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Proximate components, minerals, amino acids and some anti-nutrients in processed false yam seed meals: Potential benefits for poultry nutrition

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ABSTRACT

This study investigated the effect of sequential processing techniques (water treatment, chemical treatment and blanching) of false yam seed meal (FYSM) on its proximate composition, mineral and amino acid concentrations and anti-nutritional compounds. Matured false yam (*Icacina oliviformis*) fruits were harvested and seeds extracted. Five different FYSM samples were prepared. One sample was prepared by crushing fresh false yam seed and sun-drying (Un_T). Four other samples were crushed, each soaked in water (1:2; w/v) for 12 days with water replaced every 3 days. Afterwards, each sample was re-soaked in 1 M concentration of urea (Urea_T), sodium chloride (NaCl_T), sodium hydroxide (NaOH_T) and potassium hydroxide (KOH_T), respectively, for 24 h, washed, blanched and sun-dried to a moisture content of 12%. Sample analysis revealed high dry matter [DM; 89% (NaOH_T) – 93% (KOH_T)] and carbohydrate [71.4% (Un_T) – 83.9% (NaCl_T)] content but a reduction of crude protein from 13.2% (Un_T) to 2.2% (KOH_T). Mineral analysis showed a reduction in Ca from 280 (Un_T) to 24 mg/kg DM (NaCl_T) and in Mg from 52.8 (Un_T) to 13.29 mg/kg DM (Urea_T) but an improvement in K from 110.6 (Un_T) to 368.8 mg/kg DM (KOH_T), in Na [from 558 (Un_T) to 989 mg/kg DM (NaCl_T)] and total P [from 0.31 (Un_T) to 2.37 mg/kg DM (Urea_T)]. Amino acid composition of FYSM was negatively affected by all treatments. Concentrations of anti-nutritional factors, namely total terpenes and saponins, were reduced by 82% (KOH_T) to 92% (Urea_T) and by 68% (KOH_T) to 77% (NaCl_T), respectively. *In vitro* gas production per 380 mg of sample was similar across treatments. Reducing anti-nutritional factors by sequential use of simple processing methods with easily available chemicals offers the potential to use FYSM in livestock diets. Yet, as some nutrient concentrations are negatively affected, *in vivo* trials are needed to determine the nutritional value of treated FYSM.

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Introduction

In Africa in general, and Ghana in particular, animal farming contributes significantly to food security. Especially poultry rearing is important for domestic consumption and for sale on local markets [26]. However, chicken production is adversely affected by high feed prices and inadequate supply of feed, particularly of the conventional type [7]. The increasing cost of conventional feedstuffs for poultry is pushing the need to find less expensive alternatives [41].

Maize is the main cereal grain used in poultry feed in sub-Saharan Africa (SSA) as source of dietary energy. It is also a staple food for an estimated 50% of the population in SSA [22]. There is therefore competition between humans and animals for this commodity, which contributes to the rising prices. High feed costs have a negative impact on the profitability of poultry enterprises. The costs of feeding account for 60–80% of the total production costs of intensively reared livestock, especially poultry and pigs [32,37].

In order to address the problem of high feed costs and make poultry and poultry products affordable to the average consumer, animal nutritionists are exploring the potentials of non-conventional feed resources (NCFR) with good nutritional composition but lower costs than grains and legumes, that can serve as alternative livestock feed resources.

One of such NCFR identified is false yam [*Icacina oliviformis* (Poiret) J. Raynal] of the *Icacinaceae* family, which is a drought-resistant and fire-adapted shrub that grows in the savanna regions of West and Central Africa. Its tubers and seeds constitute a new feed resource that can serve as source of dietary energy for poultry due to its high starch content [9].

By nature, the tubers and seeds of false yam contain anti-nutritional factors known as gum resins, which have been identified as terpenes [44], and these are toxic [31]. Anti-nutritional factors diminish animal productivity but may also cause toxicity during periods of feed scarcity or confinement when the feed rich in these substances is consumed by animals in large quantities [25]. Thus, to utilize false yam NCFR in poultry feeding, they must be detoxified by adequate processing. Various processing methods have been employed in an attempt to improve the nutritional value of the false yam seed with varying degrees of success in poultry trials [9].

