Literature Reviews

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Biodiesel industry by-products used for ruminant feed¤

Co-productos de biodiésel utilizados en la alimentación de rumiantes

Coprodutos do biodiesel utilizados na alimentação de ruminantes Biodiesel by-products used as ruminant feed

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Summary

Biodiesel industry by-products appear to be an excellent alternative source for ruminant feed and may contribute to increased agricultural activity in terms of productivity and profitability. Among the various by-products, oilseed cakes have great potential for use due to their high protein and lipid contents, which make them an energetic feed source that would fulfill the nutritional requirements of animals. Thus, studies that aim to determine the optimum levels of oilseed cake in ruminant feed are important for maximizing the potential use of these by-products.

Key Words: *cattle, goats, nutrition, oilseed cake, sheep.*

Resumen

El uso de los subproductos de la industria de biodiesel para alimentar a los rumiantes parece ser una excelente alternativa, que puede contribuir al aumento de las actividades agrícolas en términos de productividad y rentabilidad. Entre los sub-productos, las tortas de semillas oleaginosas tienen un gran potencial debido a los importantes niveles de proteínas y lípidos que las caracterizan como alimentos proteicos o energéticos capaces de satisfacer las necesidades nutricionales de los animales. Así, los estudios que tienen como objetivo determinar los niveles óptimos de tortas de semillas oleaginosas en los piensos para rumiantes son importantes para maximizar el uso potencial de estos subproductos.

Palabras clave: *cabras, nutrición, ovejas, tortas de semillas oleaginosas, vacas.*

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Resumo

A utilização de coprodutos oriundos da produção do biodiesel na alimentação de ruminantes surge como alternativa, que pode contribuir para o crescimento das atividades agropecuárias, em termos de produtividade e rentabilidade. Dentre os coprodutos, as tortas apresentam grande potencial, haja vista as consideráveis concentrações de proteína e extrato etéreo, que as caracterizam como alimentos protéicos e/ou energéticos, capazes de permitir o atendimento das exigências nutricionais destas frações pelos animais. Desta forma, é importante a realização de estudos que determinem os níveis ótimos de aplicação das diversas tortas oleaginosas, visando à busca de melhores resultados.

Palavras chave*: bovinos, caprinos, nutrição, ovinos, torta de oleaginosas.*

Introduction

Global warming and an increasing demand of liquid fuels worldwide have prompted research on biofuels. In particular, attention has been given to biodiesel, which derives from both animal fats and vegetable oils. However, vegetable oils are the more important biological source for this industry, and as a result, the various sectors involved in biodiesel production have become increasingly interested in research on oleaginous plants. Studies focusing on the by-products of this new agricultural industry are only beginning to emerge, but it is important to emphasize that maximal use of all products generated during biodiesel production would be economically beneficial and increase the industry's competitiveness with mineral oil diesel.

The use of by-products to feed ruminants is an alternative that may improve the efficiency of the biodiesel industry and improve the productivity and profitability of agrarian activities, such as the rearing of cattle, goats and sheep. These benefits could improve the standard of living in rural populations, underscoring the importance of identifying potential applications for biodiesel by-products, such as the use of by-products for ruminant diets. Combining these facts, there are few studies on the reduction of methane production in ruminal fermentation in animals fed with the biodiesel by-products industry. The aim of the present review is to determine optimum levels of oilseed cakes (peanut cake, african oil palm cake and sunflower cake), which are by-products of biodiesel production, for the improvement of ruminant diets.

By-products of biodiesel production used for ruminant feed

By-products, sub-products and effluents are defined in the following ways: by-products are residues that can be traded in the market; sub-products can be sold but are not profitable; and effluents are dischargeable residues that require treatment prior to discharge (Quintella *et al*., 2009). By-products can be a) solid, obtained before oil seed plant pressing (as hull residues and cellulose) or after pressing (as a bran or cake), or b) liquid, in the form of crude glycerin (Quintella *et al*., 2009).

According to the Anuário Estatístico da Agroenergia (2011), african oil palm palms can produce approximately 10,000 kg/ha of bunches and 4,000 kg/ha of oil, indicating a potential african oil palm cake production of approximately 6,000 kg/ha. In 2009, Brazilian african oil palm bunch production was of 750,000 tons, from which 450,000 tons of cake were obtained that might have been used as ruminant feed.

The production of sunflower seeds in Brazil surpassed 30 million tons in 2009, with an average productivity of 1,800 kg/ha (Anuário Estatístico da Agroenergia, 2011). Bran yield is approximately 990 kg/ha, and this by-product could also be used profitably as ruminant feed.

Peanuts are produced in the rainy and dry seasons and have a cycle of approximately 100 days. Their average productivity is 2,400 kg/ha, and their oil amounts to 788 kg/ha (Anuário Estatístico da Agroenergia, 2011).

Brazil has the potential to produce other oleaginous plants with potential for biodiesel production. Among these are soybean (*Glycine max*), castor bean (*Ricinus communis*), jatropha (*Jatropha curcas*), radish (*Raphanus communis*), cotton (*Gossypium* spp. L.), canola (*Brassica napus*), babassu (*Orrbignya speciosa*), sesame (*Sesamum arientale*) and macaúba palm (*Acrocomia aculeata*) (Abdalla *et al.*, 2008). The oleaginous plants that are being used more for biodiesel production are soybean oil (78%), fat (16%) and cotton (2.5%) (Quintella *et al*., 2009).

