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Processing techniques of selected oilseed by-products of potential use in animal feed: Effects on proximate nutrient composition, amino acid profile and antinutrients

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ABSTRACT

The effects of processing by autoclaving (AC), soaking (SK), short-term fermentation (S-TF, 4 d) and long-term fermentation (L-TF, 14 d) on the nutritional composition, amino acid profile and some antinutrients were determined for cottonseed meal (CSM), groundnut meal (GNM) and groundnut husk (GH) in this study. After processing, crude protein content improved by 11% after L-TF, and crude lipid content 25% after SK for CSM; crude protein content improved by 27% after S-TF and L-TF, and crude lipid content 13% after SK for GNM. Soaking and fermentation were shown to significantly increase essential amino acid contents by 44% (SK, methionine) in CSM and 46% in GNM (L-TF, histidine). Phosphorus content was reduced by 59% in CSM and 57% in GNM by L-TF. All processing techniques, with the exception of AC, reduced phytic acid and gossypol contents in CSM and GNM. It was concluded that SK and fermentation were simple, cost-effective, and efficient ways to improve the nutritional value of the selected oilseed by-products.

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1. Introduction

As the production volume of fish meal has leveled off in recent years, the commodity price has risen, driving research to focus on more sustainable, non-marine alternatives of dietary protein sources (Schipp, 2008; Cocker, 2014) to satisfy rising demands from the animal production sector. Most often, agro-industrial by-products that are used in animal feeds are of modest economic value, but of reliable quantity (Agbo, 2008). Many plant-based feed resources that could be of considerable nutritional and financial

value in animal production remain unexploited, undeveloped or poorly utilized (Agbo and Prah, 2014). Under-utilization and disposal of these resources are likely due to a lack of adequate information on how their nutritional quality could be improved. Considering the expected increase in world population and the high demand for animal products due to growth in most world economies, the prospect of feeding millions and safeguarding their food security will depend on the better utilization of non-conventional feed resources and implementation of circular bio-economy (NoRest, 2016).

Agro-industrial by-products, especially residual oilseed cakes and meals from oil extraction, are available in large quantities. Global production reached 317,000,000 t in 2016 and is forecasted to rise to 386,000,000 t by 2025 (OECD/FAO, 2016). Most of these protein meals have been explored as feed ingredients in their un-refined state to replace fish meal as alternative protein sources, especially for poultry, pigs and aquatic animals. Previous studies on oilseed meal-based diets fed to various animals have reported negative, although highly variable, effects on production

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performance. For instance, studies where shea nut meal based diets were fed to broiler chickens (Atuahene et al., 1998) and Nile tilapia (Agbo et al., 2014), observed low growth performance caused by poor digestibility, and possibly reduced feed intake (Elemo et al., 2011). Dabrowski and Kozak (1979) observed a lower growth performance in grass carp fry fed with different levels of commercial soybean meal compared to fishmeal. Weaning pigs fed increasing levels (5% to 15%) of copra and palm kernel expeller meals showed a linear reduction in final body weight, while no difference in growth performance was recorded with palm kernel meal compared to a control diet containing soybean meal and 4% of fish meal (Jaworski et al., 2014).

The limited usefulness of these by-products is either partly caused by, or further restricted by, the presence of antinutrients such as trypsin (protease) inhibitors, tannins and lectins, phytate, gossypol, oxalates and glucosinolates, saponins, antioxidants, and mycotoxins (Francis et al., 2001). These compounds affect protein and mineral utilization (Francis et al., 2001; Pashwar, 2005) by decreasing palatability, digestibility, or metabolism, and may even exert a toxic effect resulting in liver damage (Pashwar, 2005).

There is a need to increase the nutritional value of oilseed by-products, and to offset certain antinutrients and toxins, in order to realize their full potential as animal feed ingredients (Annongu et al., 1996; Pashwar, 2005). Techniques such as fermentation (Lopez et al., 2001), boiling and sodium hydroxide (NaOH) treatment (Annongu et al., 1996), heating and/or autoclaving (AC) (Clatterbuck et al., 1980), and sprouting or germination (Asiedu et al., 1993) have been proposed as ways of detoxifying and improving the nutritional value of these feed ingredients. The current study was designed to assess the effect of processing cottonseed meal (CSM), groundnut meal (GNM) and groundnut husk (GH) by AC, soaking (SK), short-term fermentation (S-TF) or long-term fermentation (L-TF) on the proximate composition, amino acid profile and some antinutrients.

2. Materials and methods

2.1. Sources and preparation of raw materials

Groundnut husk was purchased from a groundnut paste processing factory, mechanically extracted GNM from a local producer, and screw-pressed CSM was purchased from a commercial agro-feed seller, all in Kumasi, Ghana. Prior to powdering with a hammer mill, the GNM was dried in an oven (Gallenkamp Hotbox Oven) at 100 °C for 24 h, and cooled in a desiccator at room temperature. The other ingredients were also finely ground using a commercial hammer mill. All ingredients were then sealed in airtight bags and shipped to the Technical University of Denmark (DTU Aqua) where they were kept at –20 °C until needed for further processing. Commercial grade dried baker's yeast (*Saccharomyces cerevisiae*) used in the fermentation process was purchased from a local supplier in Denmark.

2.2. Processing procedures

The processes of AC, SK, S-TF and L-TF were performed on 100 g samples of CSM, GNM and GH weighed out on an electronic scale (Mettler Toledo, XS4002S, Switzerland) in triplicate. Samples of each raw material were treated as unprocessed (UP).

2.2.1. Autoclaving

The samples of CSM, GNM, and GH were transferred to 500 mL Duran glass bottles. Distilled water was added at a ratio of 7:3 (wt/vol) and mixed thoroughly before AC at 120 °C for 20 min.

The samples were then allowed to cool to room temperature (20 °C), after which they were oven dried (Memmert, UN110) at 40 °C until constant weight, cooled and stored at –20 °C until analysis.

2.2.2. Soaking

The samples of CSM, GNM and GH were transferred to 2 L glass jars. Tap water was added at a ratio of 1:10 (wt/vol). The samples were allowed to soak at room temperature for 12 h with intermittent stirring every 4 h after which the water was decanted. The samples were transferred onto a fine meshed cloth (100 µm) and squeezed, to remove as much of the water as possible. The residual meal was spread on a tray and oven dried (Memmert, UN110) at 40 °C to constant weight. After drying and cooling to room temperature, the samples were finely ground, sealed in polythene bags, and stored at –20 °C until analysis.