It is known that aqueous solutions can be used in the extraction processes of terpenes [23]. However, some metabolic processes can take place during soaking which will affect the constituent compounds of treated feedstuffs [46]. Soaking false yam seed in water for 12 days improved its feed value for poultry over unprocessed seed [2,8]. Blanching of triticale (hybrid of wheat and rye) at 75 °C for 20 min reduced its tannin content from 285.6 mg/100 g to 4.7 mg/100 g while the tannin content lowered from 285.6 mg/100 g to 7.1 mg/100 g during blanching at 55 °C for 20 min [13].

However, in many instances, usage of only one detoxification method may not achieve the desired removal of anti-nutritional substances and a combination of two or more methods may be required for significant nutritional improvement.

Ologhobo et al. [33] reported that, after chemical treatment of false yam seeds, a higher concentration of anti-nutritional factors was found in base-soluble fractions, indicating a greater extractability of anti-nutritional factors by alkali treatment than by acid solutes, ether or alcohol.

In the present experiment, water extraction [8], various approaches (urea, NaCl, NaOH and KOH) of chemical extraction [33] and blanching [16] were considered in a sequential approach so as to determine how a combination of processing methods influences the concentration of nutrients and selected anti-nutritive components in false yam seed meal, and assess its potential to partly replace maize grain in diets of poultry.

Materials and methods

The study was conducted between July and September 2017, where matured fruits of false yam plants growing in the wild around Nyankpala Campus of the University for Development Studies, Tamale, were harvested by hand picking. The fruits were cracked and the false yam seeds (FYS) were partially sun-dried (7 days) to reduce their moisture content. Afterwards, the FYS were crushed to reduce size and increase surface area to facilitate processing. Five samples of false yam seed meal (FYSM) were prepared as follows: 1. freshly crushed FYS were sun-dried to approximately 12% moisture content on a cement floor and ground into flour using a hammer mill. The remaining four seed samples were subjected to multiple-stage processing where each seed sample was first soaked in ordinary water (*i.e.*, addition of fresh seeds in ordinary water at a ratio of 1:2, wt./vol.) for 12 days, with water changed every 3 days. After the 12 days of soaking, the seed samples were washed with clean ordinary water. In the second stage of processing, each soaked FYS sample was soaked in a solution of 1 M concentration (*i.e.*, addition of soaked seeds into 1 M concentration at a ratio of 1:2 wt./vol.) of an industrial chemical substance (either urea, sodium chloride, sodium hydroxide or potassium hydroxide) for 24 h, after which all the samples were washed thoroughly with clean ordinary water. The last stage of processing involved blanching of all samples that had been soaked in the chemicals. In this process, seed samples were immersed in hot water (90 °C) for 20 min and then transferred into cold water (4 °C) for 40 min. The samples were then washed with clean ordinary water, sun-dried on a cemented floor to a moisture content of about 12% and ground into gritty flour using a hammer mill (2 mm screen size). The treated false yam seed meals were labeled as follows: sun-dried=Un_T; urea treated=Urea_T; sodium chloride treated=NaCl_T; sodium hydroxide treated=NaOH_T and potassium hydroxide treated=KOH_T. Maize served as control.

Samples of all FYSM and maize (as positive control, bought in bulk from Tamale maize market) were analyzed using standard methods [4] for DM (method 934.01), nitrogen (method 968.06) and ash (method 942.05). Ether extract content was determined after a hydrochloric acid (4 M) digestion (method 920.39). Metabolisable energy content was calculated based on the formula; (37% $\times$ Protein + 81.8 $\times$ % Fat +35.5 $\times$ % NFE) [34].

Table 1
Proximate components of maize and differently treated false yam (*Icacina oliviformis*) seed meals (FYSM).