Chemical and bromatological composition of cakes obtained from biodiesel production

One of the most remarkable characteristics of cakes obtained from biodiesel production is their chemical and bromatological heterogeneity (Table 1), which may vary according to the species and/or cultivar, the extraction methods used (chemical or mechanical), and the efficiency of the processing. According to Meneghetti and Domingues (2008), the appropriate use of by-products is frequently hampered by inadequate knowledge of their nutritional characteristics and values and their effect on animals when used in animal feed.

Table 1. Chemical and bromatological composition of oilseed cakes obtained from biodiesel production for potential use as animal feed (%DM).

Cake	Analytical fraction[1]						Source
	DM	MM	CP	EE	NDF	ADF	
Cotton (*Gossypium* spp. L)	92.4	4.2	38.4	15.7	56.2	41.1	Neiva Júnior *et al.* (2007)
	94.2	4.2	26.9	11.3	56.5	37.1	Couto *et al*. (2010)
Peanut (*Arachis hypogaea*)	90.9	4.1	45.7	8.6	15.4	11.8	[2]
	-	4.3	43,4	9.2	15.2	8.6	[2]
Babassu palm (*Orrbignya speciosa*)	93.2	4.5	15.3	6.5	66.2	34.2	Silva *et al*. (2008)
	94.2	4.1	18.8	8.8	74.5	36.7	Silva *et al*. (2010a)
Rapeseed (*Brassica napus*)	91.9	4.5	33.7	21.9	35.6	-	Santos *et al*. (2009)
African oil palm (*Elaeis guineensis*)	95.3	3.3	16.6	7.8	70.0	45.7	[2]
	88.4	4.4	14.5	7.2	81.8	42.3	Silva *et al*. (2006)
Sunflower (*Helianthus annuus*)	93.3	5.5	27.4	6.7	42.4	26.9	[2]
	91.7	4.4	27.8	19.9	39.6	37.5	Chung *et al*. (2009)
Castor oil plant (*Ricinus communis*)	91.5	-	39.70	2.5	36.0	29.4	Azevêdo (2009)
	90.6	-	30.2	6.10	47.9	40.2	Pompeu (2009)
Cultivated radish (*Raphanus sativus*)	92.8	8.2	31.6	26.0	21.7	13.7	Patiño Pardo *et al*. (2008)
	92.2	8.3	35.5	24.3	15.3	13.3	Couto *et al*. (2010)
Physic Nut (*Jatropha curcas*)	91.6	5.8	25.4	24.2	44.5	43.1	Neiva Júnior *et al*. (2007)
	92.8	5.0	19.8	26.2	40.8	38.0	Couto *et al*. (2010)
Soybean (*Glycine max*)	90.5	7.1	46.8	-	12.3	8.8	Goes *et al*. (2010)

[1] DM (Dry matter); MM (Mineral matter); CP (Crude Protein); EE (Ether extract); NDF (Neutral detergent fiber); ADF (Acid detergent fiber).

[2] Evaluated by the Animal Feed in Tropical Climates research group at the Animal Nutrition Laboratory of the School of Veterinary Medicine and Agrarian Sciences (Federal University of Bahia – UFBA).

Based on their chemical and bromatological composition, certain by-products obtained from biodiesel production, such as african oil palm cake, peanut bran and sunflower bran, are protein-rich sources that could be used profitably as animal feed. Thus, farmers could substitute traditional protein feed with these by-products and improve the economic efficiency of their businesses. There is limited information regarding the use of these cakes as animal feed, but recent studies that used cakes obtained from biodiesel production as ruminant feed showed promising results (Paziani *et al*., 2001; Garcia *et al*., 2006; Silva *et al*., 2005).

As shown in table 1, the chemical and bromatological composition of cakes obtained from biodiesel production indicates that they can be used as protein sources for ruminant feed. African oil palm cake has the lowest crude protein (CP) percentage (approximately 15%) and could therefore be useful as a partial substitute for traditional feed, such as soybean meal. However, african oil palm cake is rich in fibers (Table1), which could negatively affect animal intake and hamper its use as animal feed. Silva *et al.* (2007) used african oil palm cake to feed dairy goats and found that animals fed a concentrate with 40% african oil palm cake reduced their intake compared to animals fed the control diet, which consisted of 60% roughage (ammoniated hay) and 40% concentrate.

The chemical and bromatological composition of peanut cake is similar to that of soybean meal, which is widely used as animal feed (Table 1). Both peanut cake and soybean meal have 45% CP and are thus considered protein-rich products. Moreover, peanut cake and soybean meal have low fiber content (Table 1), a quality that improves intake by ruminants. However, peanut cake intake may be limited by the aflatoxins produced by *Aspergillus flavus,* a fungus present in the environment that contaminates peanuts (Ferreira *et al*., 2006).

The by-product of oil extraction from sunflower seed has intermediate CP and neutral detergent fiber (NDF) values compared to those obtained in african oil palm and peanut cakes (Table 1). Thus, sunflower cake could also be efficiently used as a protein-rich feed for ruminants. Mendes *et al*. (2005) added 20% sunflower cake to the diet of confined cattle and reported that intake of 9.17 kg dry matter (DM) resulted in an average weight gain of 1.15 kg.

According to Abdalla *et al*. (2010), the by-products of the biodiesel industry can promote the reduction of methane production in ruminal fermentation. These authors evaluated in vitro the production of methane in concentrated it was replaced by soybean meal by-products of the biodiesel industry. We evaluated the cakes of cotton, oil palm, castor and physic nut, which reduced methane production with total replacement of soybean meal in concentrates. The use of pies can assist in the policy of reduction of methane is a global commitment to reduce greenhouse effect (Berndt, 2010).

