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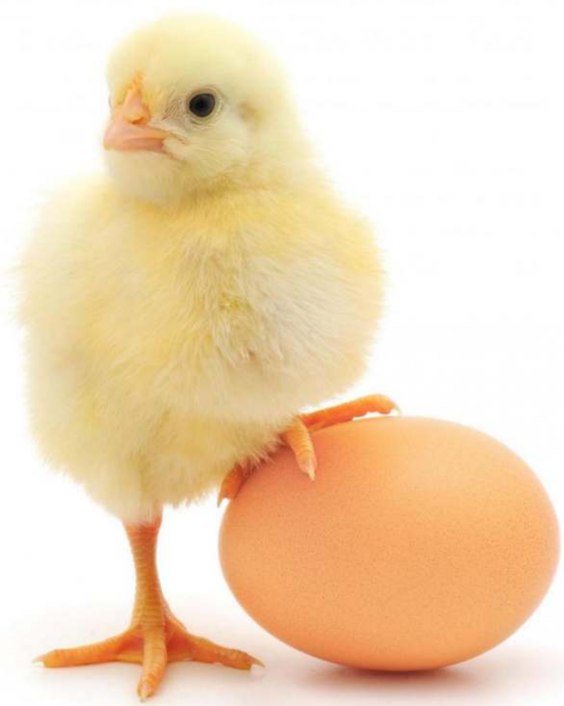

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Evaluation of Traditional Sorghum (*Sorghum bicolor*) Beer Residue, Shea-Nut (*Vitellaria paradoxa*) Cake and Cottonseed (*Gossypium Spp*) Cake for Poultry in Burkina Faso: Availability and Amino Acid Digestibility

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Abstract: The present study aimed to evaluate the nutritive value for chickens of some local by-products in Burkina Faso and to estimate their true amino acid digestibility in cockerels. Sun-dried sorghum (*Sorghum bicolor*) beer residue (n = 144) and shea-nut (*Vitellaria paradoxa*) cake (n = 36) samples were collected in two different locations during six months, while cottonseed (*Gossypium spp*) cake samples were purchased monthly in a local market for the same period (n = 24). Mean Dry Matter (DM) content of beer residue was 94.7% and Crude Protein (CP), Ether Extract (EE), Crude Fibre (CF), Calcium (Ca), Phosphorus (P) and Metabolizable Energy (ME) contents were 23.4, 5.6, 8.5, 0.14 and 0.25% of DM and 13.4 MJ/kg, respectively. Mean lysine, methionine, cystine and threonine contents were 0.87, 0.44, 0.41 and 0.63%, respectively and the corresponding true excreta digestibility values were 92, 98, 95 and 97%. Mean DM content of shea-nut cake was 95.6% and CP, EE, CF, Ca, P and ME contents were 6.7, 7.3, 10.9, 0.40 and 0.19% and 13.1 MJ/kg, respectively. Lysine, methionine, cystine and threonine contents were 0.27, 0.14, 0.09 and 0.23% and the true digestibility values were 96, 78, 88 and 77%, respectively. Mean DM, CP, EE, CF, Ca, P and ME contents of cottonseed cake were 94.8, 44.3, 5.9, 9.9, 0.34 and 1.3% and 12.7 MJ/kg. Lysine, methionine, cystine and threonine contents were 1.6, 0.80, 0.82 and 1.9% and the true digestibility values were 89, 97, 98 and 94%. Overall, higher nutritive values were found for samples collected between October and December and no difference was found between locations.