2.2.3. Fermentation

For S-TF and L-TF, CSM, GNM and GH was transferred to 500 mL Duran glass bottles, and inoculated with 3.40 mg of dried baker's yeast (*S. cerevisiae*). Tap water (80 mL) was added and mixed thoroughly before fermenting for either 4 or 14 d at room temperature in a sealed bottle. At the end of the fermentation process, the samples were soaked in 300 mL of tap water at room temperature for 5 min. Water removal, drying and storage followed the procedure described in section 2.2.2.

2.3. Analytical procedure for proximate composition, amino acid profile and antinutrients

Dry matter, crude protein and ash contents of the unprocessed and processed samples were determined following the procedures of the Association of Official Analytical Chemists (2005). Dry matter content was determined after oven drying for 24 h at 105 °C (Memmert UN110). Ash content was determined by incineration of the samples for 6 h at 550 °C in a muffle furnace (Heraeus Instruments K1252). Crude protein content was determined by the Kjeldahl method (FOSS Kjeltec 2200) and crude lipid content by the method described by Bligh and Dyer (1959). Phosphorus content was determined in accordance with ISO 6491:1998 (1998) standard method. The amino acid profile of the experimental ingredients were determined in duplicates by High Performance Liquid Chromatography (HPLC) analyses following the method of Larsen et al. (2011). Gossypol content analyses followed the procedure described by Pons and Hoffpauir (1954). Phytic acid content was determined using a commercially available kit (K-PHYT, Megazyme, Ireland) based on the method described by Fiske and Subbarow (1925).

2.4. Experimental design and statistical analysis

The oilseed by-products were subjected to 4 treatment processes by AC, SK, S-TF, and L-TF in addition to unprocessed samples. Each treatment was replicated 3 times per by-product and analysed in duplicates which gave the total number of observation as 3 (oilseed by-products) × 5 (treatments) × 3 (replicates) = 45 for each variable. The Shapiro–Wilk normality test was performed on data for each variable before that the averages of the processed samples were subjected to a one-way ANOVA at $P < 0.05$. The differences between the means of the unprocessed and the processed raw materials were determined by the Dunnett's multiple comparison test using GraphPad Prism 5.01 statistical software for Windows (San Diego California, USA). Results of the effect of AC, SK and fermentation against the raw materials are expressed as means with their standard deviations

(SD), and percentage changes in variables are presented in figures.

3. Results

3.1. Proximate composition

After 12 h of SK, S-TF (4 d) and L-TF (14 d), respectively, the nutritional contents of CSM, GNM and GH were significantly ($P < 0.05$) affected (Table 1). Autoclaving did not have any major effect on nutritional composition of the raw materials tested. Dry matter (DM) content of CSM appreciably increased by 5.50% ($P < 0.0001$) after 14 d of fermentation. In CSM, crude protein content was the highest (463.45 g/kg DM) after L-TF and the lowest (447.15 g/kg) after SK. Autoclaving however, resulted in approximately 9% reduction in crude protein content of CSM. Improvement in crude lipid content ranked as follows: SK > L-TF > S-TF. Meanwhile, ash and phosphorus contents were drastically reduced by approximately 52% and 59%, respectively, after L-TF. In GNM, dry matter content was reduced by AC (1.72% reduction), whereas S-TF and L-TF increased dry matter content by about 3%. After processing, crude protein content varied widely in GNM ranging from 416.40 g/kg DM after AC to 528.75 g/kg DM after S-TF, which corresponded to increments between 0 and 27%, respectively. Crude lipid content was increased by 13%, 5%, and 12% after SK, S-TF, and L-TF, respectively. Ash and phosphorus contents were reduced ($P < 0.0001$) by all treatment processes except AC. Phosphorus reduction was the lowest (59%) after L-TF and the highest (3%) after AC. At the end of the treatment processes on GH, marginal increases were recorded; crude protein and crude lipid contents were increased by 3% and 11%, respectively, after SK. Ash content was considerably reduced by up to approximately 22% after SK. Phosphorus content was reduced between 23% and 30% by SK, S-TF and L-TF ($P = 0.0002$).

3.2. Amino acid profile

The amino acid profile for the unprocessed and processed by-products are presented in Tables 2–4. Apart from AC, the other

Table 1
Proximate composition (g/kg DM, $n = 3$) of unprocessed and processed cottonseed meal (CSM), groundnut meal (GNM) and groundnut husk (GH).

Item	Processing technique					SEM	P-value
	UP	AC	SK	S-TF	L-TF		
CSM							
Dry matter	903.90 ^a	906.80 ^b	927.25 ^b	946.05 ^b	953.65 ^b	0.04	<0.0001
Crude protein	418.95 ^a	380.80 ^a	447.15 ^a	457.20 ^a	463.45 ^b	1.44	0.0033
Crude lipid	105.35 ^a	110.00 ^a	131.45 ^b	120.25 ^b	127.70 ^b	0.29	0.0003
Ash	80.50 ^a	80.45 ^a	53.50 ^b	54.55 ^b	38.90 ^b	0.05	<0.0001
Phosphorous	13.45 ^a	13.00 ^b	8.90 ^b	9.15 ^b	5.50 ^b	0.01	<0.0001
GNM							
Dry matter	937.25 ^a	921.10 ^b	940.20 ^b	960.85 ^b	970.15 ^b	0.05	<0.0001
Crude protein	415.35 ^a	416.40 ^a	507.95 ^b	528.75 ^b	526.50 ^b	0.29	<0.0001
Crude lipid	276.50 ^a	279.30 ^a	311.60 ^b	291.00 ^b	308.95 ^b	0.08	<0.0001
Ash	120.95 ^a	119.25 ^b	45.85 ^b	50.50 ^b	46.70 ^b	0.02	<0.0001
Phosphorous	5.15 ^a	5.00 ^a	3.35 ^b	2.95 ^b	2.20 ^b	0.01	<0.0001
GH							
Dry matter	929.70 ^a	930.75 ^a	936.40 ^b	952.40 ^b	962.15 ^b	0.05	<0.0001
Crude protein	193.35 ^a	192.65 ^a	198.50 ^b	195.95 ^a	195.70 ^a	0.12	0.0099
Crude lipid	295.15 ^a	298.20 ^a	328.75 ^b	321.95 ^b	316.50 ^b	0.27	<0.0001
Ash	38.95 ^a	39.20 ^a	30.35 ^b	32.40 ^b	31.90 ^b	0.01	<0.0001
Phosphorous	2.20 ^a	2.15 ^a	1.55 ^b	1.70 ^b	1.65 ^b	0.01	0.0002

UP = unprocessed; AC = autoclaving; SK = soaking; S-TF = short-term fermentation; L-TF = long-term fermentation; SEM = pooled standard error of means.