Research of the Animal Feed in Tropical Climates group (Federal University of Bahia, Brazil)

The studies investigating peanut cake, african oil palm cake and sunflower cake obtained from biodiesel production focused on the efficiency of these sources for cattle, goat and sheep feed. The aim of the research group was to determine the optimum levels of by-products in animal feed to increase productivity, ensure high-quality products, reduce feed costs, and increase the profitability of the production system.

Dairy cows

In one of the experiments, supplements of peanut cake (8% DM), african oil palm cake (45% DM) or sunflower cake (15% DM) were given to dairy cattle raised on pasture. The following factors were assessed: diet intake, digestibility, production, the composition and fatty acid profile of milk, and the feed costs and revenue as a function of milk production (Tables 2, 3 and 4).

Table 2. Intake and digestibility of diets containing peanut cake, african oil palm cake or sunflower cake fed to Holstein Friesian /Zebu cows.

Variable	Supplement			
	Soybean meal (Control)	Peanut cake	African oil palm cake	Sunflower cake
Intake (kg/day)				
Total DMI	14.41	14.18	13.48	14.64
Grass DMI	11.67	11.43	11.60	11.84
Supplement DMI	2.74[a]	2.75[a]	1.88[b]	2.80[a]
Grass CPI	0.67	0.66	0.67	0.68
Supplement CPI	0.61[a]	0.58[a]	0.38[b]	0.58[a]
Grass NDFI	8.32	8.15	8.27	8.44
Supplement NDFI	0.46[b]	0.47[b]	0.76[a]	0.55[b]
Grass ADFI	5.24	5.13	5.21	5.32
Supplement ADFI	0.16[c]	0.18[c]	0.40[a]	0.26[b]
Digestibility (%)				
DMDC	56.65[ab]	56.98[a]	53.85[b]	56.42[ab]
CPDC	52.39	56.01	49.63	54.28
EEDC	36.34[b]	43.40[ab]	51.07[a]	44.59[ab]
NDFDC	50.00	51.59	51.20	51.06
TCDC	76.79[a]	75.54[a]	67.64[b]	76.03[a]
NFCDC	63.67	63.15	60.61	64.26

Values in the same row followed by different letters indicate that they are significantly different (P<0.05) according to Tukey's test. DMI: Dry matter intake; CPI: Crude protein intake; NDFI: Neutral detergent fiber intake; ADFI: Acid detergent fiber intake; DMDC: Dry matter digestibility coefficient; CPDC: Crude protein digestibility coefficient; EEDC: Ether extract digestibility coefficient; NDFDC: Neutral detergent fiber digestibility coefficient; NFCDC: Nonfiber carbohydrate digestibility coefficient; TCDC: Total carbohydrate disgestibility coefficient. Source: Adapted from Lima *et al*. (2010 ab).

Supplements of soybean meal, peanut cake, african oil palm cake or sunflower cake did not affect dry matter intake (DMI) or the grass nutrients, indicating the absence of a substitution effect of the concentrate on roughage. However, african oil palm cake supplements reduced DMI and crude protein intake (CPI) and increased neutral and acid detergent fiber intake (NDFI and ADFI). The reduction in CPI can be attributed to the low protein content of these cakes, while the increase in NDFI and ADFI can be attributed to the high levels of fibers present in african oil palm cake. Cows fed african oil palm cake supplements had lower dry matter digestibility coefficients than cows that received peanut cake supplements. The crude protein digestibility coefficient (CPDC) did not differ among the various supplements because they are isonitrogenic. Ether extract digestibility coefficients (EEDC) were higher with african oil palm cake supplements than soybean meal supplements because of the difference in ether extract (EE) concentration (6.59% and 2.87%, respectively).

Table 3. Production, composition and fatty acid profile of milk produced by Holstein Friesian/Zebu cows fed a diet containing peanut cake, african oil palm cake or sunflower cake obtained from biodiesel production.

Variable	Supplement			
	Soybean meal	Peanut cake	African oil palm cake	Sunflower cake
Production (kg)				
Daily milk production	8.10	8.33	7.73	8.04
Corrected production (4.0% fat)	6.65	6.55	6.35	6.26
Chemical composition (%)				
Fat	2.85	2.66	2.81	2.65
Crude protein	3.26	3.17	3.16	3.24
Lactose	4.73	4.78	4.73	4.77
Total dry extract	11.81	11.59	11.69	11.65
Defatted dry extract	8.96	8.93	8.88	9.01

Table 3. Continúa

Table 3. Continuación

Variable		Supplement			
		Soybean meal	Peanut cake	African oil palm cake	Sunflower cake
Fatty acid profile (%)					
C6:0	(caproic)	2.44[a]	2.43[a]	2.00[b]	1.89[b]
C8:0	(caprylic)	1.72	1.73	1.52	1.61
C12:0	(lauric)	4.22[b]	4.13[b]	5.02[a]	4.01[b]
C14:0	(myristic)	15.74	15.35	15.62	14.78
C14:1	(myristoleic)	1.43	1.09	1.39	1.34
C16:0	(palmitic)	38.18	38.74	36.91	39.18
C16:1	(palmitoleic)	1.40[b]	0.95[c]	1.65[a]	1.32[b]
C17:0	(heptadecanoic)	1.27	0.89	0.85	0.96
C18:0	(stearic)	8.10	9.34	8.78	7.96
C18:1	(oleic)	23.98[bc]	23.10[c]	25.00[ab]	26.21[a]
C18:3	(linoleic)	1.41	1.04	0.91	1.38
C20:0	(arachidic)	1.30	0.77	1.42	1.21

Values in the same row followed by different letters indicate that they are significantly different (P<0.05) according to Tukey's test. Source: Adapted from Lima *et al.* (2009), and Santos *et al.* (2010).