Key words: Amino acid digestibility, beer residue, Burkina Faso, cockerels cottonseed cake, shea-nut cake

Introduction

Studies on the nutritional status of village chickens in Burkina Faso show that scavenged feeds are mainly a source of energy and therefore any supplementation should be done with protein-rich feedstuffs (Pousga *et al*., 2005; Kondombo, 2005). However, in West Africa conventional poultry feed ingredients, particularly protein supplements, are expensive and not always readily available (Olorede *et al*., 1999). According to FAO (1984), when feed resources are limited, the best approach is to utilize crop residues and agro-industrial by-products more efficiently. The main locally available potential protein feeds for poultry in Burkina Faso, which are not in competition with humans, are shea-nut cake, local beer residue and cottonseed cake. Burkina Faso is the first cotton producer in Sub-Saharan Africa, the second shea-nut producer and sorghum production in the country is the highest among the cereals grown (Mission Economique, 2006). Annual production was estimated to be 750,000, 122,100 and 1,552,900 tonnes, respectively, for cotton, shea-nut and sorghum (Mission Economique, 2006). Many developing countries are self-sufficient in monogastric meat but few are self-reliant, since they have to import most of the inputs (FAO, 1995). Very little research has been done in Burkina Faso to find alternative feeds to cereals and imported fishmeal and soybean meal. Thus, there is a need to develop alternative feeding systems in the country, based for example on cottonseed cake, shea-nut cake and local beer residue. Cottonseed cake is a fairly common poultry feed ingredient in Burkina Faso, but shea-nut cake and beer residue are rarely used non-conventional feedstuffs and there is little information on their nutritive value and digestibility.

All dietary components, such as amino acids, vitamins and minerals are important when formulating feeds for poultry, but critical attention should be given to the dietary amino acids, as approximately 25% of the cost of practical poultry diets can be accounted for by amino acids (McNab, 1994). Methods to estimate the digestibility of amino acids in chickens have been developed and tested by numerous authors (Likuski and

Dorrell, 1978; Sibbald, 1979; Song *et al.*, 2003). However, there is still debate as to the accuracy and suitability of the different methods used. According to Borin *et al.* (2002), besides the scientific aspects, the appropriateness of the methods to be used must be based on the local context and available facilities and be economically viable. A review by McNab (1994) of the different methods used for determination of amino acid digestibility concluded that the digestibility values based on the excreta from normal intact birds have the decided advantage of simplicity over those taken from caecectomized birds or of values based on ileal concentrations. The overall objectives of this study were to determine the proximate composition and amino acid digestibility of three local by-products in Burkina Faso collected in different locations and at different times of the year.

Materials and Methods

Site: This study includes collection and analysis of three locally available by-products in Burkina Faso and a digestibility trial. Samples of sorghum (*Sorghum bicolor*) beer residue and shea-nut (*Vitellaria paradoxa*) cake were collected in two different locations, Sapone in the Central Region and Bobo-Dioulasso in the South, while cottonseed (*Gossypium spp*) cake was bought in a local market in Ouagadougou. Bobo-Dioulasso is situated at around 365 km from Ouagadougou, in the Sub-humid zone, while Sapone is in the Soudano-Sahelian zone. The digestibility trial was carried out in the INAGOR Research Centre, situated in Sapone, around 35 km South of Ouagadougou.

Sample collection: Three locally available by-products, shea-nut cake, beer residue and cottonseed cake were evaluated. The crops from which they originated are harvested only once per year: From October to December for sorghum and cotton and from June to September for shea-nut. Shea-nut cake and beer residue were collected, already sun-dried, from three households in each of the two locations (Sapone and Bobo-Dioulasso) from July to December, representing three months of the rainy season (July to September) and three months of the dry season (October to December). Cottonseed cake samples were collected in the same period. Sample collection was done four times per month, according to the by-product availability.

Experimental animals: Thirty six crossbred cockerels (RIR×local hens) of between 0.5 and 0.6 kg live weight were paired on a weight basis and placed in individual metabolism cages (0.25×0.25×0.35m).

Experimental assay for amino acid digestibility determination: A force-feeding trial was carried out according to the procedures of Likuski and Dorrell (1978), Sibbald (1979) and Song *et al.* (2003) concerning the feeding technique and the estimation of endogenous amino acids. Samples of shea-nut cake and sorghum beer residue from the two locations (Sapone and Bobo-Dioulasso) were pooled and each of the three by-products was tested with six replications of two birds per treatment (paired on a weight basis, designated fed and fasted). The birds were starved for 24 hours prior to the beginning of the experiment, but given free access to water. Thereafter, one of each pair was randomly selected and force-fed 8 g of its respective sample and returned to the cage over a clean excreta collection tray and was allowed to stay for a further 48 hours. The other member of each pair continued without feed for the same period and was referred to as the fasted member, while the former was the fed member. Both the fed and fasted birds had free access to water. Excreta were collected for 48 hours after force-feeding, three times per day and stored at 4°C, then oven dried at 60°C. Excreta samples were pooled per group of three birds and per feedstuff, then ground in a Cyclotec grinder to pass through a 1 mm screen and stored in air-tight sample bottles for amino acid analysis.

