



# Effects of fungal (*Aspergillus niger* or *Ceriporiopsis subvermispota*) fermentation on the nutritive value of shea nut (*Vitellaria paradoxa*) meal for 'broiler chicks

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Herbert Kwabla Dei, Paul Stephen Rose, Alexander Mackenzie. Effects of fungal (*Aspergillus niger* or *Ceriporiopsis subvermispota*) fermentation on the nutritive value of shea nut (*Vitellaria paradoxa*) meal for 'broiler chicks. *British Poultry Science*, 2008, 49 (03), pp.360-367. 10.1080/00071660802126651 . hal-00545332

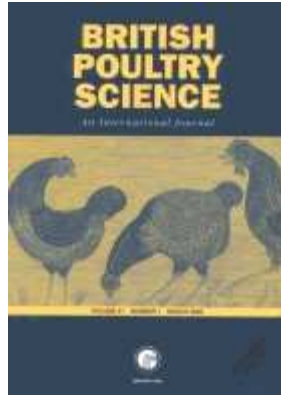
**HAL Id: hal-00545332**

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Submitted on 10 Dec 2010

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**Effects of fungal (*Aspergillus niger* or *Ceriporiopsis subvermispora*) fermentation on the nutritive value of shea nut (*Vitellaria paradoxa*) meal for broiler chicks**

Journal:	<i>British Poultry Science</i>
Manuscript ID:	CBPS-2007-260.R1
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	13-Feb-2008
Complete List of Authors:	Dei, Herbert; Harper Adams University College, Animal Science Research Centre Rose, Paul; Harper Adams University College, Animal Science Research Centre Mackenzie, Alexander; Harper Adams University College, Animal Science Research Centre
Keywords:	Shea nut meal, Anti-nutrients, Broilers, Fermentation, <i>Aspergillus niger</i> , <i>Ceriporiopsis subvermispora</i>



Effects of fungal (*Aspergillus niger* or *Ceriporiopsis subvermispota*) fermentation on the nutritive value of shea nut (*Vitellaria paradoxa*) meal for broiler chicks

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RUNNING TITLE: FERMENTATION OF SHEA NUT MEAL

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Accepted for publication 19<sup>th</sup> February 2008

**Abstract** 1. Shea nut (*Vitellaria paradoxa* Gaertn) meal was fermented for 8 d with either *Aspergillus niger*, *Ceriporiopsis subvermispora*, or a mixture of the two organisms. The fermentation was completed using two methods, an opened container or a closed container.

2. Each of the 6 samples was dried and incorporated into basal broiler diets at 90g/kg.

3. In addition, the unfermented shea nut meal was incorporated in the diet at 90 g/kg and the basal diet (maize and soybean meal-based) was also provided as an 8th dietary treatment to individually caged broiler chickens.

4. All fermented fungi-treated shea nut meals had similar proximate nutrient compositions to the unfermented shea nut meal, but there were substantial decreases in their hydrolysable tannins and saponin contents. Both fermentation methods gave similar reductions in the concentrations of tannins and saponins.

5. Shea nut meal fermented with individual or both fungal organisms gave greater ( $P<0.001$ ) growth performance than that of unfermented shea nut meal. However, all shea nut meals including the unfermented meal gave lower ( $P<0.001$ ) growth variables than those for the maize-soybean meal control.

6. The nutritional improvement of shea nut meal achieved in this study still falls far short of what is expected for it to become valuable for the poultry feed industry. These fermentation methods using *A. niger* or *C. subvermispora* require further improvements to provide satisfactory feed products.

## INTRODUCTION

Shea nut (*Vitellaria paradoxa*, Gaertn.) meal is a by-product obtained from the shea fat processing industry in West Africa. It is increasingly available in large quantities for feeding animals and it has the potential to supply significant amounts of dietary protein and energy to poultry feeds in Western Africa. However, its utilisation in the diet is limited by the presence of high concentrations of anti-nutritive factors such as tannins and saponins (Annongu *et al.*,

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1996; Atuahene *et al.*, 1998). The adverse effects of these anti-nutritive factors in shea nut meal can be minimised by hot water treatment (Okai *et al.*, 1995), but this also gives a considerable loss of dry matter. *Aspergillus niger* (Pinto *et al.*, 2001) or *Ceriporiopsis subvermispota* (Gamble *et al.*, 1996) fungi can degrade tannins. Microbial fermentation can also reduce the concentration of saponins in a feedstuff (Reddy and Pierson, 1994). Solid state fermentation using fungal cultures such as *Aspergilli* can improve the nutritive value of feedstuffs for broiler chickens (Mathivanan *et al.*, 2006; Yamamoto *et al.*, 2007). The potential uses of these two organisms to improve the nutritional value of shea nut meal by fermentation have not been studied.

    If fermentation of shea nut meal is valuable, a practical system of fermentation would need to be applied at the oil extraction factory or on-farm. It is unlikely that controlled fermentation conditions would be available at these sites. There is a need to examine whether the method of fermentation is an important factor in the nutritional improvement of shea nut meal. The simplest practical fermentation method would be to apply the fungal organisms to the shea nut meal and then leave windrowed. Alternatively, after the application of the fungal organisms, the material could be compacted and sheeted to exclude some, but not all, air and reduce other fungal or bacterial contamination. Two laboratory-based fermentation methods were devised to examine these two fermentation options.