^{a,b}Mean values within a row without a common lowercase superscript differ at $P < 0.05$.

processing techniques (SK, S-TF and L-TF) induced significant changes ($P < 0.05$) especially in the essential amino acids (EAA) profile of the selected oilseed meals. Total amino acids (TAA) as a percentage of the calculated crude protein ranged from 74% to 86%.

3.2.1. Cottonseed meal

Autoclaving CSM improved all EAA except lysine and methionine (Fig. 1A), and resulted in an overall increase in total essential amino acids (TEAA) of 11% (Table 2). All of the EAA and non-essential amino acids (NEAA) increased after SK, S-TF and L-TF. For the EAA, the highest increment was recorded for methionine after L-TF at 44%, while the lowest increment was observed for isoleucine (5%) also after L-TF. Soaking and S-TF processes increased TEAA by 31% and 28%, respectively, of which the majority came from methionine, and the minority from lysine (Fig. 1B–D). Total non-essential amino acids (TNEAA) content was unaffected by AC, but increased by 16% to 18% after SK, S-TF, and L-TF (Table 2).

3.2.2. Groundnut meal

The majority of the EAA and NEAA in GNM at the end of the study increased after SK, S-TF and L-TF ($P < 0.05$) (Table 3), whereas the effects from AC treatment were marginal with a tendency to decrease (Fig. 2A). Increments in EAA in GNM varied widely from 8% in lysine to 26% in phenylalanine after SK; from 18% to 12% in lysine to 40% and 46% in histidine after S-TF and L-TF, respectively (Fig. 2B–D). All other EAA were increased by about one-quarter after SK and about one-third for both S-TF and L-TF. Among NEAA, glutamic acid was essentially unaffected whereas hydroxyproline increased by 23% after SK. The S-TF and L-TF processes notably increased the NEAA content; for aspartic acid by 4% and for alanine by 61%. Overall, the TEAA accounted for 43% to 45% of the measured crude protein after processing, compared to 43% in the unprocessed sample (Table 3).

3.2.3. Groundnut husk

Groundnut husk had a very low amino acid content in the unprocessed form ranging from 0.13% to 1.39% for the EAA, with methionine being the least and arginine the most abundant (Table 4). Fermentation and SK of GH appears to lead to an inhibition of the derivatization of amino acids by the 6-aminoquinolyl-N-hydrosysuccinimidyl carbamate (AQC) used, therefore amino acids analysis in these treatments was not possible. Autoclaving of GH reduced lysine, methionine, alanine, aspartic acid, and glutamic acid contents by 25%, 38%, 16%, 31%, and 26% ($P < 0.05$), respectively (Fig. 3), whereas cysteine content was improved (31%) ($P < 0.05$).

3.3. Nitrogen constituents

The total nitrogen (TN), total amino acid nitrogen (TAA-N) and non-protein nitrogen (NPN) before and after processing are given in Table 5. Overall, TN increased slightly in GNM, but was marginally reduced in CSM and GH after AC. Nonetheless, considerable TN gains (up to 27% in GNM) were recorded in all SK and fermented samples. Similarly, NPN doubled after SK in GNM, and reduced by half after AC in CSM. On the other hand, TAA-N increased by approximately 25% after SK, S-TF and L-TF in CSM, and between 14% and 26% after SK and S-TF in GNM, respectively.

3.4. Anti-nutritional factors

The results of the effect of processing on the gossypol and phytic acid contents in CSM, GNM and GH are presented in

Table 2

Amino acid profile of cottonseed meal (CSM) before and after autoclaving (AC), soaking (SK), short-term fermentation (S-TF) and long-term fermentation (L-TF) processes.

Item	Processing technique					SEM	P-value
	UP	AC	SK	S-TF	L-TF		
EAA, g/100 g DM							
Arginine	3.64 ^a	3.97 ^a	4.67 ^b	4.44 ^b	4.22 ^b	0.20	0.0071
Histidine	0.85	1.00	1.14	1.14	1.11	0.11	0.0646
Isoleucine	1.04 ^a	1.27 ^a	1.46 ^b	1.40 ^a	1.09 ^a	0.14	0.0444
Leucine	2.09 ^a	2.36 ^a	2.74 ^b	2.65 ^b	2.64 ^b	0.15	0.0127
Lysine	1.30 ^a	1.25 ^a	1.49 ^b	1.56 ^b	1.53 ^b	0.11	0.0002
Methionine	0.45 ^a	0.40 ^a	0.64 ^b	0.61 ^b	0.65 ^b	0.04	0.0019
Phenylalanine	1.81 ^a	2.08 ^a	2.40 ^b	2.43 ^b	2.31 ^b	0.16	0.0150
Threonine	1.22 ^a	1.31 ^a	1.55 ^b	1.56 ^b	1.59 ^b	0.05	0.0004
Valine	1.42 ^a	1.71 ^b	1.97 ^b	1.88 ^b	1.61 ^a	0.09	0.0027
TEAA	13.80 ^a	15.35	18.05	17.65	16.75		
NEAA, g/100 g DM							
Alanine	1.92 ^a	2.11 ^a	2.49 ^a	2.56 ^b	2.91 ^b	0.23	0.0142
Aspartic acid	2.79	2.59	2.92	2.95	3.07	0.20	0.1379
Cysteine	0.76 ^a	0.65 ^a	1.01 ^b	0.94 ^a	1.03 ^b	0.09	0.0109
Glutamic acid	6.46	6.24	7.03	7.01	7.07	0.54	0.2905
Glycine	1.45 ^a	1.60 ^a	1.78 ^b	1.77 ^b	1.84 ^b	0.07	0.0034
Hydroxyproline	0.07	0.07	0.07	0.08	0.07	0.01	0.5673
Proline	1.30 ^a	1.38 ^a	1.61 ^b	1.53 ^a	1.67 ^b	0.09	0.0217
Serine	1.41 ^a	1.64 ^a	1.97 ^b	1.77 ^b	2.13 ^b	0.10	0.0028
Tyrosine	1.03 ^a	1.15 ^a	1.41 ^b	1.39 ^b	1.39 ^b	0.07	0.0036
TNEAA	17.19	17.43	20.29	20.01	21.23		
TAA, g/100 g DM							
TEAA:TNEAA ratio	45:55	47:53	47:53	47:53	44:56		
TAA, % of crude protein	74.03	86.03	85.74	82.38	82.02		