Chemical analysis of the feedstuffs collected: The collected samples were pooled within feedstuff, to get two samples per month and stored for analysis. Samples were analyzed for proximate composition using standard methods: Dry Matter (DM) was determined after drying at 60 and 103°C and the Kjeldahl method (AOAC, 1985) was used for determination of Crude Protein (CP) (N*6.25). ADF was determined according to AOAC (1985), NDF according to Chai and Uden (1998) and Ether Extract (EE) was determined after acid hydrolysis. Total Ash was determined by burning at 550°C (3 hours) and minerals by flame spectrometry. Amino acids were determined using standard methods (AnalyCen, Lidköping, Sweden). Metabolisable energy was calculated according to INRA (1987) using the following formula:
True ME (MJ/kg dry matter) = (3951+54.4EE-88.7CF-40.8Ash) *0.004184.

Amino Acid (AA) digestibility: The AA digestibility coefficients were calculated according to McNab (1994):

$$\text{Total tract AA digestibility} = \frac{\text{AA consumed} - \text{AA in faeces}}{\text{AA consumed}}$$

$$\text{True AA digestibility} = \frac{\text{AAC} - (\text{AAF} - \text{EAAF})}{\text{AAC}}$$

AAC = amino acid consumed
AAF = amino acid in faeces from fed birds
EAAF = endogenous amino acids in faeces from unfed birds

Table 1: Chemical composition of sorghum beer residue from two areas of Burkina Faso (% of DM) (n = 144)

Item	Bobo-Dioulasso*	Sapone**	SEM	P-value
Dry matter	94.7	94.8	0.4	0.89
Organic matter	92.5	93.3	0.36	0.101
Ash	7.5	6.7	0.36	0.101
Crude protein	23.3	23.6	0.45	0.57
Ether extract	5.5	5.7	0.23	0.53
Crude fibre	7.9[b]	9.0[a]	0.24	0.004
NDF	40.1[b]	49.5[a]	1.6	0.00
ADF	20.7[b]	31.3[a]	0.83	0.00
ME (MJ/kg)***	13.5	13.3	0.12	0.24

*Sub-humid zone, **Soudano-Sahelian zone, ***Calculated values, according to INERA, 1995.

Statistical analysis: Data were subjected to the GLM procedure in MINITAB 14 (Minitab, 2000). Pairwise comparisons were made using the Tukey Test to compare the effect of location and month on the chemical composition of the by-products.

Results

Availability of the by-products: Local beer residue is available in Burkina Faso after home brewing, usually done by women. Normally red sorghum, yeast and water are the sole ingredients, although red sorghum is often replaced by millet and milo, according to tradition and availability.

Shea-nut cake is a by-product of the indigenous technology for extraction of fat from the kernel of the shea butter tree (*Butyrospermum parkii* or *Vitellaria paradoxa*). The Shea tree is a sacred tree in the Sahel region of Africa and is 15 to 20m high with a stout trunk and large leathery oval leaves (Göhl, 1981). It grows only in the wild, is very difficult to cultivate and can live for several hundred years (Kariderm, 2006). Harvesting the nuts and making the butter have traditionally been womens' work. The processing technique includes boiling, roasting and frying.

Cottonseed cake is available in Burkina Faso after oil extraction in the factories. Two types of cottonseed cake are produced: decorticated expeller, which is fed to monogastric animals and non-decorticated expeller cake, which is fed to ruminants. Only samples of decorticated expeller cake were collected in this study.