    Therefore, this study was undertaken to determine if the fermentation of shea nut meal using *A. niger* or *C. subvermispota*, or a combination of the two organisms could change tannin and saponin contents or change the growth performance of broiler chickens relative to the unfermented shea nut meal or a basal diet (containing no shea nut meal). A second objective was to compare two methods of fermentation for the same variables of chemical composition, nutrient availability and broiler chicken growth performance for each of the

three fungal organism treatments (*A. niger*, *C. Subvermispora* or a combination of both organisms). Eight dietary treatments were compared.

## MATERIALS AND METHODS

### Culturing of fungal species

*Ceriporiopsis subvermispora* (ATTC number 90466) was obtained from the American Type Culture Collection (ATTC, 10801 University Blvd., Manassas, VA 20110-2209), cultured in ATTC medium (#200 YM or Difco 0712) and incubated at 24°C for 7 d. The *Aspergillus niger* was a laboratory strain isolate obtained from the University of Wolverhampton, UK, cultured by agar plating technique using Sabouraud dextrose agar (Oxoid Ltd, Basingstoke, UK) and incubated at 24°C for 7 d. *A. niger* spores were harvested by tapping, whereas those of *C. subvermispora* were scraped off. Spore counts were determined using an haematocytometer according to the Fuchs-Rosenthal technique to be approximately  $1.6 \times 10^6$  spores, which were equivalent to 0.25 g (*A. niger*) and 0.49 g (*C. subvermispora*). The spores were preserved at 4°C until the organisms were used for solid medium inoculation.

### Preparation of fermented fungi-treated shea nut meal samples

An expeller shea nut meal (Shebu-Loders Crocklaan Ltd, Savelugu-Ghana) was used for this study (Dei *et al.*, 2008) and this was divided into 7 lots. Six of these shea nut meal samples were mixed with water in the ratio 1:2 (1 part shea nut meal: 2 parts water) and the spores of *A. niger* (0.25g per kg of shea nut meal) were added to two samples. The spores of *C. subvermispora* (0.49g per kg of shea nut meal) were added to two further shea nut meal samples and a mixture of spores of *A. niger* (0.25g) and *C. subvermispora* (0.49g) were added to the two remaining shea nut meal samples. Each of the two fungal treatment samples was allocated to one of two fermentation treatment methods. Method 1 involved fermentation of the wet material in an opened plastic container, whereas in Method 2, the material was gently compacted and then the plastic container was closed and sealed with adhesive film. All the

1 samples were kept in a room at ambient temperature (24°C) for 8 d. Although *A. niger* is an  
2 aerobic organism, there would be a production phase under the micro-aerobic conditions that  
3 existed in the closed container (David *et al.*, 2003).

4 The pH of the fermented samples was determined using a pH Meter (Model 3510,  
5 Jansway, UK). The mats of fungal growth on the surface of samples in the opened containers  
6 were scraped-off before drying. Each sample was dried at 56°C and ground.

7 **Broiler chick assay**

8 The 6 fermented and one unfermented shea nut meal samples were each substituted for the  
9 basal diet (Table 1) at 90 g/kg. Ross 308 male broiler chicks were reared in a litter-floored  
10 pen and fed a proprietary broiler starter feed for 10 d. At 10 d of age, 64 broilers of similar  
11 body weight were individually caged (0.3m x 0.3m x 0.36m) and fed one of the 8 meal-form  
12 experimental diets (8 replicates) to 18 d of age. During the last 4 d of the 8-d experiment, the  
13 droppings were collected daily and stored at 4°C until the combined 4-d sample was dried in a  
14 force-draught oven at 60°C.

Table 1 near here

15 **Chemical analyses**

16 The ground shea nut meal samples were analysed using standard methods (AOAC, 2000) for  
17 dry matter (Method 934.01), nitrogen (Method 968.06), ash (Method 942.05) and gross  
18 energy (adiabatic bomb calorimeter Model 1261; Parr Instrument Co., Moline, IL). Ether  
19 extract content was determined after an hydrochloric acid (4M) digestion (Method 920.39).  
20 The neutral detergent fibre content was determined by the method of van Soest (1963) using  
21 neutral detergent solution. Each sample of bird droppings was also analysed for dry matter,  
22 nitrogen and gross energy.

23 Tannin concentrations of the shea nut meal samples were determined at the Institute of  
24 Animal Reproduction and Food Research of the Polish Academy of Sciences, Olsztyn,  
25 Poland. The content of total soluble phenolics was determined according to the method

described by Naczek and Shahidi (1989) using catechin as a standard. The bound plus soluble proanthocyanidins were assayed colorimetrically by the method of Price *et al.* (1978) using catechin as a standard. The soluble proanthocyanidins were determined by the acid-butanol reagent method of Porter *et al.* (1986) as cyanidins using an HPLC (Beckman DU 7500, Fullerton, CA) and detected at a 550 nm wavelength. Hydrolysable tannins were determined as gallic acid after enzymatic hydrolysis by tannase according to the procedure of Karamać *et al.* (2006) using a Shimadzu HPLC system (Shimadzu Corp., Kyoto, Japan) and detected at a 280 nm wavelength. The saponin in the samples was determined at the Institute of Agricultural Research and Training, Ibadan, Nigeria) by the method of Wall *et al.* (1952). The sample was extracted with ethanol in a soxhlet apparatus, and the extract was defatted with benzene in a continuous liquid-liquid extractor. The addition of butanol formed a butanol-saponin extract that was quantified using rat red blood cells.