UP = unprocessed; EAA = essential amino acids; TEAA = total essential amino acids; NEAA = non-essential amino acids; TNEAA = total non-essential amino acids; TAA = total amino acids; SEM = pooled standard error of means.

^{a,b}Mean values within a row without a common lowercase superscript differ at $P < 0.05$.

Table 3

Amino acid profile of groundnut meal (GNM) before and after autoclaving (AC), soaking (SK), short-term fermentation (S-TF) and long-term fermentation (L-TF) processes.

Item	Processing technique					SEM	P-value
	UP	AC	SK	S-TF	L-TF		
EAA, g/100 g DM							
Arginine	4.44 ^a	4.27 ^a	5.43 ^b	5.57 ^b	5.71 ^b	0.36	0.0089
Histidine	0.84 ^a	0.81 ^a	1.02 ^b	1.18 ^b	1.23 ^b	0.06	0.0006
Isoleucine	1.37 ^a	1.36 ^a	1.68 ^b	1.79 ^b	1.76 ^b	0.09	0.0036
Leucine	2.63 ^a	2.62 ^a	3.22 ^b	3.44 ^b	3.39 ^b	0.14	0.0012
Lysine	0.98	0.92	1.06	1.15	1.11	0.08	0.0772
Methionine	0.33 ^a	0.32 ^a	0.39 ^a	0.43 ^b	0.45 ^b	0.04	0.0191
Phenylalanine	2.07 ^a	2.04 ^a	2.60 ^b	2.70 ^b	2.78 ^b	0.19	0.0094
Threonine	1.11 ^a	1.09 ^a	1.37 ^b	1.36 ^b	1.49 ^b	0.08	0.0046
Valine	1.64 ^a	1.73 ^a	2.00 ^a	2.18 ^b	2.14 ^b	0.14	0.0124
TEAA	15.41	15.16	18.77	19.81	20.05		
NEAA, g/100 g DM							
Alanine	2.30 ^a	2.32 ^a	2.74 ^b	3.17 ^b	3.71 ^b	0.16	0.0003
Aspartic acid	4.21	4.18	4.29	5.08	4.39	0.51	0.2584
Cysteine	0.68 ^a	0.63 ^a	0.79 ^b	0.87 ^b	0.90 ^b	0.04	0.0012
Glutamic acid	7.42 ^a	7.33 ^a	7.52 ^a	8.95 ^b	7.94 ^a	0.53	0.0490
Glycine	2.10 ^a	2.04 ^a	2.38 ^a	2.43 ^a	2.47 ^b	0.15	0.0192
Hydroxyproline	0.13 ^a	0.13 ^a	0.16 ^a	0.17 ^b	0.20 ^b	0.01	0.0020
Proline	1.75 ^a	1.72 ^a	2.07 ^b	2.23 ^b	2.19 ^b	0.07	0.0006
Serine	1.98 ^a	1.89 ^a	2.14 ^a	2.52 ^b	2.57 ^b	0.08	0.0003
Tyrosine	1.70 ^a	1.66 ^a	2.09 ^a	2.17 ^b	2.26 ^b	0.15	0.0110
TNEAA	22.27	21.90	24.18	27.59	26.63		
TAA, g/100 g DM							
TEAA:TNEAA ratio	37:68	37:06	42:95	47:40	46:68		
TAA, % of crude protein	41:59	41:59	44:56	42:58	43:57		

UP = unprocessed; EAA = essential amino acids; TEAA = total essential amino acids; NEAA = non-essential amino acids; TNEAA = total non-essential amino acids; TAA = total amino acids; SEM = pooled standard error of means.

^{a,b}Mean values within a row without a common lowercase superscript differ at $P < 0.05$.

Table 6. Autoclaving of CSM resulted in the largest degradation of gossypol, removing 34% ($P = 0.0043$), followed by SK and fermentation. Short-term fermentation was the most efficient means of removing gossypol in GNM (45%, $P = 0.0041$) and GH

(67%, $P = 0.0005$). Long-term fermentation was found to be most efficient in decreasing phytic acid from both CSM (72%, $P < 0.0001$) and GNM (69%, $P = 0.0003$), whereas the lowest degradation was recorded after AC.

Table 4
Amino acid profile of unprocessed and processed groundnut husk (GH).

Parameter	Processing technique		SEM	P-value
	UP	AC		
EAA, g/100 g DM				
Arginine	1.39	1.43	0.07	0.5160
Histidine	0.41	0.46	0.04	0.0891
Isoleucine	0.53 ^a	0.56 ^b	0.01	0.0069
Leucine	0.96	0.96	0.01	0.6626
Lysine	0.60 ^a	0.45 ^b	0.05	0.0128
Methionine	0.13 ^a	0.08 ^b	0.00	<0.0001
Phenylalanine	0.69	0.78	0.05	0.0796
Threonine	0.51	0.50	0.02	0.6555
Valine	0.62	0.64	0.01	0.3235
TEAA	5.84	5.86		
NEAA, g/100 g DM				
Alanine	1.37 ^a	1.15 ^b	0.06	0.0062
Aspartic acid	1.37 ^a	0.94 ^b	0.21	0.0431
Cysteine	0.26 ^a	0.34 ^b	0.01	0.0039
Glutamic acid	2.23 ^a	1.65 ^b	0.29	0.0492
Glycine	2.15	2.26	0.08	0.1000
Hydroxyproline	0.37	0.39	0.02	0.4704
Proline	0.68	0.66	0.02	0.1069
Serine	1.06	1.09	0.05	0.5253
Tyrosine	0.68	0.72	0.04	0.2649
TNEAA	10.17	9.21		
TAA, g/100 g DM	16.01	15.07		
TEAA:TNEAA ratio	36:64	39:61		
TAA, % of crude protein	82.89	78.23		

UP = unprocessed; AC = autoclaving; EAA = essential amino acids; TEAA = total essential amino acids; NEAA = non-essential amino acids; TNEAA = total non-essential amino acids; TAA = total amino acids; SEM = pooled standard error of means.