Average daily milk production was 8.05 kg/day and did not vary across diets. Moreover, diet did not affect the chemical composition of milk, whose values were within the quality standards established by the 51st Normative Proceeding (MAPA, 2002). Therefore, the milk produced by cows that consumed these cakes can be considered suitable for use in the dairy industry, according to the established legislation. Fatty acids C6:0, C12:0, C16:1 and C18:1 differed across diets, reflecting the fatty acid profiles of the cakes and soybean meal. Cows fed sunflower cake supplements produced milk with the highest levels of C18:1, while milk from cows fed african oil palm cake supplements had higher levels of C12:0 and C16:1.

Table 4. Feed costs and revenue in relation to the milk production of Holstein Friesian/Zebu cows fed peanut cake, african oil palm cake or sunflower cake supplements obtained from biodiesel production.

Variable	Supplement			
	Soybean meal	Peanut cake	African oil palm cake	Sunflower cake
Offered concentrate/day (kg)	3.00	3.00	3.00	3.00
Concentrate intake/day (kg)	2.86	2.88	1.95	2.91
Supplement cost	0.81	0.78	0.64	0.74
Supplement cost/animal/day (U$)	1.31	1.26	0.70	1.22
Period of supplementation (days)	60.0	60.0	60.0	60.0
Total supplementation cost	139.2	134.7	74.8	129.4
Daily milk production (kg/animal)	8.00	8.33	7.73	8.04
Total production (kg/animal)	480.0	499.8	463.8	482.4
Price of milk/kg (U$)	0.36	0.36	0.36	0.36
Price of milk/total production (U$)	175.6	182.4	169.7	176.5
Marketed milk gross margin (R$/animal)	172.8	190.2	226.7	184.2

Source: Adapted from Santana Filho *et al.* (2010). U$: United States Dollar.

The highest costs were observed when animals were given supplements without additional cake, followed by supplements of peanut cake, sunflower cake and african oil palm cake. The highest marketed milk gross margin was obtained when cows were fed african oil palm cake supplements, although the gross margins of marketed milk obtained from cows fed peanut cake or sunflower cake were still higher than the margins obtained when a soybean meal supplement was offered. These results indicate that cakes derived as biodiesel by-products may be suitable feed supplements for lactating and grazing cows.

From the data obtained in the present study, the research group concluded that african oil palm cake, peanut cake and sunflower cake are efficient alternative supplements for lactating cows raised on pasture for several reasons. The cakes do not alter the productive performance or milk quality of the animals, and they reduce the total feeding costs, which are as follows (in US dollar): U$78.4 without additional cake; U$75.8 for peanut cake; U$72.8 for sunflower cake; and U$42.1 for african oil palm cake.

A second set of experiments was performed to determine the optimum level of african oil palm cake (0, 25, 50, and 75%) that should be included in the diet of lactating cows. Intake, production, chemical composition and flavor of milk, as well as feeding costs and revenue were evaluated (Figures 1 and 2; Tables 5 and 6).

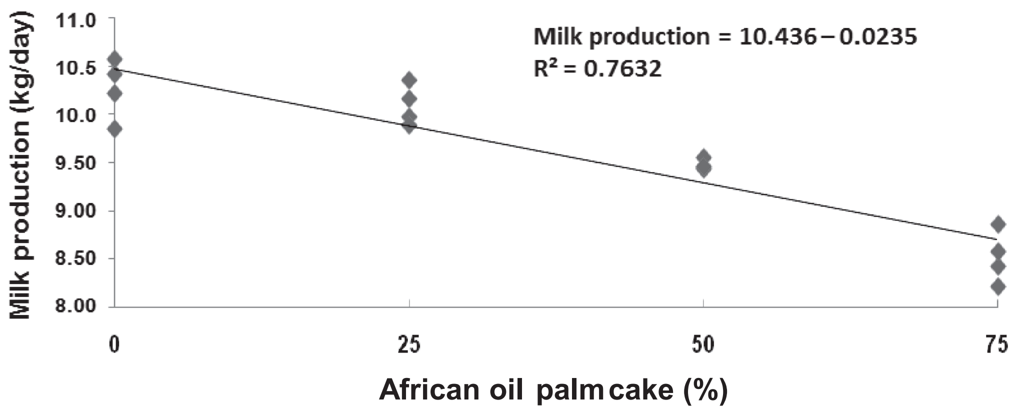

Figure 1. Milk production of Holstein Friesian/Zebu cows fed different levels of african oil palm cake obtained from biodiesel production (Faria *et al.,* 2010 ab)