### Statistical analysis

A randomised block analysis of variance was used to compare the treatment means using GENSTAT (10<sup>th</sup> version). The tier level of cages was considered as a blocking factor. The three fungal treatments and two methods of fermentation were considered as treatment factors with their interactions. Two further orthogonal contrasts were used to compare the means of all the fermentation treatments with each of the two additional controls (maize-soybean meal diet and unfermented shea nut meal diet).

## RESULTS

The pH of the fermented shea nut meals were 5.3 (opened container) and 5.6 (closed container) indicating that a significant amount of fermentation had taken place in each of the 6 samples. The proximate nutrient compositions of all fermented fungi-treated and unfermented shea nut meal samples were similar (Table 2). However, there were appreciable reductions in hydrolysable tannins (44-79%) as well as saponins (10-87%) in the fermented samples (Table

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3). The reduction in hydrolysable tannins was greatest when both organisms were present in the meal fermented by method two (closed container). The fungal degradation of proanthocyanidins was less than that of hydrolysable tannins in both fermentation methods (Table 3).

The nutrient metabolisabilities of the experimental diets were greater ( $P<0.05$ ) for the control (maize-soybean meal diet) than any of the shea nut meal containing diets (Table 4). However, dietary AME of the unfermented meal was similar to that of the other control. Although there were no significant differences between the fermented and unfermented meals, dietary AME of the fermented meals tended ( $P=0.052$ ) to be lower. This may have been due to the utilisation of some of more available nutrients by the fungal organisms (Egli and Zinn, 2003).

Tables 2 & 3 near here

A correlation matrix of the chick growth and nutrient metabolisability variables of the fermented samples and their contents of anti-nutritive factors is shown in Table 4. There were no significant correlations between the variables. However, the correlation ( $r = -0.794$ ) between crude protein metabolisability and saponin approached a significant level ( $P = 0.059$ ).

The birds fed the fermented shea nut meal treatments had higher ( $P<0.001$ ) feed intakes, weight gains and feed conversion efficiencies compared to the birds fed the unfermented shea nut meal (Table 5). Also, all growth variables of birds fed the unfermented meal were far lower ( $P<0.001$ ) than those of birds fed the basal diet (maize and soybean meal-based). Although the birds fed the shea nut meal fermented with both fungal organisms had lower ( $P<0.05$ ) feed intakes, there were no significant differences in their weight gains or feed conversion efficiencies compared to birds fed the fermented meals using the individual fungal organisms (Table 5).

Tables 4 & 5 near here

## DISCUSSION

The amounts of tannins and saponins in some feeds can be reduced by fermentation (*i.e.* wet incubation of a feedstuff), although the mechanism by which these components are eliminated is not fully understood (Reddy and Pierson, 1994). The fermentation process can create conditions for the growth of microbes (*Bacillus*, *Corynebacterium*, *Klebsiella*, *Aspergillus*, *Penicillium*, *Fusarium* and *Candida*) that break down tannins (Bhat *et al.*, 1998). However, the microbial degradation of condensed tannins (proanthocyanidins) is less than that of hydrolysable tannins in both aerobic and anaerobic environments (Bhat *et al.*, 1998). In this study, the fungal fermentation treatments resulted in higher reductions in hydrolysable tannins than proanthocyanidins (Table 3). Annongu *et al.* (1996) reported a poor reduction (34%) in proanthocyanidins in naturally fermented shea nut meal, probably because of the action of endogenous micro-organisms. *A. niger* strains are noted for tannase synthesis ability (Pinto *et al.*, 2001; Ramirez-Coronel *et al.*, 2003) that can degrade hydrolysable tannins into glucose and gallic acid. As is evident from the results, gallic acid concentrations increased (21-93%) in the fermented samples. Also, *A. niger* is capable of ligno-cellulolytic enzyme production such as cellulases and xylanases (Villena and Gutierrez-Cornea, 2007), which can degrade tannins associated with cell wall polysaccharides. *C. subvermispora* can degrade condensed tannins (Gamble *et al.*, 1996) as well as hydrolysable tannins (Aikin *et al.*, 1995) through the production of ligno-cellulolytic enzymes that degrade fibre. *C. subvermispora* is among the most selective lignin-degraders in the wood industry.