Chemical composition of the by-products: The proximate composition of the beer residues from the two locations and according to month is shown in Table 1 and 2. The data show acceptable Crude Protein (CP), Metabolizable Energy (ME) and Ether Extract (EE) values, but mineral and amino acid concentrations were low. Mean Dry Matter (DM), CP, EE, Crude Fibre (CF) and ME contents were 94.7, 23.4, 5.6, 8.5% and 13.4 MJ/kg, respectively. The contents of CF, NDF and ADF were significantly higher in Sapone (9.0, 49.5 and 31.3% of DM, respectively) compared to Bobo-Dioulasso (7.9, 40.1 and 20.7%, respectively). No significant differences were found between the two locations for the other proximate components. The DM content of sun-dried beer residue was significantly higher in October and November (95.9 and 95.8%), than in August (92.2%). Ether extract was highest in October, November and December (7.0, 8.7 and 6.5%, respectively) and lowest in July and August (4.7 and 3.8%, respectively). No significant location and month effects were found for Organic Matter (OM), CP and Ash content. The overall values for mineral and amino acid contents are shown in Table 3. Mean calcium and phosphorus contents were 0.14 and 0.25% and lysine, methionine, cystine and threonine contents were 0.87, 0.44, 0.41 and 0.63% of DM, respectively.

The proximate composition of shea-nut cake collected from the two locations is presented in Table 4. Mean DM, CP, EE, CF and ME contents were 95.6, 6.7, 7.3, 10.9% and 13.1 MJ/kg, respectively. No significant difference was found in proximate composition between the two locations. However, OM, CP and ME contents were numerically higher in Bobo-Dioulasso (94.5 and 7.4% and 13.3 MJ/kg, respectively) compared to Sapone (93.3 and 5.9% and 12.9 MJ/kg, respectively), while Ash, CF and EE were higher in Sapone (6.7, 11.5 and 8.0%, respectively) compared to Bobo-Dioulasso (5.4, 10.3 and 6.6%, respectively) ($p>0.05$). Mean calcium and phosphorus contents were 0.40 and 0.19%, respectively. Amino acid contents were 0.27, 0.14, 0.09 and 0.23%, respectively, for lysine, methionine, cystine and threonine (Table 3).

Analysis data for cottonseed cake are given in Table 5. Mean DM, CP, EE, CF and ME contents were 94.8, 44.3, 5.9, 9.9% and 12.7 MJ/kg, respectively. No significant differences were found according to month of collection for DM and OM content. However, Ash and fibre contents were higher from July to October, while CP and ME were highest in November and December ($p<0.05$). Mean calcium and phosphorus contents were 0.34 and 1.3%, respectively and lysine, methionine, cystine and threonine contents were 1.6, 0.80, 0.82 and 1.9%, respectively (Table 3).

Amino acid digestibility of local beer residue, shea-nut cake and cottonseed cake in cockerels: Apparent and true DM and amino acid digestibility data are shown in Table 6. True digestibility coefficients show that 93% of the DM in local beer residue was digestible and the most important amino acids, lysine, methionine, cystine and threonine, were 92, 98, 95 and 97 percent digested, respectively. In shea-nut cake DM digestibility was 96% and lysine, methionine, cystine and threonine were 96, 78, 88 and 77% digested, respectively.

Dry matter digestibility in cottonseed cake was 91% and lysine, methionine cystine and threonine digestibility values were 89, 97, 98 and 94%, respectively.

Table 2: Monthly variation in the chemical composition of local sorghum beer residue (% of DM) (n = 144)*