^{a,b}Mean values within a row without a common lowercase superscript differ at $P < 0.05$.

4. Discussion

4.1. Proximate composition

The moderate losses in crude protein content from AC raw materials were not significant in comparison to unprocessed samples, and do not appear critical. Nonetheless, these losses could be nutritionally detrimental if specific amino acids were more sensitive to AC treatment than others. The extent of protein change or destruction has been correlated with duration and temperature of AC treatment, as well as moisture content (Goh et al., 1979; McNaughton and Reece, 1980; Papadopoulos, 1989). This effect was demonstrated by Chrenková et al. (1986) who found that lengthy exposure time (60 to 130 min) coupled with high hydrothermic temperatures (110 to 130 °C) significantly decreased soluble crude protein content in soybean meal, alfalfa meal, wheat meal and field pea. Although the samples in the present study were autoclaved at high temperature (121 °C), the relatively short time of exposure (20 min) could account for the moderate losses observed. Nonetheless, these losses are not regarded as critical especially as the nitrogen contents in the samples were not limited.

Soaking and fermentation (S-TF and L-TF) positively affected the crude protein and crude lipid contents of the CSM and GNM tested. These are comparable to the report of Mukhopadhyay and Ray (1999), in which marginal increases in protein (3.28%) and lipid (17.54%) contents of sesame seed meal were found after combined SK and fermenting with lactic acid bacteria (*Lactobacillus acidophilus*). They indicated that although small nutrient losses occur during fermentation and SK through microbial utilization or leaching, increases occur through microbial synthesis. Similarly,

Sun et al. (2015) reported a net protein increment of 7.6% in CSM after fermentation with *Bacillus subtilis*. In the current study, fermentation increased crude protein contents in the fermented oilseed meals and by-product between 1% in GH to 27% in GNM. The higher protein levels in this study were likely due to longer duration of fermentation which allowed the yeast to convert NPN into amino acids. Single cell proteins (SCP) such as yeast, contain 45% to 65% crude protein, and 2% to 6% crude lipid on a dry weight basis (Nasseri et al., 2011). In all likelihood, the increased protein content after fermentation resulted from yeast cells mixed with the fermented samples at termination of experiment. After 12 h of SK mungbean, Sattar et al. (1989) reported approximately 5% and 9% increases in protein content, with a positive temperature correlation. The increase in protein after SK in their work is somewhat similar to our observations for CSM (6.71%), while our results for GNM were considerably higher (22.30%). These positive changes in protein content in the oilseed by-products may be attributed to the breakdown of soluble starch and losses of fine solids, which increased the relative contribution from protein.

The increased content of crude lipid after SK of oilseed meals in the present study contradicts previous reports (Siddhuraju et al., 2000; Nwaoguikpe et al., 2011). However, the lipid increment observed in this study could be the result of the leaching of soluble components that caused that the content of lipid in the oilseed meals (Agume et al., 2017), and the destruction of cell structure causing the efficient release of oil reserve (Cuevas-Rodriguez et al., 2004), which were probably retained in the meals by the fine mesh cloth during removal of excess water.

Fermentation has only previously been shown to moderately alter ash content (Plaipetch and Yakupitiyage, 2012; Sun et al., 2015). In the current study fermentation resulted in large reductions in ash content, corresponding to 52% in CSM, 61% in GNM and 18% in GH. The loss in ash was accompanied by decreases in phosphorus content for all samples. This could be due to the hydrolysis of phytate by endogenous phytases which might have possibly transformed the free phosphorus as a result of phytate degradation into other phosphorus compounds such as inorganic phosphoric acids, orthophosphates and lower inositol phosphates (Türk et al., 2000; Shunmugam et al., 2015). The reductive effect of SK on ash in all samples is likely due to the solubilisation of some vitamins and minerals like phosphorus in the SK media (water) (Agume et al., 2017). In general, some reductions could also be consequences of changes in other constituents such as increases in crude protein and lipid contents.

4.2. Amino acid composition

Soaking, S-TF and L-TF improved the amino acid profile of CSM and GNM compared to unprocessed samples. Generally, water-soluble amino acids are expected to be lost through SK yet, the non-deleterious effect of SK on the amino acid profile could be linked to the plant by-products' composition of higher proportions of insoluble amino acids that may primarily function as structural parts of the plant (Wade, 2009). A possible explanation for the significant increases in most of the amino acids observed for the fermented and soaked samples could be that the oilseed by-products in their raw state contained sufficient quantities of NPN to meet the yeast's nitrogen requirements. Alternatively, the amino acid contents of the raw samples were protein bound, and not available for the yeast to assimilate (Vinqury, 2014; Howell, 2011). Therefore, any amino acid synthesized by the yeast ended up as an add-on contributing to the increase contents of amino acids in the processed samples.