The fermentation process can produce organic acids that break down saponins (Delaude, 1974). The reduction in saponin concentrations in the fermented shea nut meals may have been due to the production of organic acids. Many authors have reported the importance of *A. niger* in the industrial production of citric acid using agro-industrial by-products as substrates (Leangon *et al.*, 1999; Vandenberghe *et al.*, 2000). Heng *et al.* (2006)

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3 1 reported degradation of saponins in peas at acidic pH. Annongu *et al.* (1996) attributed the  
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5 2 reduction in saponin (50%) in naturally fermented shea nut meal to organic acids.  
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8 3 The fermentation of shea nut meal using both fungal organisms in the same culture  
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10 4 failed to elicit far greater reductions of tannins or saponins than individual organisms. This  
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12 5 was probably due to antagonistic activity between the two fungal organisms. Although the  
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14 6 mode of the antagonism was not known, the modes of action proposed for microbial  
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16 7 antagonism in other studies (Shrivastava *et al.*, 1996; Sipiczki, 2006) include competition for  
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18 8 space and nutrients, and production of enzymes that break down cell wall. Thus microbial  
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20 9 fermentation of shea nut meal should preferably involve single micro-organisms.  
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24 10 Generally, the effects of the fungal treatments on the tannins in particular were not as  
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26 11 great as expected. The residual tannins in the fermented meals could, therefore, still have  
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28 12 adverse effects on the growth of broiler chickens. Fungal fermentation processes can be  
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30 13 affected by several factors such as type of substrates (Lu *et al.*, 1995; David *et al.*, 2003),  
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32 14 aeration conditions (Meijer *et al.*, 2007) and water activity (Romero *et al.*, 2007) on fungal  
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34 15 growth and productivity. Also, as the fungal cells divide and the culture develops, the amount  
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36 16 of biomass makes the culture congested. This is a recognised practical problem with fungal  
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38 17 fermentation (Ward *et al.*, 2006). This may limit mass-transfer processes in the culture system  
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40 18 of enzymes and metabolites produced or retard growth of the fungal organisms. Thus there is  
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42 19 a need to subject fermentation methods of the shea nut meal to further studies. These may  
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44 20 include the use of other natural or genetically-engineered fungal organisms and manipulation  
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46 21 of the growth conditions of the microbe in order to provide acceptable feed products.  
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53 22 The poor growth performance of birds fed on unfermented shea nut meal was to be  
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55 23 expected. Many studies involving shea nut meal have shown reduced feed intakes, weight  
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57 24 gains and feed conversion efficiencies in broiler chickens (Annongu *et al.* 1996; Atuahene *et*  
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59 25 *al.*, 1998; Olorede *et al.*, 1999), rats (Okai *et al.*, 1995) and pigs (Okai and Bonsi, 1989).  
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1 These authors have attributed the poor utilisation of shea nut meal in monogastric diets  
2 variously to the presence of anti-nutritive factors such as tannins and saponins. The biological  
3 significance of tannins and saponins in poultry nutrition is related to their characteristic  
4 adverse effects on feed intake (Cheeke, 1971; Armstrong *et al.*, 1974) and nutrient utilisation  
5 (Shimoyamada *et al.*, 1998; Smulikowska *et al.*, 2001). In this study, the adverse effects of  
6 tannins and saponins probably resulted in low feed intakes as well as low nutrient  
7 metabolisability in the unfermented meal.

8 The chicks fed diets containing shea nut meal fermented with the fungal organisms  
9 had an improved growth performance compared to the unfermented shea nut meal group.  
10 Annongu *et al.* (1996) also reported significant improvements in feed intakes and growth rates  
11 of adult broilers when fed shea nut meal that had undergone natural fermentation. Other  
12 reports have shown that chicks fed on diets containing guar meal (Nagra *et al.*, 1998),  
13 soybeans (Mathivanan *et al.*, 2006) or koji feed (Yamamoto *et al.*, 2007) cultured with  
14 *Aspergilli* significantly improved growth rates of broiler chickens. In this study, there were  
15 substantial improvements in the feed conversion efficiencies of the fermented meals. This  
16 may have been due to protein-sparing effects, as a result of reductions in the concentrations of  
17 anti-nutrients (Nelson *et al.*, 1975). All anti-nutrients in the fermented meals tended to be  
18 negatively correlated with crude protein metabolisability, particularly saponins ( $P=0.059$ ).  
19 However, the residual concentrations of these anti-nutrients were still high. Thus growth rates  
20 of birds fed the fermented meals were relatively poor compared to that of birds fed on the  
21 control diet. Within the 6 fermented shea nut meal treatments, there were no strong  
22 correlations between bird growth performance and determined tannin and saponin levels. This  
23 may have been just a reflection of the high variability in animal-based experiments; but the  
24 tannin break-down products may also have had significant effects on bird growth  
25 performance. Despite the lack of correlations between the available tannins and growth

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3 1 variables, dietary tannins have been shown to inhibit *in vivo* activities of trypsin and  $\alpha$ -  
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5 2 amylase (Longstaff and McNab, 1991), which may affect digestion of proteins and starch.  
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7 3 Also, total phenolics may include non-tannin polyphenolic compounds or tannin precursors.  
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9 4 These low molecular weight polyphenol components associated with tannins are more readily  
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11 5 absorbed from chick diets than tannins, and may account for the major anti-nutritive effects  
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13 6 (Butler and Rogler, 1992).  
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17 7 The nutritional improvement of shea nut meal achieved in this study still falls far short  
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19 8 of what is expected for it to become valuable for the feed industry. The fermentation methods  
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21 9 presently used require further research to enable a nutritionally valuable feedstuff to be  
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23 10 produced.  
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27 11 ACKNOWLEDGEMENTS