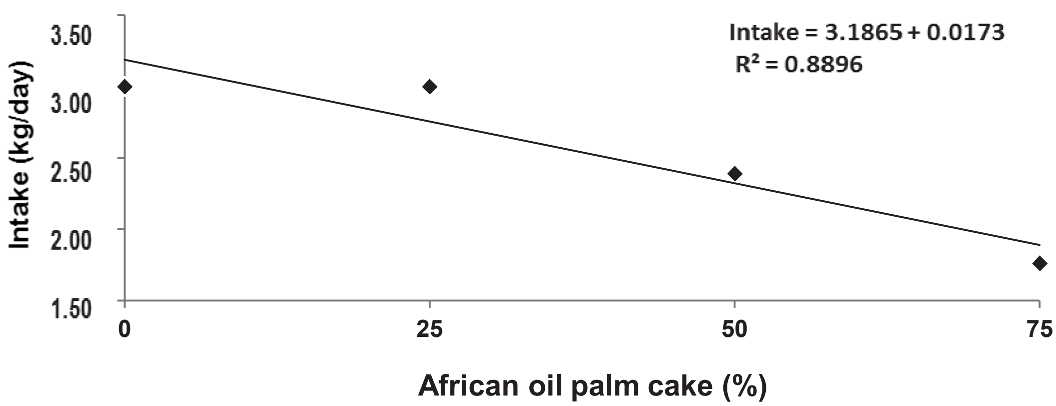

Figure 2. Intake of Holstein Friesian/Zebu cows fed different leves of african oil palm cake obtained from biodiesel production (Faria *et al.,* 2010 ab).

The data indicate that average milk production decreased with increasing african oil palm cake levels (Figure 1). This reduction corresponds to the intake decrease observed in figure 2, which may be a consequence of the increased fiber in diets containing african oil palm cake.

Table 5. Chemical composition and flavor of milk produced by Holstein Friesian/Zebu cows fed supplements containing different levels of african oil palm cake obtained from biodiesel production.

Variable	African oil palm cake (%)				Regression equation
	0	25	50	75	
Chemical composition *(%)*					
Fat	3.33	3.24	3.39	3.86	Ŷ= 3.45
Crude protein	2.89	2.86	2.83	2.77	Ŷ= 2.83
Lactose	4.57	4.43	4.49	4.64	Ŷ= 4.53
Total dry extract	11.73	11.02	11.64	11.75	Ŷ= 11.53
Defatted dry extract	8.40	8.22	8.26	8.39	Ŷ= 8.31
Sensory characteristics					
Flavor	5.98	6.38	6.37	6.10	Ŷ= 6.20

Source: Adapted from Faria *et al*. (2010 ab).

The various levels of african oil palm cake tested did not alter the chemical composition of milk, which exhibited values within the quality standards established by the 51st Normative Proceeding (MAPA, 2002). Milk produced by cows fed african oil palm cakes at a concentration not exceeding 75% of the supplement can be considered suitable for use in the dairy industry, based on the established legislation. Furthermore, the scores given by testers indicate that the supplements had no effect on milk flavor.

Table 6. Feed costs and revenue in relation to milk production of Holstein Friesian /Zebu cows fed supplements containing different levels of african oil palm cake obtained from biodiesel production.

Variable	African oil palm cake (%)			
	0	25	50	75
Offered concentrate /day (kg)	3.00	3.00	3.00	3.00
Concentrate intake/day (kg)	3.00	3.00	2.50	1.80
Concentrate supplemention cost/kg	0.68	0.60	0.52	0.43
Supplementation cost/animal/day (U$)	1.15	1.01	0.72	0.44
Period of supplementation (days)	60	60	60	60
Total feed cost	122.3	107.7	77.4	46.9
Daily milk production (kg/animal)	10.4	9.70	9.40	9.30
Total production (kg/animal)	624.0	582.0	564.0	558.0
Price of milk/kg (U$)	0.37	0.37	0.37	0.37
Feed cost/kg milk	0.20	0.19	0.14	0.08
Gross margin/kg milk	0.46	0.47	0.52	0.58
Price/total production (U$)	231.8	216.2	209.5	207.3
Marketed milk gross margin (U$)	163.0	155.6	165.9	180.9

Source: Adapted from Silva *et al*., (2010b). U$: United States Dollar.

The inclusion of african oil palm cake in the diet reduced costs, and the costs were highest when animals were offered supplements without additional african oil palm cake. The highest marketed milk gross margin was obtained when animals were offered supplements containing 75% african oil palm cake, and the lowest margin was obtained when animals were fed soybean meal. These results highlight the potential advantages and feasibility of african oil palm cake as an alternative feed for lactating cows.

Although cows that were fed african oil palm cake supplements produced less milk (without changes in the chemical composition or sensory characteristics), the rate of return increased due to the reduction of supplementation costs.

Goats raised for meat

In order to determine the optimum levels of sunflower cake (0, 8, 16, and 24%) in the diet of goats, the following variables were evaluated: intake, digestibility, daily average weight gain and carcass quantitative characteristics (Tables 7 and 8; Figure 3).

Table 7. Intake and digestibility of diets with different levels of sunflower cake obtained from biodiesel production fed to half-blood Boer goats.

Variable	Sunflower cake (%)				Regression equation
	0	8	16	24	
Intake (g/day)					
DMI	699	674	643	690	Ŷ= 676
CPI	105	100	88	100	Ŷ= 99
EEI	17	19	19	25	Ŷ= 0.288*X + 16.3
NDFI	247	253	237	286	Ŷ= 256
ADFI	143	151	146	179	Ŷ= 155
NFCI	245	219	180	192	Ŷ= -2.449*X + 239.1
MEI (Mcal/day)	1.60	1.41	1.42	1.35	Ŷ= 1.44
Digestibility (%)					
DMDC	72.48	72.25	68.85	62.86	Ŷ= -0.306*X + 71.62
CPDC	80.66	78.60	84.72	78.52	Ŷ= 80.61
EEDC	84.18	84.04	87.72	84.26	Ŷ= 85.05
NDFDC	54.24	47.78	53.88	45.70	Ŷ= 50.40
ADFDC	48.72	38.70	49.26	39.32	Ŷ= 44.06
NFCDC	86.73	84.58	83.94	75.70	Ŷ= -0.369*X + 86.14

DMI: Dry matter intake; CPI: Crude protein intake; EEI: Ether extract intake; NDFI: Neutral detergent fiber intake; ADFI: Acid detergent fiber intake; NDCI: Nonfiber carbohydrate intake; MEI: Metabolizable energy intake; DMDC: Dry matter digestibility coefficient; CPDC: Crude protein digestibility coefficient; EEDC: Ether extract digestibility coefficient; NDFDC: Neutral detergent fiber digestibility coefficient; ADFDC: Acid detergent fiber digestibility coefficient; NFCDC: Nonfiber carbohydrate digestibility coefficient. Source: Adapted from Agy (2010).