Proximate components (% DM) Mean ± SD							
Treatments	Dry matter*	Crude protein	Crude fibre	Ether extract	Nitrogen free extractives	Ash	*ME (kcal/kg)
Normal maize	92.1 ± 1.67	9.7 ± 1.31	1.7 ± 0.55	4.3 ± 0.21	77.8 ± 0.72	1.4 ± 0.11	3464 ± 64.74
Un_T	91.3 ± 0.25	13.2 ± 0.09	2.7 ± 0.56	1.5 ± 0.50	71.4 ± 0.73	2.5 ± 0.00	3132 ± 12.11
Urea_T	91.3 ± 0.75	9.1 ± 0.23	1.3 ± 0.15	2.5 ± 0.50	74.9 ± 1.17	1.0 ± 0.50	3190 ± 8.74
NaCl_T	92.0 ± 0.00	4.0 ± 0.12	1.7 ± 0.56	2.0 ± 0.00	83.9 ± 0.68	0.50 ± 0.00	3284 ± 19.65
NaOH_T	89.0 ± 0.00	2.7 ± 0.32	2.7 ± 0.58	2.5 ± 0.50	78.1 ± 1.39	3.0 ± 0.00	3073 ± 2.90
KOH_T	92.8 ± 1.25	2.2 ± 0.06	2.7 ± 0.54	1.5 ± 0.50	82.6 ± 1.02	3.8 ± 0.75	3149 ± 79.11

* Dry matter (DM) given in % of fresh matter; each mean represents triplicate determinations; FYSM treatments: Un_T = untreated, Urea_T = urea treated, NaCl_T = sodium chloride treated, NaOH_T = sodium hydroxide treated, KOH_T = potassium hydroxide treated; sd = standard deviation, *ME metabolizable energy; calculated using the formula of Pauzenga (1985).

Mineral element analysis followed the official method of the Association of Official Analytical Chemists [5]. One gram (1.0 g) of each sample was suspended in 20 ml HNO_3 in a 100 ml beaker. The mixture was placed on a hot plate and the temperature maintained at 130 °C for four hours until the solution became clear. After cooling, the solution was filtered through Whatman filter paper (11 µm pore space) to remove the insoluble particles and made up to a final volume of 50 ml with distilled water in a standard flask. Appropriate dilutions were made for each sample before analysis. Potassium and sodium were determined using a Jenway Digital Flame Photometer (Cole-Parmer, Beacon Road, Stones Staffordshire, ST15, OSA, UK), while other mineral elements were determined using a Buck Scientific Atomic Absorption Spectrophotometer (Unicam Model 929, Unicam Cambridge, England). The resulting solutions were analyzed using the concentrations of the metals extrapolated from the calibration graphs generated using standard mineral solutions. The procedures employed in these determinations followed the protocols in the manufacturer's manual for the equipment.

To determine essential amino acids (except tryptophan), ion chromatographic methods were used that conformed to the German Food and Feed Code (§64 LFGB L 49.07-2). Tryptophan was quantified in accordance with procedures specified by the Association of German Agricultural Analytic and Research Institutes using HPLC methods [45]. Amino acid concentrations were determined for maize, untreated FYSM and the chemically treated FYSM.

Quantitative estimation of total steroidal saponins followed the method of Baccou et al. [6] while quantitative determination of total saponins was done by the method described by Hiai et al. [21]. Effects of tannins on *in vitro* gas production (IVGP) using rumen fluid were assessed by incubating approximately 0.375 mg (DM bases) of triplicate test feed samples with or without 0.75 mg PEG with MW 6000 (Merck Schuchardt OHG, Hohenbrunn, Germany). Feed samples were incubated in 100 mL glass syringes based on Menke et al. [27] procedures.