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29 12 The financial assistance provided by Ghana Educational Trust Fund (GETFUND) as well as  
30  
31 13 technical assistance provided for tannin analysis by Ryszard Amarowicz (Institute of Animal  
32  
33 14 Reproduction and Food Research of the Polish Academy of Sciences, Olsztyn, Poland) and  
34  
35 15 saponin analysis by Adeboye Fafiolu (College of Animal Science and Livestock Production,  
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37 16 University of Agriculture, Abeokuta, Nigeria) is gratefully acknowledged.  
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41 17 REFERENCES

42  
43 18 AIKIN, D.E., RIGSBY, L.L., SETHURAMAN, A., MORRISON, W.H., GAMBLE, G.R. &  
44  
45 19 ERIKSSON, K-E. L.L. (1995). Alterations in structure, chemistry, and biodegradability of  
46  
47 20 grass lignocellulose treated with the white rot fungi (*Ceriporiopsis subvermispora* and  
48  
49 21 *Cyathus stercoreus*). *Applied Environmental Microbiology*, **61**: 1591-1598.  
50  
51 22 ANNONGU, A.A., TERMEULEN, U., ATTEH, J.O. & APATA, D.F. (1996). Toxicological  
52  
53 23 assessment of native and industrial fermented sheabutter cake in nutrition of broilers. *Archiv*  
54  
55 24 *fur Geflugelkunde*, **60**: 221-226.  
56  
57  
58  
59  
60

- 1 ARMSTRONG, W.D., FEATHERSTON, W.R. & ROGLER, J.C. (1974). Effects of bird  
2 resistant sorghum grain and various commercial tannins on chick performance. *Poultry*  
3 *Science*, **53**: 2137-2142.
- 4 ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS (2000). *Official methods of*  
5 *analysis*. Association of Official Analytical Chemists, Washington, D.C.
- 6 ATUAHENE, C.C., DONKOH, A. & ASANTE, F. (1998). Value of sheanut cake as a  
7 dietary ingredient for broiler chicken. *Animal Feed Science and Technology*, **72**:133-142.
- 8 BHAT, T.K., SINGH, B. & SHARMA, O.P. (1998). Microbial degradation of tannins - A  
9 current perspective. *Biodegradation*, **9**: 343-357.
- 10 BUTLER, L.G. & ROGLER, J.C. (1992). Biochemical mechanisms of the anti-nutritional  
11 effects of tannins. *American Chemical Society Symposium Series*, **506**: 298-304.
- 12 CHEEKE, P.R. (1971). Nutritional and physiological implication of saponins: a review.  
13 *Canadian Journal of Science*, **51**: 621-632.
- 14 DAVID, H, AKESSON, M. & NIELSEN, J. (2003). Reconstruction of the central carbon  
15 metabolism of *Aspergillus niger*. *European Journal of Biochemistry*, **270**: 4243-4253
- 16 DEI, H.K., ROSE, S.P. & MACKENZIE, A.M. (2008). Metabolisable energy in different  
17 shea nut (*Vitellaria paradoxa*) meal samples for broiler chickens. *Poultry Science*, **87**: in  
18 press.
- 19 DELAUDE, C. (1974). Chemical study of the saponins of Sapindaceae. Identification of the  
20 saponin of *Radikofera calodendra*. *Bullentin of Society of Royal Science Liege*, **43**: 693-696.
- 21 EGLI, T. & ZINN, M. (2003). The concept of multiple-nutrient-limited growth of micro-  
22 organisms and its application in biotechnological processes. *Biotechnology Advances*, **22**: 35-  
23 43.
- 24 GAMBLE, G.G., AKIN, D.E., MAKKAR, H.P.S. & BECKER, K. (1996). Biological  
25 degradation of tannins in *Sericea lespedeza* (lespedeza cuneata) by the White Rot Fungi