The addition of sunflower cake did not affect Crude protein intake (CPI), Neutral detergent fiber intake (NDFI) or Acid detergent fiber intake (ADFI) due to the fact that DM intake was similar in all diets. However, sunflower cake increased EEI and reduced non-fiber carbohydrate intake (NFCI), corresponding to the amount of these nutritional fractions in the diets. The observed reduction of dry matter digestibility coefficient (DMDC) may be attributed to the reduced digestibility of the NFCs, which was caused by the increase in ADFs as the sunflower cake fraction in the diets increased.

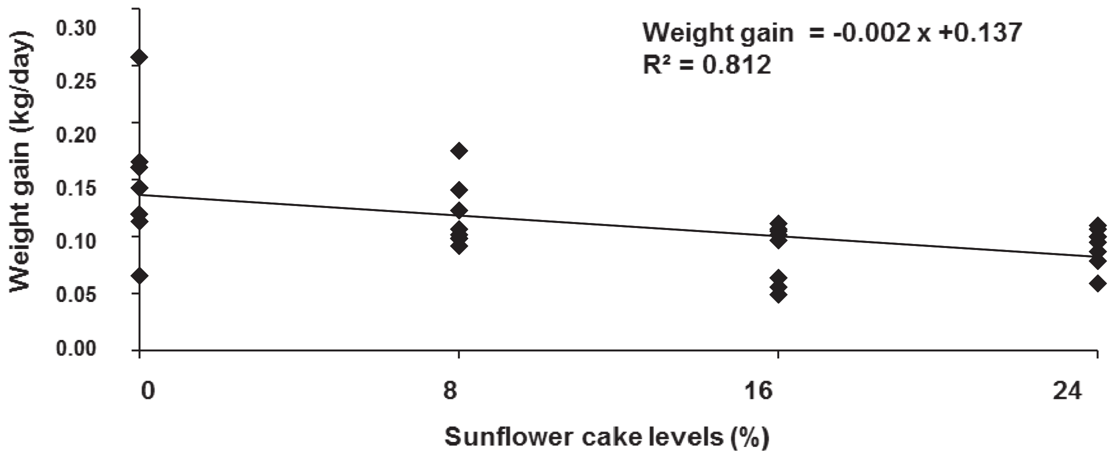

Figure 3. Average daily weight gain of half-blood Boer goats fed different levels of sunflower cake. Adapted from Agy (2010).

The addition of sunflower cake had a negative effect on the average daily weight gain and resulted in a weight loss of 0.0002 kg/ 1% increase in the amount of sunflower cake. Consequently, the feed conversion ratios increased according to the concentration of sunflower cake: 5.36, 5.87, 7.75 and 7.58 for 0, 8, 16 and 24%, respectively (AGY, 2010).

Table 8. Carcass characteristics and leg tissue composition of half-blood Boer goats fed diets containing different levels of sunflower cake obtained from biodiesel production.

Variable	Sunflower cake (%)				Regression equation
	0	8	16	24	
Carcass characteristics					
Slaughter weight – SW (kg)	23.73	22.54	20.60	21.69	$\hat{Y}$= 22.14
Hot carcass weight – HCW (kg)	8.53	9.53	9.04	8.59	$\hat{Y}$= 8.92
Hot carcass yield - HCY (%)	36.47	42.50	44.31	39.43	$\hat{Y}$= 40.67
Leg tissue composition					
Total muscle (%)	68.95	67.68	66.99	70.29	$\hat{Y}$= 68.48
Total fat (%)	3.92	3.05	2.71	2.18	$\hat{Y}$= 2.79
Total bone (%)	27.62	29.28	30.30	28.08	$\hat{Y}$= 28.82

Source: Adapted from Caribé *et al*. (2010) and Palmieri *et al*. (2010).

Feed supplemented with sunflower cake did not affect hot and cold carcass weight and yield or the percentages of leg bone, muscle and fat, probably due to the metabolizable energy intake MEI , which did not differ across diets (Table 7).

The data obtained from this research indicate that the addition of sunflower cake to the diet of goats reduces the average daily weight gain but does not hamper meat production.

Sheep raised for meat

To assess the optimum levels of african oil palm cake (0, 6.5, 13.0 and 19.5%) in the diet of growing lambs, the following variables were evaluated: intake, digestibility, animal performance, quantitative characteristics of the carcass, fatty acid profiles and sensory characteristics of the meat, and feeding costs and meat revenue (Tables 9, 10, 11, 12, and 13).

Table 9. Intake and digestibility of diets with different levels of african oil palm cake obtained from biodiesel production fed to Santa Inês lambs.