The heat treatment (AC) applied in this study had little incremental effect on the TAA content of CSM, whereas no changes were

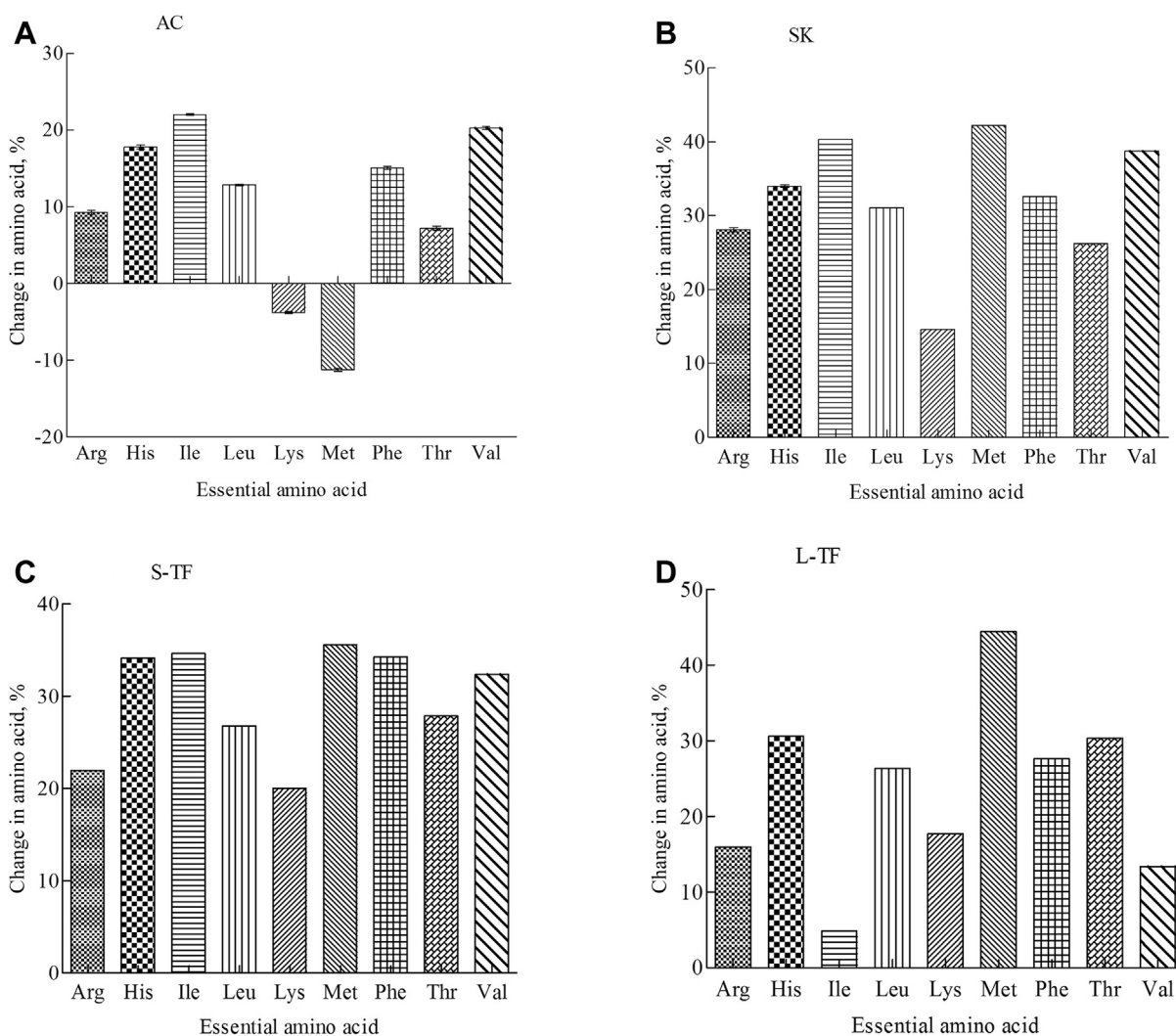


Fig. 1. Changes in essential amino acid contents in cottonseed meal after autoclaving (AC, A), soaking (SK, B), short-term fermentation (S-TF, C) and long-term fermentation (L-TF, D). Arg = arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylalanine; Thr = threonine; Val = valine.

recorded in GNM. However, major depletion occurred especially in lysine and methionine in GH. These losses could be nutritionally detrimental since these EAA cannot be synthesized by fed animals. This is in support of Papadopoulos (1989) and Bellagamba et al. (2015) who concluded that heat processing of feedstuff causes the racemization of amino acids and the formation of cross-linkages with resultant reduction in amino acid digestibility. Certain amino acids like cysteine and lysine are reported to be heat-sensitive even during limited exposure. Many authors have also reported significant reductions in lysine, serine, arginine, and threonine among others in CSM (Craig and Broderick, 1981), soybean meal (McNaughton and Reece, 1980) and rapeseed meal (Goh et al., 1979) by AC. Fermentation, on the other hand, has been shown to increase glutamic and aspartic acid contents in cocoa bean, groundnut, garbanzo bean and soybean (Adeyeye et al., 2010; Bujang and Taib, 2014). These authors further reported significant increases in lysine, histidine, arginine, serine, glycine, alanine, valine, isoleucine, tyrosine and phenylalanine with a conclusion that fermentation particularly improves the EAA content of oilseed by-products. Comparatively, similar increments were obtained in the current study. Furthermore, Bujang and Taib (2014) recorded 71%, 63% and 53% enhancements in total amino acids in groundnut, garbanzo bean and soybean, respectively, after 24 h of fermenting with *Rhizopus oligosporus*. Transamination, has been proposed as a

responsible mechanism for these increases (Baumann and Bisping, 1995). In the current study, SK the oilseed by-products in water for 24 h resulted in appreciable improvements in the majority of EAA. This agrees with Adeyeye (2008), Abu-Salem and Abou-Arab (2011), and Bujang and Taib (2014) who recorded higher EAA contents in *Sorghum bicolor* grains, chickpea seeds and groundnut, garbanzo bean and soybean, respectively. Based on the present data on amino acids, SK and fermentation are very important processing techniques that could be adopted by feed manufacturers to improve the nutritional quality of oilseed by-products intended for use in animal feed at low cost.

4.3. Changes in nitrogen constituents

From a nutritional perspective, the increase in TN especially after SK and fermentation in GNM is positive since it directly reflects an increase in crude protein. However, the elevated contents of NPN compared to the TAA-N constituents is not ideal, since most fish possess simple stomachs that lacks the mechanisms to effectively utilize NPN. The increase in NPN content is reported to be partially influenced by the types of microorganism and endogenous proteolytic activity present during fermentation (Demasi et al., 1990).