- 1
- 2
- 3 1 *Ceriporiopsis subvermispora* and *Cyathus stercoreus* analyzed by Solid-State <sup>13</sup>C Nuclear
- 4
- 5 2 Magnetic Resonance Spectroscopy. *Applied and Environmental Microbiology*, **62**, 3600-
- 6
- 7 3 3604.
- 8
- 9
- 10 4 HENG, L., VINCKEN, J-P., HOPPE, K., VAN KONINGSVELD, G.A., DECROOS, K.,
- 11
- 12 5 GRUPPEN, H., VAN BOEKEL, M.A.J.S. & VORAGEN, A.G.J. (2006). Stability of pea
- 13
- 14 6 DDMP saponin and the mechanism of its breakdown. *Food Chemistry*, **99**: 326-334.
- 15
- 16
- 17 7 KARAMAĆ, M., KOSIŃSKA, A. & PEGG, R.B. (2006). Content of gallic acid in selected
- 18
- 19 8 plant extracts. *Polish Journal of Food Nutrition Science*, **15**: 55-58.
- 20
- 21
- 22 9 LEANGON, S., MADDOX, I.S. & BROOKS, J.D. (1999). Influence of the glycolytic rate on
- 23
- 24 10 production of citric acid and oxalic acid by *Aspergillus niger* in solid state fermentation.
- 25
- 26 11 *World Journal of Microbiology and Biotechnology*, **15**: 493-495.
- 27
- 28
- 29 12 LONGSTAFF, M. & MCNAB, J.M. (1991). The inhibitory effects of hull polysaccharides
- 30
- 31 13 and tannins of field beans (*Vicia faba* L.) on the digestion of amino acids, starch and lipids
- 32
- 33 14 and on digestive enzyme activities in young chicks. *British Journal of Nutrition*, **65**: 199-216.
- 34
- 35
- 36 15 LU, M.Y., MADDOX, I.S. & BROOKS, J.D. (1995). Citric acid production by *Aspergillus*
- 37
- 38 16 *niger* in solid-substrate fermentation. *Bioresource Technology*, **54**: 235-239.
- 39
- 40
- 41 17 MATHIVANAN, R., SELVARAJ, P. & NANJAPPAN, K. (2006). Feeding of fermented
- 42
- 43 18 soybean meal on broiler performance. *International Journal of Poultry Science*, **5**: 868-872.
- 44
- 45
- 46 19 MEIJER, S., PANAGIOTOU, G., OLSSON, L. & NIELSEN, J. (2007). Physiological
- 47
- 48 20 characterization of xylose metabolism in *Aspergillus niger* under oxygen-limited conditions.
- 49
- 50 21 *Biotechnology and Bioengineering*, **98**: 462-475.
- 51
- 52
- 53 22 NACZK, M. & SHAHIDI, F. (1989). The effect of methanol-ammonia-water treatment on
- 54
- 55 23 the content of phenolic acids of canola. *Food Chemistry*, **31**: 159-164.
- 56
- 57
- 58
- 59
- 60

- 1 NAGRA, S.S., SETHI, R.P. & CHOPRA, A.K. (1998). Feeding of fermented guar  
(*Cyamopsis tetragonoloba* L. *taub*) meal to broiler chicks. *Industrial Journal of Animal  
Production and Management*, **14**: 40-44.
- 2 NELSON, T.S., STEPHENSON, E.L., BURGOS, A., FLOYD, J. & YORK, J.O. (1975).  
3 Effect of tannin content and dry matter on energy utilisation and average amino acid  
4 availability of hybrid sorghum grains. *Poultry Science*, **54**: 1620-1623.
- 5 OKAI, B.D. & BONSI, M.K.L. (1989). Sheanut cake as a substitute for maize in the diets of  
6 growing gilts. *Journal of the University of Science and Technology*, **9**:45-50.
- 7 OKAI, D.B., TOPPS, J.H., ENGLISH, P., TUAH, A.K. & OSAFO, E.L.K. (1995). The  
8 effects of processed sheanut cake and groundnut skins on the growth performance and organ  
9 characteristics of rats. *Ghana Journal of Biochemistry, Biotechnology and Molecular Biology*,  
10 **3**: 76-82.
- 11 OLOREDE, B.R., LONGE, O.G. & BABANTUNDE, G.M. (1999). Growth performance,  
12 organs measurement and economics of production of broiler chickens fed a high shea butter  
13 cake diet supplemented with fish meal or groundnut cake. *International Journal of Animal  
14 Science*, **14**: 203-207.
- 15 PINTO, G.A.S., LEITE, S.G.F., TERZI, S.C. & COURI, C. (2001). Selection of tannase-  
16 producing *Aspergillus niger* strains. *Brazilian Journal of Microbiology*, **32**: 24-26.
- 17 PORTER, L.J., HIRSTICH, L.N. & CHAN, B.G. (1986). The conversion of procyanidins and  
18 prodelphinidins to cyanidins and delpinidin. *Phytochemistry*, **25**: 223-230.
- 19 PRICE, M.L., VAN SCOYOC, S. & BUTLER, L.G. (1978). A critical evaluation of the  
20 vanillin reaction as an assay for tannin in sorghum grain. *Journal Agriculture and Food  
21 Chemistry*, **26**: 1214-1218.

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2  
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59  
60

1     RAMIREZ-CORONEL, M.A., VINIGERA-GONZALEZ, G., DARVILLE, A. & AUGUR, C.  
2     (2003). A novel tannase from *Aspergillus niger* with beta-glucosidase activity. *Microbiology*,  
3     **149**: 2941-2946.

4     REDDY, N.R. & PIERSON, M.D. (1994). Reduction in antinutritional and toxic components  
5     in plant foods by fermentation. *Food Research International*, **27**: 281-290.

6     ROMERO, S.M., PATRIARCA, A., FERNANDEZ PINTO, V. & VAAMONDE, G. (2007).  
7     Effect of water activity and temperature on growth of ochratoxigenic strains of *Aspergillus*  
8     *carbonarius* isolated from Argentinean dried vine fruits. *International Journal of Food*  
9     *Microbiology*, **115**: 140-143.

10    SHIMOYAMADA, M., IKEDO, S., OOTSUBO, R. & WATANABE, K. (1998). Effects of  
11    soybean saponins on chymotryptic hydrolyse of soybean proteins. *Journal of Agricultural and*  
12    *Food Chemistry*, **46**: 4793-4797.