Results

Proximate, mineral and amino acid components

The proximate composition of maize, sun-dried and treated FYSM is presented in Table 1. The results revealed that maize and FYSM treated with potassium hydroxide had highest dry matter contents (92.1% and 92.8%, respectively). The lowest dry matter content was observed in FYSM treated with sodium hydroxide (89.0%). Protein content was highest in sun-dried FYSM (13.2%) and lowest in KOH_T (2.2%). The crude fiber content of maize (1.7%) compared favourably to that of Urea_T (1.3%) and NaCl_T (1.7%). Ether extract (EE) content of maize (4.3%) was higher than those of FYSM. Among the processed FYSM, Un_T (1.5%) and KOH_T (1.5%) were similar in concentration of EE but lower than those of Urea_T, NaCl_T and NaOH_T. Ash content varied widely from 3.8% for KOH_T to 0.5% for NaCl_T. On the other hand, NaCl_T contained the highest share (83.9%) of nitrogen free extractives (NfE); yet NfE concentration of FYSM was generally high, indicating that treated seed meals may be a good source of energy. At 3464 kcal/kg DM, the calculated ME content of maize was higher than those of the FYSM, where ME contents (per kg DM) ranged from 3073 kcal for NaOH_T to 3284 kcal for NaCl_T.

The concentrations (per kg DM) of macro-elements (Table 2) indicated higher levels of calcium (800 mg Ca) and magnesium (78.4 mg Mg) in maize than in the processed FYSM. However, Un_T recorded highest calcium (280 mg Ca) and magnesium (52.8 mg Mg) levels within the FYSM. Potassium concentration, on the other hand, was higher in processed FYSM than in maize (87.5 mg K), ranging from 111 mg K (Un_T) to 368.8 mg K (KOH_T). With the exception of KOH_T (281 mg Na), all processed FYSM had higher sodium concentrations than maize (440 mg Na). Total phosphorus concentration was lower (0.31 mg P) in Un_T and higher (2.37 mg P) in Urea_T than in maize (4.3 mg P). Among the trace elements (per kg DM) considered in this study, iron concentration was as low as 0.01 mg Fe in Un_T and as high as 24.6 mg Fe in Urea_T, whereas the concentration in maize was 5.24 mg Fe. Manganese, copper and zinc concentrations (per kg DM) ranged from <0.002 to 1.16 mg Mn, 0.003 to 29.0 mg Cu and 0.76–1.84 mg Zn.

Comparing the concentration of essential amino acids (Table 3) of Un_T *versus* maize, seven out of ten determined amino acids were higher in Un_T than in maize, and only leucine, alanine and methionine concentrations were higher in maize

Table 2
Concentration of macro- and micro-minerals in maize and differently treated false yam (*Icacina oliviformis*) seed meals (FYSM).

Feedstuff	Macro elements Mean ± SD (mg/kg DM)					Trace elements Mean ± SD (mg/kg DM)			
	Calcium	Potassium	Magnesium	Sodium	Phosphorus	Iron	Manganese	Copper	Zinc
Maize	800 ± 2.00	87.5 ± 1.01	78.4 ± 0.20	440.2 ± 2.15	0.4 ± 0.00	5.2 ± 0.03	1.2 ± 0.10	0.01 ± 0.00	1.2 ± 0.02
Un_T	280 ± 2.00	110.6 ± 1.53	52.8 ± 1.00	558.0 ± 1.00	0.3 ± 0.00	0.01 ± 0.002	<0.002 ± 0.001	2.1 ± 0.10	1.8 ± 0.02
Urea_T	56.0 ± 2.00	236.1 ± 1.05	13.3 ± 0.00	602.0 ± 0.20	2.4 ± 0.01	24.6 ± 0.02	<0.002±0.001	1.7 ± 0.02	1.2 ± 0.02
NaCl_T	24.0 ± 1.00	210.3 ± 1.00	14.1 ± 0.01	989.0 ± 1.00	1.2 ± 0.00	19.7 ± 0.02	<0.002 ± 0.001	2.0 ± 0.01	0.8 ± 0.02
NaOH_T	168.0 ± 3.00	275.2 ± 1.00	15.5 ± 0.10	601.0 ± 1.00	0.3 ± 0.01	20.3 ± 0.03	<0.002 ± 0.001	1.7 ± 0.03	1.5 ± 0.02
KOH_T	184.0 ± 1.00	368.8 ± 1.00	17.6 ± 0.10	281.0 ± 0.10	1.9 ± 0.00	19.8 ± 0.02	<0.002 ± 0.001	2.9 ± 0.50	1.2 ± 0.01

Each mean represents triplicate determinations; FYSM treatments: Un_T = untreated, Urea_T = urea treated, NaCl_T = sodium chloride treated, NaOH_T = sodium hydroxide treated, KOH_T = potassium hydroxide treated, SD = standard deviation.