Item	July	Aug	Sep	Oct	Nov	Dec	Mean	Max	Min	SEM	P-value
DM	94.4	92.2^{b}	95.1	95.9^{a}	95.8^{a}	95.2	94.7	97.5	83.7	0.70	0.010
OM	94.5	92.3	92.7	91.7	92.5	93.5	92.8	95.8	88.4	0.62	0.055
Ash	5.47	7.7	7.21	8.3	7.51	6.4	7.1	11.5	4.1	0.62	0.055
CP	21.6	24.0	22.6	23.3	24.8	24.4	23.4	29.5	18.2	0.78	0.064
EE	4.7^{b}	3.8^{b}	3.0b	7.0^{a}	8.7^{a}	6.6^{a}	5.6	10.5	2.0	0.41	0.00
CF	8.5	8.5	8.9	8.3	8.1	8.7	8.5	11.3	6.9	0.42	0.85
NDF	48.6^{a}	48.9^{a}	49.7^{a}	38.6^{b}	35.3^{b}	34.8^{b}	44.8	64.0	26.3	2.78	0.003
ADF	22.8	29.6	26.2	25.7	26.6	25.2	26.0	39.5	16.0	1.44	0.072
ME (MJ/kg)**	13.5	12.9^{bc}	12.7^{b}	13.6	14.2^{a}	13.6^{ac}	13.4	14.8	11.6	0.21	0.00

*Total samples from Sapone and Bobo-Dioulasso, **Calculated values, according to INRA, 1987

Table 3: Mineral and amino acid composition of the by-products, maximum, minimum and mean values (% of DM) (n = 12)

	Sorghum beer residue				Shea-nut cake				Cottonseed cake			
Item	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
Calcium	1.20	0.03	0.14	0.04	0.55	0.30	0.40	0.10	0.65	0.20	0.34	0.08
Phosphorus	0.32	0.15	0.25	0.07	0.30	0.11	0.19	0.07	3.50	0.50	1.3	0.20
Magnesium	0.17	0.04	0.10	0.04	0.30	0.11	0.15	0.04	0.80	0.42	0.72	0.09
Potassium	0.16	0.05	0.11	0.03	0.90	0.10	0.54	0.27	2.30	0.65	1.8	0.33
Sodium	0.02	0.001	0.06	0.05	0.21	0.01	0.05	0.04	1.30	0.24	0.35	0.09
Lysine	1.01	0.65	0.87	0.12	0.32	0.19	0.27	0.5	2.50	0.90	1.6	0.25
Methionine	0.54	0.33	0.44	0.13	0.17	0.10	0.14	0.22	1.50	0.40	0.8	0.09
Cystine	0.53	0.26	0.41	0.10	0.12	0.07	0.09	0.15	1.70	0.40	0.82	0.08
Threonine	0.90	0.47	0.63	0.30	0.29	0.17	0.23	0.42	3.50	1.10	1.90	0.40

Table 4: Chemical composition of traditional shea-nut cake from two climatic zones of Burkina Faso (% of DM) (n = 36)

Item	Bobo-Dioulasso*	Sapone**	Mean	Max	Min	SEM	P-value
Dry matter	95.1	96.1	95.6	98.0	87.3	1.03	0.47
Organic matter	94.5	93.3	93.9	97.3	89.1	0.76	0.30
Ash	5.4	6.7	6.1	10.3	2.6	0.76	0.30
Crude protein	7.4	5.9	6.7	10.3	2.5	0.89	0.29
Ether Extract	6.6	8.0	7.3	9.6	5.3	0.37	0.29
Crude fibre	10.3	11.5	10.9	11.0	7.8	0.33	0.98
NDF	34.0	35.9	34.9	42.0	28.2	1.46	0.39
ADF	28.7	29.4	29.0	41.5	18.6	2.17	0.84
ME (MJ/kg)***	13.3	12.9	13.1	14.1	12.4	0.15	0.65

*Sub-humid zone, **Soudano-Sahelian zone, ***Calculated value, according to INRA, 1987

Table 5: Monthly variation in the chemical composition of decorticated expeller cottonseed cake (% of DM) (n = 24)