13    SHRIVASTAVA, J.N., GHAWANA, V.K. & KUMAR, A. (1996). Biodegradation of wool  
14    by *Trichophyton simii* and *Aspergillus niger*. *Mycoses*, **39**: 483-487.

15    SMULIKOWSKA, S., PASTUSZEWSKA, B., SWIECH, E., OCHTABINSKA A.,  
16    MIECZKOWSKA, A., NGUYEN, V.C. & BURACZEWSKA, K. (2001). Tannin content  
17    affects negatively nutritive value of pea for monogastrics. *Journal of Animal and Feed*  
18    *Sciences*, **10**: 511-523.

19    SIPICZKI, M. (2006). *Metschnikowia* strains isolated from botrytized grapes antagonize  
20    fungal and bacterial grown by iron depletion. *Applied Environmental Microbiology*, **68**: 4884-  
21    4893.

22    VAN SOEST, P.J. (2003). Use of detergent in the analyses of fibrous feeds. II. A rapid  
23    method of determination of fibre and lignin. *Journal of the Association of Analytical*  
24    *Chemists*, **46**:829-835.

- 1 VANDENBERGHE, L.P.S., SOCCOL, C.R., PANDEY, A. & LEBEAULT, J.-M. (2000).  
2 Solid-state fermentation for the synthesis of citric acid by *Aspergillus niger*. *Bioresource*  
3 *Technology*, **74**: 175-178.
- 4 VILLENA, G.K. & GUTIERREZ-CORREA, M. (2007). Production of lignocellulolytic  
5 enzymes by *Aspergillus niger* biofilms at variable water activities. *Journal of Biotechnology*,  
6 **10**: 124-140.
- 7 WALL, M. E., M. M. KRIDAR, E. J. ROCHMAN & C. R. EGGY. (1952). The steroidal  
8 sapogenin 1: Extraction, isolation and identification. *Journal of Biological Chemistry* **198**:  
9 533-543.
- 10 WARD, O.P., QIN, W.M., DHANJOON, J., YE, J. & SINGH, A. (2006). Physiology and  
11 biotechnology of *Aspergillus*. *Advances in Applied Microbiology*, **58**: 1-75.
- 12 YAMAMOTO, M., SALEH, F., TAHIR, M., OHTSUKA, A. & HAYASHI, K. (2007). The  
13 effect of Koji-feed (fermented distillery by-product) on the growth performance and nutrient  
14 metabolizability in broiler. *The Journal of Poultry Science* **44**: 291-296.

**Table 1.** *Composition of the experimental diets*

Ingredients (g/kg)	Basal diet	Shea nut meal diets
Maize	515.5	469.1
Dehulled soybean meal	250.0	227.5
White fishmeal	60.0	54.6
Wheatfeed	150.0	136.5
Lysine hydrochloride	1.0	0.9
D,L-methionine	2.0	1.8
Dicalcium phosphate	10.0	9.1
Limestone	5.5	5.0
Vitamin and trace element premix <sup>1</sup>	3.0	2.75
Sodium chloride	3.0	2.75
Experimental shea nut meal sample <sup>2</sup>	-	90.0
Calculated composition (g/kg)		
Crude protein	230.8	223.0
Lysine	13.5	12.8
Methionine	5.9	5.6
Methionine + Cystine	9.8	9.4
Calcium	7.5	7.4
Phosphorus	7.6	7.2
Sodium	1.8	1.7
Metabolisable Energy (MJ/kg)	12.2	12.4

<sup>1</sup>Vitamin-trace mineral premix for broilers (Ian Hollows Feed Supplement, UK) added per kg: 800 mg retinol, 150 mg cholecalciferol, 1.25 g tocopherol, 150 mg thiamin, 500 mg riboflavin, 150 mg pyridoxine, 750 mg cyanocobalamin, 3 g nicotinamide, 0.5 g pantothenic acid, 75 mg folic acid, 6.25 g biotin, 12.5 g choline chloride, Iron 1 g, 50 mg cobalt, 5 g manganese, 0.5 g copper, 4 g zinc, 50 mg iodine, 10 mg selenium 25 mg molybdenum.

<sup>2</sup>Nutrient compositions of the experimental shea nut meal samples were assumed to be similar. Dietary formulation was based on an expeller shea nut meal (Dei *et al.*, 2008).

**Table 2.** Chemical composition of unfermented and fermented fungi-treated samples of shea nut meal (g/kg dry matter basis)

Treatments		Crude protein	Ether extract	Ash	Neutral detergent fibre	Gross energy (MJ/kg)
Unfermented shea nut meal		143.6	101.4	52.3	455.7	22.8
<b><u>Fermented shea nut meals</u></b>						
<i>A. niger</i>	Method 1	143.1	117.0	49.6	498.1	23.9
	Method 2	141.9	113.5	50.0	470.3	23.6
<i>C. subvermispora</i>	Method 1	143.0	116.3	55.4	448.6	23.8
	Method 2	141.2	115.3	53.6	467.0	23.6
<i>A. niger</i> + <i>C. subvermispora</i>	Method 1	142.0	111.2	53.6	451.9	23.6
	Method 2	139.3	120.0	49.4	467.4	24.2

