. Soybean meal was the component presenting the best nutritional composition, although other products as macauba seeds cake, cottonseed meal and peanut and turnip cakes had presented good composition as well. Testing feedstuffs during *in vivo* evaluations is highly recommended in order to establish the possibility of whether or not to use these feedstuffs and which would be the best amount to include them.

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