Table 3
Amino acid concentrations (% DM) of maize and differently treated false yam (*Icacina oliviformis*) seed meals (FYSM).

Amino acid	Maize	SFYSM*	Un_T	Urea_T	NaCl_T	NaOH_T	KOH_T
Phenylalanine	0.47	0.45	0.58	0.24	0.19	0.15	0.11
Leucine	1.18	0.72	0.9	0.37	0.31	0.23	0.17
Alanine	0.63	ND	0.6	0.26	0.2	0.15	0.11
Valine	0.45	0.49	0.5	0.22	0.19	0.14	0.11
Threonine	0.33	0.35	0.42	0.18	0.14	0.1	0.07
Methionine	0.23	0.06	0.1	0.04	0.03	0.03	<0.03
Lysine	0.27	0.28	0.35	0.17	0.14	0.07	0.06
Arginine	0.53	0.74	1.45	0.45	0.34	0.17	0.1
Histidine	0.3	0.23	0.36	0.17	0.13	0.15	0.12
Tryptophan	0.07	0.15	0.16	0.08	0.06	0.05	0.04

FYSM treatments: Un_T= untreated, Urea_T= urea treated, NaCl_T= sodium chloride treated, NaOH_T= sodium hydroxide treated, KOH_T= potassium hydroxide treated; *SFYSM= water-soaked false yam seed meal, values according to Dei et al. [11].

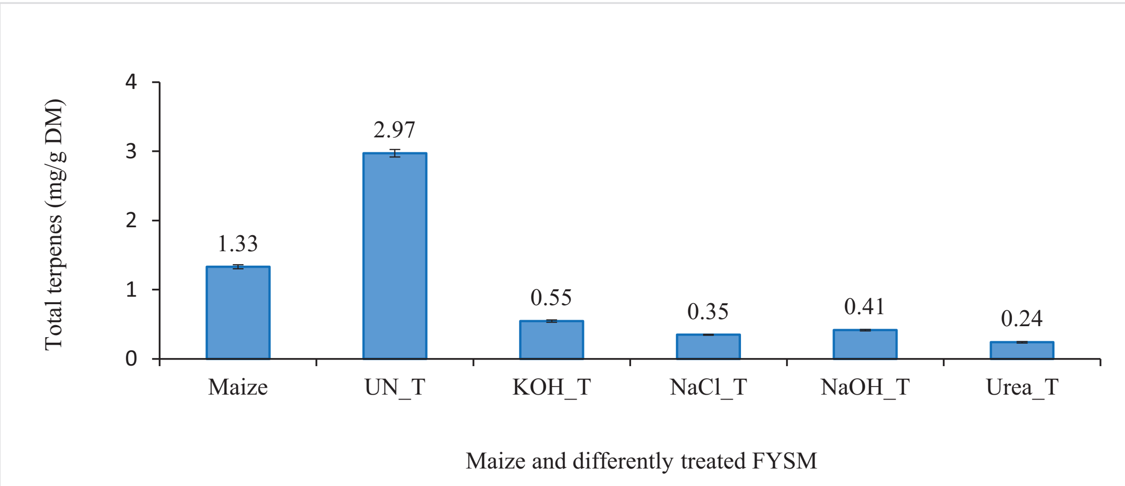

Fig. 1. Concentration of total terpenes in maize, untreated and differently treated false yam seed meals (FYSM). FYSM treatments: Un_T = untreated, KOH_T = potassium hydroxide treated, NaCl_T = sodium chloride treated, NaOH_T = sodium hydroxide treated, Urea_T = urea treated. Where visible, error bars represents standard error of means of 3 replicates.

than in Un_T. However, there was a decline in the concentrations of all amino acids determined within the treated FYSM as follows: Urea_T > NaCl_T > NaOH_T > KOH_T.