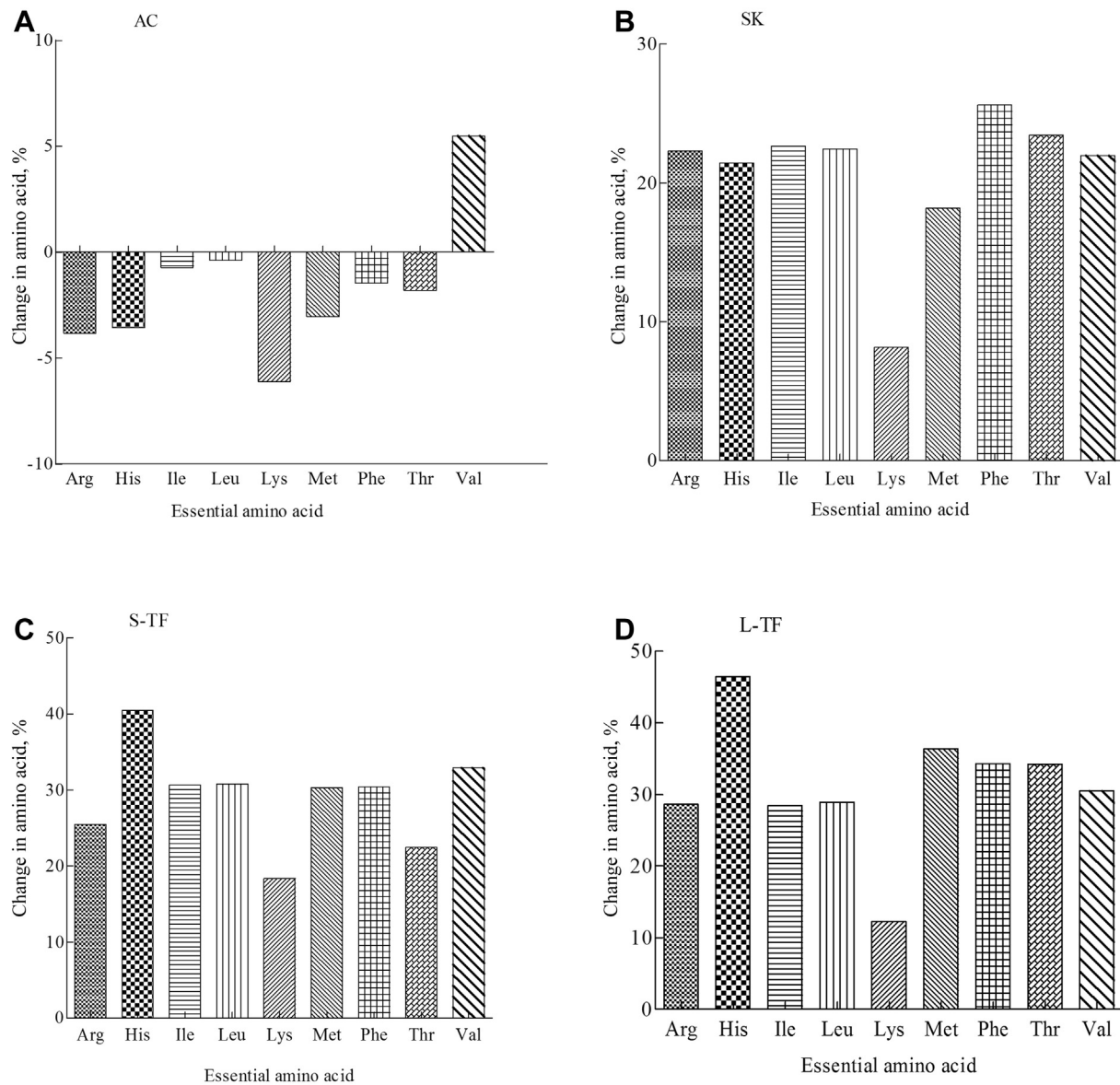


Fig. 2. Changes in essential amino acid contents in groundnut meal after autoclaving (AC, A), soaking (SK, B), short-term fermentation (S-TF, C) and long-term fermentation (L-TF, D). Arg = arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylalanine; Thr = threonine; Val = valine.

4.4. Anti-nutritional factors

The application of heat is widely accepted as a superior way of removing antinutrients that affect nutrient digestibility. Autoclaving has proven efficient in reducing gossypol contents, especially in CSM, but cooking has also been shown to be an efficient approach (Nagalakshmi et al., 2002). Gossypol reduction in CSM by yeast fermentation in the current study was approximately 17% for S-TF. This reduction for the fermented CSM is less than reported by Sun et al. (2015) after solid state fermentation. Zhang et al. (2007) fermented CSM with 3 different yeast strains (*Candida capsuligena*, *Candida tropicalis*, and *Saccharomyces cerevisiae*) and 3 different fungi strains (*Aspergillus terricola*, *Aspergillus oryzae*, and *Aspergillus niger*) for 48 h. Their results showed a reduction of free gossypol as high as 94.6% when CSM was fermented with *C. tropicalis* followed by *S. cerevisiae* (88.5%), *A. niger* (85.2%) and *A. terricola* (82.9%). These

reductions in free gossypol were attributed to microbial or enzymatic degradation of gossypol, or possibly the incorporation of free gossypol into gossypol–protein complexes or gossypol–lipid complexes.

The content of phytic acid after 20 min of AC the oilseed by-products at a temperature of 121 °C were reduced the most in GNM (approximately 15%). Similar observations were reported by Embaby (2010), who recorded degradation in peanut seeds by 9.5% and 24.7% after AC at 121 °C for 10 and 20 min, respectively. Agbo (2008) only reported marginal decreases in PA after AC at 121 °C for 30 min. Studies investigating SK times and temperatures show that phytate reduction is somewhat dependent on pH and highly dependent on temperature (Sattar et al., 1989; Gustafsson and Sandberg, 1995). This assertion is also supported by Lopez et al. (2001) who reported that in addition to pH and temperature, water and duration are of

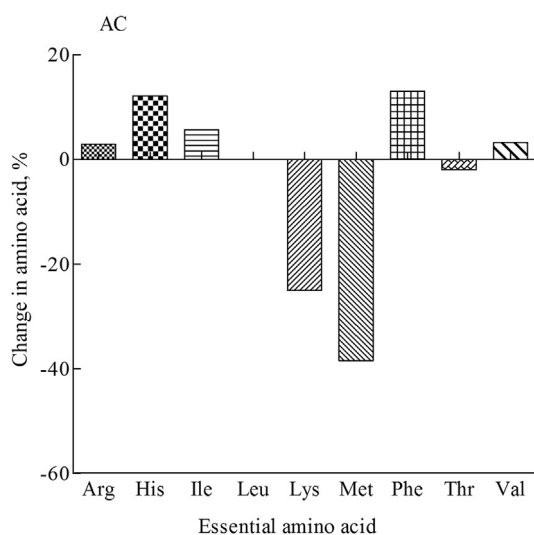


Fig. 3. Changes in essential amino acid contents in groundnut husk after autoclaving (AC). Arg = arginine; His = histidine; Ile = isoleucine; Leu = leucine; Lys = lysine; Met = methionine; Phe = phenylalanine; Thr = threonine; Val = valine.