Item	July	Aug	Sep	Oct	Nov	Dec	Mean	Max	Min	SEM	P-value
DM	94.2	94.6	95.3	95.5	94.0	95.6	94.8	97.4	88.5	0.62	0.56
OM	91.0	90.8	91.0	91.0	92.7	92.9	91.5	94.2	87.6	0.48	0.66
Ash	9.0^{a}	9.20^{a}	9.0^{a}	8.9^{a}	7.3^{b}	7.1^{b}	8.4	10.5	4.2	0.50	0.027
CP	44.3	45.4	41.1^{b}	43.0	46.3^{a}	45.9^{a}	44.3	57.3	39.8	1.60	0.045
EE	5.5^{b}	5.5^{b}	5.5^{b}	5.5^{b}	6.8^{a}	6.8^{a}	5.9	8.2	4.3	0.04	0.001
CF	10.5^{a}	11.0^{a}	11.5^{a}	10.4^{a}	7.4^{b}	8.5^{b}	9.9	12.8	6.5	0.40	0001
NDF	20.3^{a}	21.0^{a}	20.5^{a}	20.8^{a}	17.7^{b}	17.4^{b}	19.6	22.6	15.4	0.50	0.001
ADF	15.3^{a}	15.8^{a}	15.9^{a}	16.3^{a}	12.2^{b}	12.6^{b}	14.6	17.7	10.5	0.50	0.001
ME (MJ/kg)*	12.3^{b}	12.1^{b}	12.0^{b}	12.3^{b}	14.0^{a}	13.7^{a}	12.7	14.8	12.2	0.22	0.00

*Calculated values, according to INRA, 1987

Discussion

Local beer, called "dolo", is an important alcoholic drink in Burkina Faso. Little published data are available on the utilisation of the residue after local alcohol preparation and traditionally, beer residue is given to pigs in the rural areas (Bosma *et al.*, 2004). Kondombo (2005) carried out a feeding trial with chickens using sorghum beer residue and found that it was not very palatable. Shea-nut residue after oil extraction is not used as a feed for livestock in Burkina Faso and there is little data concerning the utilization of this by-product in the country. Traditionally, the residue is used by women as a fuel and as source of potassium for traditional soap manufacture (Kariderm, 2006). The most common variety of cotton cultivated in Burkina Faso is gossypol-free (a glandless variety) and the seeds are used in both

Table 6: Dry matter and apparent and true essential amino acid digestibility in young cockerels of sorghum beer residue, shea-nut cake and cottonseed cake in Burkina Faso (% of DM)

	Sorghum beer residue		Shea-nut cake		Cottonseed cake	
Item	Apparent	True	Apparent	True	Apparent	True
Dry matter	63	93	83	96	83	91
Lysine	86	92	75	96	82	89
Methionine	91	98	62	78	82	97
Cystine	76	95	57	88	91	98
Threonine	88	97	53	77	83	94

human nutrition and for livestock (Schwartz, 1993; INERA, 1995). The cottonseed cake which is used in monogastric animal feeding is decorticated expeller, while the non-decorticated expeller is given to ruminants.

The chemical composition of traditional sorghum beer residue in this study is similar to the data obtained in Ethiopia by Demeke (2007) for traditionally brewed beer residue. However, proximate composition data show higher nutritive content compared to values reported for dried brewer's grain in Africa (Göhl, 1981), in particular for DM, CP, calcium and phosphorus. This difference was probably a result of differences in the type of cereal used for beer brewing and also due to differences between traditional and commercial brewing techniques. The differences obtained in fibre content between the two locations in this study can be explained by possible differences in sorghum processing after harvesting the cereal, or due to the different varieties of sorghum used in the two locations, as there are more than thirty varieties of sorghum grown in Burkina Faso (Sereme *et al.*, 1994). The higher DM and EE content from November to December can be attributed to the fact that sorghum is harvested between October and November in Burkina Faso and is stored and used over the following 12 months. Therefore, the chemical components may undergo some changes during storage. The differences seen in chemical composition can also be a result of variations in brewing techniques. Despite the relatively high nutritive value of sorghum beer residue, it is important to note that it may contain high tannin levels and varieties with high tannin levels (more than 0.2%) are generally used in Burkina Faso for local alcoholic drinks (Sereme *et al.*, 1994).