Total terpenes, saponin and tannin concentrations

Untreated FYSM (Un_T) had the highest concentration of total terpenes (2.97 mg/g DM) and Urea_T recorded the lowest value. The reduction in total terpenes (Fig. 1) due to processing relative to Un_T was 91.9% (Urea_T), 88.3% (NaCl_T), 86.1% (NaOH_T) and 81.6% (KOH_T).

Total saponin concentration (mg/kg DM) was highest in Un_T (12.5) and lowest in NaCl_T (2.9). The reduction in total saponin concentration (Fig. 2) relative to Un_T was 76.8% (NaCl_T), 69.6% (NaOH_T), and 68.0% (KOH_T, Urea_T).

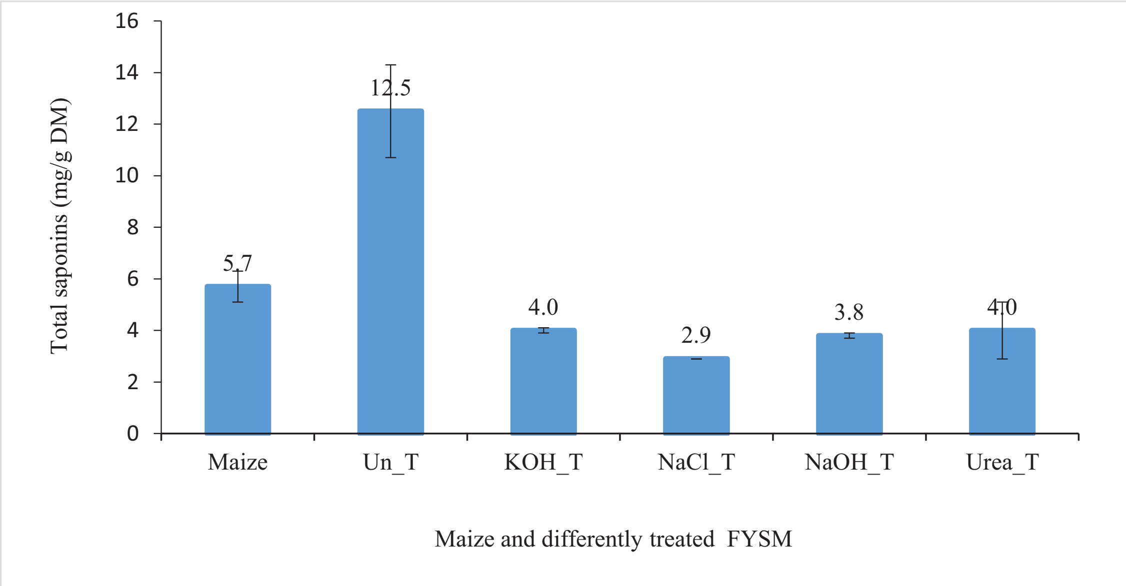

Fig. 2. Concentration of saponins in maize, untreated and differently treated false yam seed meals (FYSM). FYSM treatments: Un_T = untreated, KOH_T = potassium hydroxide treated, NaCl_T = sodium chloride treated, NaOH_T = sodium hydroxide treated, Urea_T = urea treated. Where visible, error bars represents standard error of means.

Table 4
In vitro gas production (IVGP) of maize, untreated and differently treated false yam seed meals when incubated for 24 h with rumen fluid without (-PEG) or with (+PEG) addition of polyethylene glycol (PEG).