**Table 3.** Total soluble phenolics, proanthocyanidins, hydrolysable tannins, free gallic acid and saponins in unfermented (control) and fermented fungi-treated samples of shea nut meal (dry matter basis)

Treatments		Total soluble phenolics (mg catechin/g)	Bound+soluble proanthocyanidins (mg catechin/g)	Soluble proanthocyanidins (mg cyanidin/g)	Hydrolysable tannins (mg gallic acid/g)	Free gallic acid (mg gallic acid/g)	Saponins (mg/g)
Unfermented shea nut meal		116.7	253.5	18.2	3.4	1.4	6.0
<b>Fermented shea nut meals</b>							
<i>A. niger</i>	Method 1	103.2	186.7	16.6	1.5	2.5	3.7
	Method 2	91.1	166.0	13.7	1.6	1.8	0.8
<i>C. subvermispora</i>	Method 1	102.6	200.2	15.1	1.5	2.7	1.1
	Method 2	83.3	166.8	11.5	1.6	1.7	1.7
<i>A. niger</i> + <i>C. subvermispora</i>	Method 1	93.9	191.3	14.1	1.9	2.7	0.8
	Method 2	96.7	166.4	12.7	0.7	2.5	5.4

**Table 4.** *Correlation matrix<sup>1</sup> of some chick growth and nutrient metabolisability variables, and anti-nutrients in the fermented shea nut meal samples*

	Feed	Weight	CPM	AME	HT	Pas	TPas	TSP
	intake	gain						
Weight gain	0.968							
CPM	-0.016	-0.122						
AME	0.290	0.044	0.484					
HT	0.689	0.578	-0.314	0.430				
PAs	0.284	0.315	-0.633	-0.045	0.219			
TPAs	0.029	-0.045	-0.480	0.240	0.415	0.709		
TSP	-0.155	-0.120	-0.413	-0.092	-0.221	0.862	0.677	
Saponins	0.010	-0.028	-0.794	0.030	0.583	0.386	0.487	0.131

<sup>1</sup>Coefficients between -0.81 and +0.81 were not statistically significant ( $P>0.05$ ).

CPM-crude protein metabolisability, AME-apparent metabolisable energy, HT-hydrolysable energy, Pas-soluble proanthocyanidins, TPas-bound + soluble proanthocyanidins, TSP-total soluble phenolics.

**Table 5.** Growth performance of broiler chicks (10-18 d), apparent metabolisable energy, dry matter and crude protein metabolisability coefficients of basal diet and diets containing 90 g/kg of unfermented and fermented fungi-treated samples of shea nut meal

Treatments		Feed intake (g/b/d)	Weight gain (g/b/d)	Gain: Feed (g/g)	Dry matter metabolisability coefficient	Crude protein metabolisability coefficient	AME (MJ/kg)
Basal diet (no shea nut meal)		59.0	41.3	0.71	0.80	0.72	13.4
Unfermented shea nut meal		23.0	5.0	0.21	0.75	0.57	12.7
<b>Fermented shea nut meals</b>							
<i>A. niger</i>	Method 1	34.5	14.3	0.39	0.68	0.44	11.1
	Method 2	37.9	15.4	0.37	0.73	0.57	12.3
	<b>Mean</b>	<b>36.2</b>	<b>14.9</b>	<b>0.38</b>	<b>0.71</b>	<b>0.51</b>	<b>11.7</b>
<i>C. subvermispora</i>	Method 1	33.2	12.2	0.36	0.72	0.54	12.1
	Method 2	33.5	13.1	0.39	0.68	0.53	11.4
	<b>Mean</b>	<b>33.4</b>	<b>12.7</b>	<b>0.38</b>	<b>0.70</b>	<b>0.54</b>	<b>11.8</b>
<i>A. niger</i> + <i>C. subvermispora</i>	Method 1	32.2	11.1	0.33	0.71	0.49	12.3
	Method 2	27.3	8.8	0.31	0.69	0.55	11.5
	<b>Mean</b>	<b>29.8</b>	<b>10.0</b>	<b>0.32</b>	<b>0.70</b>	<b>0.52</b>	<b>11.9</b>
<b>Probability of treatment differences</b>							
<u>Orthogonal treatment comparisons</u>							
Basal vs. Fermented meals		***	***	***	*	**	*
Unfermented vs. Fermented meals		***	***	***	ns	ns	ns
<u>Fermented meals only</u>							
Methods of fermentation (M)		ns	ns	ns	ns	ns	ns
Fungal organisms (F)		*	ns	ns	ns	ns	ns
M x F interaction		ns	ns	ns	ns	ns	ns
SED for comparing:							
Individual treatment means (n=8)		2.865	2.665	0.056	0.034	0.063	0.678
Fermentation method means (n=24)		1.654	1.663	0.032	0.020	0.036	0.391
Fungal organisms means (n=16)		2.026	2.037	0.039	0.024	0.044	0.479

SED-significant error difference, n-number of replicates, ns-not significant ( $P>0.05$ ), \* $P<0.05$ , \*\* $P<0.01$ , \*\*\* $P<0.001$ .