Variable	African oil palm cake (%)				Regression equation
	0.0	6.5	13.0	19.5	
Intake (kg/day)					
DMI	1.339	1.179	1.285	1.120	$\hat{Y}$= 1.314 - 0.09X
CPI	0.153	0.139	0.154	0.134	$\hat{Y}$= 0.145
EEI	0.028	0.030	0.033	0.037	$\hat{Y}$= 0.028 + 0.489X
NDFI	0.576	0.550	0.664	0.641	$\hat{Y}$= 0.562 + 0.005X
NFCI	0.528	0.410	0.376	0.269	$\hat{Y}$= 0.519 - 0.013X
LIGI	0.095	0.099	0.115	0.113	$\hat{Y}$= 0.092 + 0.01X
TDNI	0.868	0.769	0.854	0.720	$\hat{Y}$= 0.802
Digestibility (%)					
DMDC	75.38	75.18	75.88	72.68	$\hat{Y}$= 74.80
MOCD	77.11	76.98	79.13	72.70	$\hat{Y}$= 75.74
CPDC	69.36	67.78	67.22	67.87	$\hat{Y}$= 68.10
EEDC	79.90	80.34	84.89	84.96	$\hat{Y}$= 82.50
NDFDC	67.24	69.18	73.40	71.30	$\hat{Y}$= 70.28
ADFDC	65.52	72.50	74.02	70.16	$\hat{Y}$= 71.10
NFCDC	85.72	84.46	80.72	73.80	$\hat{Y}$= 87.10 – 0.60X

DMI: Dry matter intake; CPI: Crude protein intake. EEI: Ether extract intake; NDFI: Neutral detergent fiber intake; NDCI: Nonfiber carbohydrate intake; LIGI: Lignin intake; TDN: Total digestible nutrients intake; DMDC: Dry matter digestibility coefficient; CPDC: Crude protein digestibility coefficient; EEDC: Ether extract digestibility coefficient; NDFDC: Neutral detergent fiber digestibility coefficient; ADFDC: Acid detergent fiber digestibility coefficient; NFCDC: nonfiber carbohydrate digestibility coefficient. Source: Adapted from Macome (2009).

The addition of african oil palm cake to the diet of lambs resulted in a linear decrease in DMI (Table 9), which may be explained by the increase in NDF and a higher lignin intake. The decrease in NFC intake may be due to the low concentration of NFCs in the diets. The increase of EE and NDF intake was likely due to their high concentration in african oil palm cake. Furthermore, the digestibility coefficients of DM (Table 9), organic matter (MO), CP, EE, NDF and ADF were similar, and there was a linear decrease in non-fiber carbohydrate digestible coefficient (NFCDC), indicating that NFCs present in the african oil palm cake may have been protected by less digestible components of the cell wall. It is important to emphasize that lignin concentrations in the diets increased and, owing to a recalcitrant effect, may have inhibited the digestion of other cell wall elements.

Table 10. The effects of african oil palm cake obtained from biodiesel production on the performance of Santa Inês lambs.

Variable	African oil palm cake (%)				Regression equation
	0.0	6.5	13.0	19.5	
DM intake	1.339	1.179	1.285	1.120	$\hat{Y}$= 1.314 - 0.09X
Weight gain	0.177	0.157	0.176	0.168	$\hat{Y}$= 0.169
Feed conversion	7.738	7.411	7.439	6.780	$\hat{Y}$= 7.340

Source: Adapted from Macome (2009).

The addition of african oil palm cake to the diet of lambs resulted in a decrease in DM intake. However, daily weight gain and feed conversion did not differ across diets (Table 10) due to similarities in total digestible nutrient (TDN) intake, which provides the necessary amount of protein and energy for weight gain.

Table 11. Carcass quantitative characteristics of Santa Inês lambs fed diets containing different levels of african oil palm cake obtained from biodiesel production.

Variable	African oil palm cake (%)				Regression equation
	0.0	6.5	13.0	19.5	
Slaughter weight – SW (kg)	37.51	35.93	37.48	35.53	$\hat{Y}$= 36.60
Cold carcass weight – CCW (kg)	17.08	15.40	16.44	14.41	$\hat{Y}$= 16.87 - 0.107X
Cold carcass yield - CCY	45.49	42.80	43.78	40.72	$\hat{Y}$= 45.20 - 0.205X
Longissimus muscle - LM (cm^2)	8.49	7.76	8.64	7.30	$\hat{Y}$= 8.05

Source: Adapted from Macome (2009).

The longissimus muscle area was not affected by diet (Table 11), and this finding likely reflects similar protein and energy intakes that produced parallel increases in live and slaughter weights. The observed linear reduction of cold carcass yield (CCY) may be attributed to an increase in NDF intake (Table 9) that subsequently increased the gastrointestinal content and diluted carcass weights.

The addition of african oil palm cake resulted in higher C12:0 and C14:0 concentrations in lamb meat as a consequence of their increase in the diets (Table 12). Moreover, a linear increase in C16:0 and a linear decrease in C18:2 cis-9, cis-12 were observed. However, diets did not affect conjugated linoleic acid (CLA), which is synthesized during ruminal biohydrogenation of linoleic acid.

Table 12. Fatty acid profile and sensory characteristics of meat from Santa Inês lambs fed diets with different levels of african oil palm cake obtained from biodiesel production.