Feedstuff	IVGP (ml / 380 mg DM) Mean ± sd	
	–PEG	+ PEG
Maize	132 ± 12.8	121 ± 22.3
Un_T	138 ± 14.7	144 ± 22.1
KOH_T	135 ± 8.2	122 ± 6.7
NaCl_T	163 ± 16.7	157 ± 16.8
NaOH_T	132 ± 12.5	119 ± 6.7
Urea_T	163 ± 14.2	159 ± 11.9

[1]weight of PEG, [2]molecular weight of PEG, FYSM treatments: Un_T= untreated, KOH_T= potassium hydroxide treated, NaCl_T= sodium chloride treated, NaOH_T= sodium hydroxide treated, Urea_T= urea treated; -PEG= without polyethylene glycol, +PEG=with polyethylene glycol.

Table 4 shows the *in vitro* gas production of maize and FYSM samples incubated for 24 h in rumen fluid, with or without adding polyethylene glycol (PEG). The similarity in gas production with or without PEG indicates that the tested feed samples do not contain biologically active tannins.

Discussion

The information on proximate composition, mineral concentrations, essential amino acids and anti-nutritional components of differently treated false yam seed meals provides substantial information on the nutritional value of FYSM and serves as guide in diet formulation that considers FYSM as a partial replacement of, for example, maize in diets of monogastric animals. Generally, the dry matter (DM) contents of all false yam seed meals compared favourably with that of maize. The latter was within the range of 88–98% reported by Enyisi et al. [15] whereas the DM content of FYSM was similar to values reported by Golly and Amadotor [19], Salifu et al. [38] and Sunday et al. [39]. The similarity in DM content of maize and FYSM indicates that on dry matter basis both feedstuffs can complement each other in monogastric animals, particularly poultry. The crude protein concentration of maize in the present study (9.7%) compares well with the range of 9–10% CP in maize DM reported by Sverker et al. [40] but was higher than values reported by Deka and Sarkar [12] and Edema et al. [14] and lower than the values given by Aminogo and Ogutunde, [3] and Gupta [20]. Such variations might be associated to varietal differences. Processing of FYSM resulted in a reduction of the CP content by 31% with Urea_T and up to 83.5% with KOH_T as compared to Un_T. The remarkable decrease in CP concentration in the treated FYSM may be attributed to the leaching out of soluble nitrogenous seed components during the soaking procedure. The CP content of soaked false yam seed meal reported by Dei et al. [8] was higher than the values observed in this study. However, Valantine and Sulemana [43] reported a CP concentration of 14% in the untreated seed, comparable to the value determined here. Golly and Amadotor [19] observed a 15% reduction in CP content of false yam seeds after soaking them for 17 days in ordinary water. The present drastic reduction in CP content of treated FYSM suggests that the sequential treatment involving the use of chemical solutions aggravated nutrient loss. Yet, a variability in the complexity of the utilized processing methods could result in wide variation of nutrient concentrations. Ether extract content of maize (4.3%) was comparable to the values of 4.4% and 4.1% reported by Aminogo and Ogutunde [3] and Edema [14], respectively, but was higher than the values determined by Deka and Sarkar [12]. However, ether extract of FYSM observed in the present study was generally lower than of maize (Table 1). Untreated FYSM had an ether extract content similar to that reported for untreated false yam tuber meal by Dei et al. [9]. The nitrogen free extractive content of maize (78%) obtained in our study was higher than the 66–70% reported by Ujabadenyi and Adebolu [42] and the 72–73% reported by Wilson et al. [47]; as a general rule, the carbohydrate content of maize may be environmentally or genetically controlled. The high carbohydrate content of FYSM treated with NaCl, KOH and NaOH as compared to Un_T and Urea_T samples might be explained by differences in the employed chemicals and their reaction with seed proximate constituents. Soaking in NaOH and KOH resulted in a gelatinization of the seed which might enhance the carbohydrate content, as also observed in high-starch tubers [35]. The ash content of our samples of maize and FYSM falls within the range (1.4–3.3%) for maize flour reported by Enyisi et al. [15] and Mlay et al. [28], as well as in the range (1.2–1.5%) reported for maize flour by Yadav & Yadav [48] – with only the exception of Urea_T and NaCl_T. The ash content of untreated false yam seeds was reported as 2.6% [19], which compares well with the ash content (2.5%) of Un_T in our study.