Table 5

Nitrogen contents (g/kg DM) and their changes (% in brackets) of unprocessed and processed cottonseed meal (CSM), groundnut meal (GNM) and groundnut husk (GH).

Item	Processing technique					SEM	P-value
	UP	AC	SK	S-TF	L-TF		
CSM							
TN	67.00	60.95 (-9.02)	71.55 (6.79)	73.15 (9.18)	74.15 (10.67)	0.23	<0.0001
TAA-N	49.70	52.40 (5.43)	61.35 (23.44)	60.25 (21.22)	60.75 (22.23)	0.27	<0.0001
NPN	17.40	8.55 (-50.86)	10.20 (-41.38)	12.90 (-25.86)	13.40 (-22.99)	0.45	0.0124
GNM							
TN	66.40	66.60 (0.30)	81.30 (22.44)	84.60 (27.41)	84.20 (26.81)	0.05	<0.0001
TAA-N	60.30	59.30 (-1.66)	68.80 (14.10)	75.80 (25.71)	74.70 (23.88)	0.24	<0.0001
NPN	6.20	7.40 (19.35)	12.50 (101.61)	8.80 (41.94)	9.50 (53.23)	0.28	0.0047
GH							
TN	30.90	30.80 (-0.32)	31.80 (2.91)	31.40 (1.62)	31.40 (1.62)	0.06	<0.0001
TAA-N	25.70	24.10 (-6.23)	—	—	—	1.39	0.0013
NPN	5.30	6.70 (26.42)	—	—	—	0.03	0.0025

UP = unprocessed; AC = autoclaving; SK = soaking; S-TF = short-term fermentation; L-TF = long-term fermentation; SEM = pooled standard error of means; TN = total nitrogen; TAA-N = total amino acid nitrogen; NPN = non-protein nitrogen.

Table 6

Gossypol content (mg/g DM), Phytic acid content (g/100 g) and loss (% in bracket) of unprocessed and processed cottonseed meal (CSM), groundnut meal (GNM) and groundnut husk (GH).

Item	Processing technique					SEM	P-value
	UP	AC	SK	S-TF	L-TF		
Gossypol							
CSM	0.29 ^a	0.19 ^b (34.48)	0.21 ^b (27.59)	0.24 ^b (17.24)	0.25 ^a (13.79)	0.02	0.0043
GNM	0.31 ^a	0.28 ^a (9.68)	0.21 ^b (32.26)	0.17 ^b (45.16)	0.20 ^b (35.48)	0.03	0.0041
GH	1.75 ^a	0.93 ^b (46.86)	0.67 ^b (61.71)	0.58 ^b (66.86)	0.61 ^b (65.14)	0.14	0.0005
Phytic acid							
CSM	3.84 ^a	3.53 ^a (8.07)	2.23 ^b (41.93)	2.25 ^b (41.1)	1.08 ^b (71.86)	0.13	<0.0001
GNM	1.40 ^a	1.19 ^a (15.00)	0.85 ^b (39.29)	0.73 ^b (47.86)	0.43 ^b (69.29)	0.10	0.0003
GH	0.41 ^a	0.41 ^a (0.00)	0.28 ^b (31.71)	0.35 ^a (14.63)	0.29 ^b (29.27)	0.03	0.0085

UP = unprocessed; AC = autoclaving; SK = soaking; S-TF = short-term fermentation; L-TF = long-term fermentation; SEM = pooled standard error of means.

^{a,b}Mean values within a row without a common lowercase superscript differ ($P < 0.05$).

importance. Furthermore, [Abou-Arab and Abu-Salem \(2010\)](#) reported a 29% phytic acid reduction in whole seeds of *Jatropha curcas* after SK in water for 12 h at room temperature, which is in line with results from the present study where phytic acid was reduced by 40%, 39% and 31% for CSM, GNM and GH, respectively, after SK for 12 h at room temperature.

Fermentation has been reported by many authors to reduce phytic acid content in plant products irrespective of the type of fermenting agent used. The significant reduction of phytic acid as a result of yeast fermentation in this study showed reductions to tolerable levels. However, the differences in the extent of degradation (S-TF and L-TF) can be associated with the length of time for fermentation. Likewise, significant depletion (52% to 70%) of phytic acid in *J. curcas* kernel cake was reported by [Belew and Sam \(2010\)](#) after a 7 d solid-state fermentation with 5 different types of fungi (*A. niger*, *Penicillium chrysogenum*, *R. oligosporus*, *Rhizopus nigricans* and *Trichoderma longibrachitum*). Phytic acid content in yeast fermented canola meal was reduced by approximately 8% after 24 h of fermentation according to [Plaipetch and Yakupitiyage \(2012\)](#). According to a study by [Fardiaz and Markakis \(1981\)](#), phytic acid reduction of up to 96% was recorded after fermenting peanut press cake for 72 h at 30 °C and they attributed the decrease to the release of phytase by the moulds (*Neurospora sitophila* ATCC 14151, *R. oligosporus* ATCC 22959, and *Neurospora* sp.) isolated from Indonesian fermented peanut press cake used. However, in this study, phytase activity in the fermented samples might have originated from the yeast and the phytase inherent in the GNM.

5. Conclusion

Soaking and fermentation (S-TF or L-TF) were better tools for enhancing the nutritional composition of GNM and CSM by improving the crude protein, crude lipid contents and amino acid profile. Effective reduction of gossypol was achieved by AC while

SK and L-TF were found to efficiently reduce phytic acid content from CSM and GNM. However, further studies should investigate combined processing techniques to completely remove gossypol and phytic acid in the tested oilseed by-products.

Conflicts of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the content of this paper.

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