The mean CP content of shea-nut cake (6.7%) was lower compared to data from other studies showing CP contents of between 16-18% (Morgan and Trinder, 1980; Göhl, 1981; Atuahene *et al.*, 1998; Olorede *et al.*, 1999). The mean EE content in our study (7.3%) was higher compared to the data of Morgan and Trinder (1980) and Göhl (1981), who reported values of around 4%. The differences seen in the chemical composition of shea-nut cake in this study compared to other reports, especially regarding CP and EE contents, can be explained by possible differences in the variety of shea tree, in the processing method or contamination. The traditional oil extraction in Burkina Faso includes roasting and frying for several hours to separate the oil from the nut and this can lead to protein degradation, as indicated by the black colour of the cake. It was also reported that traditional artisan methods leave a higher proportion of oil in the residue compared to commercial techniques (Niess, 1983), as was found in the present study. The differences observed between the two locations can also be explained by differences in processing method or by contamination. Unlike local beer residue, shea-nut residue is not available on a regular basis in the same household. Oil extraction is done on an irregular basis at different-times by groups of women according to time availability. This explains the absence of data on the chemical composition of shea-nut cake in different months in the present study. Several authors found that shea-nut cake is unpalatable to livestock due to its bitter taste and it has been shown to contain anti-nutritional factors such as saponins and theobromine (Atuahene *et al.*, 1998) which can be deleterious to chick health (Owusu-Domfeh *et al.*, 1978; Clarke and Clarke, 1979).

The nutrient composition of cottonseed cake used in monogastric feeds in Burkina Faso is similar to values found for glandless cottonseed cake and expeller cake in India (Nagalakshmi *et al.*, 2007) and is also similar to the data of Smith (2001). The higher level of ash and fibre from July to October can be attributed to the long period of storage and possible contamination of the seeds, as cotton is harvested from November to December and the seeds are stored and used throughout the following 12 months for oil extraction. This can also explain the higher level of ME and CP in samples from November to December compared to July to October. However, another possible explanation could be the difference in growing conditions between 2005 and 2006 for the crop harvested in November-December.

Based on chemical analysis, the by-products analyzed in this study seem to be potentially useful in chicken nutrition, although proximate analysis has been shown to be of limited value in defining feed quality and therefore digestibility data should also be taken into account (Morgan and Trinder, 1980).

Cottonseed cake amino acid digestibility values are close to values found by Perez-Maldonado (2000) in

Australia. Despite the relatively high fibre contents of the by-products, the digestibility values of the important essential amino acids indicate that they could be of value as ingredients in chickens feed. In particular the protein content of local beer residue and cottonseed cake indicates their potential value for monogastrics, although the CP content in shea-nut cake is too low for it to be useful. However, these feedstuffs have been exposed to heat and pressure during processing, which are necessary to inactivate some antinutritional factors in the raw material (Gatel, 1994; Nagalakshmi *et al*., 2007), but result in chemical reactions between protein-bound amino acids and reducing compounds present in the feed matrix, which may render some of the amino acids nutritionally unavailable for the animal (Hodgkinson, 2006). Lysine is the amino acid which is most affected by processing as it is more exposed to early Maillard reactions, which provoke the formation of a reacted lysine (Amadori compounds) which is partially absorbed from the gut but has no nutritional value to the animals (Hurrell and Carpenter, 1981). Moreover, a proportion of the reacted lysine derivatives are acid labile and can revert back to lysine during the acid hydrolysis step of conventional amino acid analysis, but this does not occur in the animal's digestive tract (Rutherfurd *et al*., 1997a; Moughan, 2005). Consequently, the lysine concentrations of the feed and excreta, determined by conventional amino acid analysis, will be overestimated and the conventional true digestibility assay will overestimate the amounts of available lysine and possibly other amino acids for the animal. This can explain the higher digestibility coefficients (92, 96 and 89%, respectively, for beer residue, shea-nut cake and cottonseed cake) obtained in this study. Therefore, other methods of evaluation, such as bioassays (Rutherfurd *et al*., 1997b) and feeding trials are necessary to evaluate the effect of different inclusion levels in the diet on growth and egg production performance. In addition, studies on the utilisation of shea-nut cake by poultry should be done on oil cake from commercial "press" extraction, due to its higher protein content, rather than the cake from traditional oil extraction.

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