Variable	African oil palm cake (%)				Regression equation
	0.0	6.5	13.0	19.5	
Fatty acid profile (%)					
C12:0	0.10	0.23	0.37	0.54	$\hat{Y}$= 0.02X + 0.06
C14:0	2.23	3.27	3.94	4.60	$\hat{Y}$= 0.12X + 2.25
C16:0	23.26	24.60	25.23	24.80	$\hat{Y}$= 0.06X + 24.34
C18:2 cis-9 cis-12	2.66	2.33	2.71	1.52	$\hat{Y}$= -0.06X + 3.31
CLA[1]	0.30	0.28	0.20	0.31	$\hat{Y}$= 0.27
SFA[2]	45.08	48.71	49.08	48.32	$\hat{Y}$= 47.80
IFA[3]	54.92	51.29	50.92	51.68	$\hat{Y}$= 52.20
AI[4]	0.59	0.75	0.83	0.86	$\hat{Y}$= 0.01X + 0.61
MCFA[5]	30.92	32.74	34.23	34.92	$\hat{Y}$= 0.22X + 31.37
LCFA[6]	68.89	67.10	65.59	64.94	$\hat{Y}$= -0.22X + 68.47
Sensory characteristics					
Appearance	6.5	6.7	6.5	6.6	$\hat{Y}$= 6.5
Aroma	6.9	7.3	6.9	6.6	$\hat{Y}$= 6.9
Palatability	7.0	7.3	7.0	6.7	$\hat{Y}$= 7.0
Juiciness	6.2	6.6	6.7	6.4	$\hat{Y}$= 6.5
Tenderness	6.8	7.5	7.6	7.1	$\hat{Y}$= - 0.0073x^2 + 0.1594x + 6.76

[1]Conjugated linoleic acid; [2]Saturated fatty acids; [3]Unsaturated fatty acids; [4]Atherogenicity index; [5]Medium-chain fatty acids (11 to 16 carbons); and [6]Long-chain fatty acids (more than 16 carbons).Source: Adapted from Ribeiro *et al.* (2009) and Ribeiro *et al.* (2010).

The atherogenicity index increased when african oil palm cake was added to the diets due to the increase of saturated fatty acids (SFA) in the meat. The increase in medium-chain fatty acids (MCFA) and reduction in long-chain fatty acids (LCFA) when african oil palm cake was included in the diet reduced the average length of fatty acid chains.

African oil palm cake diets did not affect the meat sensory characteristics (appearance, aroma, palatability and juiciness), and the scores obtained indicate good taste acceptability (Table 12). However, the inclusion of african oil palm cake produced a quadratic relationship for tenderness, with a maximum value of 7.63 at a 10.92% level of cake. This increase may be related to an increase in EE intake (Table 9), which may have caused a higher deposition of adipose tissue and the resulting enhancement of meat tenderness.

Although the gross margin was positive for all the diets tested, the highest feed costs were observed when animals were fed a diet without additional african oil palm cake, while the addition of cake reduced costs (Table 13). The lowest break-even point, which indicates how much product must be sold to recover total costs, was observed with a 19.5% level of african oil palm cake in the diet.

Table 13. Feed costs and revenue in relation to the meat production of Santa Inês lambs fed different levels of african oil palm cake obtained from biodiesel production.

Variable	African oil palm cake (%)			
	0.0	6.5	13.0	19.5
Feed cost/animal/day	0.78	0.77	0.75	0.72
Feedlock days	70	70	70	70
Total feed cost/animal	54.60	53.90	52.50	50.40
Average daily weight gain	0.177	0.157	0.176	0.168
Average weight gain (kg/animal)	12.39	10.99	12.32	11.76
Slaughter weight (kg/animal)	37.51	35.93	37.48	35.53
Cold carcass weight (kg/animal)	17.07	15.40	16.43	14.41
Price of meat (U$/kg)	3.09	3.09	3.09	3.09
Total revenue (U$)	52.73	47.58	50.76	44.51
Gross margin (U$)[1]	22.06	17.30	21.27	16.21
Break-even point (kg)[2]	9.92	9.80	9.54	9.16
cost/kg of carcass (U$)[3]	1.79	1.97	1.79	1.96

[1]Total revenue (U$) – total costs (U$); [2]Total costs ÷ price/kg of meat; [3]Total costs ÷ cold carcass weight (kg), U$: United States Dollar. Source: Adapted from Macome, (2009).

The results of the present study indicate that the inclusion of 19.5% african oil palm cake in the diet of growing lambs reduces DMI and feed costs without adversely affecting daily weight gain or fat deposition in the carcass and while maintaining the quality of the meat.

Final considerations

Cakes are obtained as by-products from biodiesel production, and their use in ruminant feed reduces costs and usually does not affect the productivity or quality of the final product. In order to generate profit margins, by-products should be acquired at low prices at locations close to the properties were the animals are reared.

The by-products derived from the processing of these species also have the potential to be used as animal feed. However, further research is required to minimize the gap between theoretical knowledge and its application. Improved and novel approaches would strengthen the various production sectors involved in biodiesel production and improve the standard of living in rural populations.

Based on the results obtained in the experiments, the cake of peanut, sunflower and palm oil in concentrated supplement of dairy cows. However, supplementation with palm kernel cake (45% DM concentrate) was the one that had the best economic result. The sunflower cake can be added to the diet of goats to the level of 24% of the total diet without affecting weight gain. But the use of 19.5% palm kernel cake in the diet reduced the total weight gain and fat accumulation in the carcass of sheep.

The objectives of the Animal Feed in Tropical Climates research group – UFBA are to assess the optimum levels of the following: a) peanut cake, african oil palm cake and sunflower cake in the diet of beef cattle (in progress); b) peanut cake and african oil palm cake in the diet of goats (in progress); and c) peanut cake and sunflower cake in the diet of lambs. The results obtained will be published and shared with agricultural producers as a way of returning the public funds invested to support this research.

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