Generally, Ca and Mg concentrations in the sun-dried false yam seed meals were lower than in maize, and processing the FYSM further reduced Ca and Mg concentrations. This could be due to leaching during the soaking process. However, K and Na were lower in maize than in FYSM. Golly and Amadotor [19] reported a concentration of 56.3 mg Ca/kg DM in untreated false yam seeds and 52.1 mg Ca/kg DM in water treated FYSM. The Mg value obtained for maize was higher than the 29–47 mg Mg/kg DM reported for maize by Enyisi et al. [15]. FYSM concentrations of micro-minerals such as Fe, Cu and Zn were enhanced and Mn reduced due to processing. Differences in mineral composition between differently treated FYSM are most probably due to differences in the chemical agents used for treatment and their reactivity [24].

The concentrations of essential amino acids determined in Un_T were superior to those reported for untreated false yam tuber meal [9] and for soaked false yam seed meal ([11]; see Table 3); they were also higher than those of maize determined in this study, except for leucine, alanine and methionine. Soaking has been reported to wash toxic substances out of false yam tubers [10] but alongside it removes soluble nutrients from the treated feedstuffs, as observed in this study. In consequence, treated FYSM showed a reduction in total CP as well as individual amino acid concentrations as compared to Un_T, indicating that the negative effect of soaking on the concentrations of valuable nutrients was reinforced by chemical treatments and blanching. The variation of the amino acid concentrations in the treated FYSM might again be due to differences in the properties of the chemical agents used for treatment. Therefore, to balance the nutrient composition of a diet containing treated FYSM, additional feeds and/or feed additives might be needed to compensate for the low protein content of false yam seed meals as indicated by Dei et al. [10] for false yam tuber meal.

Anti-nutritional factors such as terpenes in false yam [44] are plant biosynthetic substances which have profound effects on animal metabolism [17] and some terpenic components can act as toxins, growth inhibitors, or are deterrent to animals [18]. The chemical analysis of the untreated Un_T sample confirmed the presence of resins identified to be terpenes [44], determined at a concentration of 2.97 mg total terpenes per gram DM. No information is available in literature on the concentration of total terpenes in untreated false yam seeds. However, Dei et al. [9] reported a total resin concentration of 37.5 g/kg DM in untreated false yam tuber meal which was higher than the maximum amount of 28 g total resin per kg of DM reported by NRI [31]. Chemical treatments used in the present study proved effective in reducing total terpenes in FYSM by 82–92 and saponins by 68–77%; this was a greater removal than the 39% reduction of total terpenes reported by Dei et al. [9] for boiled false yam tuber meal, although it is known that aqueous solutions can also be used for the extraction of terpenes [23]. The significant reduction observed can be attributed to the characteristics of the chemical agents used, which were all basic in nature. A higher concentration of anti-nutritional factors was found in base-soluble than in other fractions [33], suggesting a greater extractability of anti-nutritional factors by basic reagents. Limonoids, the triterpenoids in neem seed kernel cake, were reduced by soaking in water (1:5 wt./vol.) containing either NaOH (2% wt./wt.) for 24 h or by ensiling with 2.5% urea (wt./wt.) for 5–6 days [29,30]. Alkali treated and urea-ammoniated neem seed kernel cake was found suitable for feeding broiler poultry [29,30] without affecting their growth, nutrient utilization, blood profile and gross and histopathology of vital organs. The observed reduction of anti-nutritional factors may thus enhance the feeding value of treated FYSM for monogastric animals. Tannins, another major group of plant secondary compounds, cause decreased feed consumption in animals, bind to dietary protein to form complexes that are not readily digestible and inactivate digestive enzymes [1]. They also cause decreased palatability and reduced growth rate [36]. The biological test for tannins conducted in this study, namely the *in vitro* gas production with or without polyethylene glycol addition, yielded similar 24 h gas production values for all samples; this indicates that tannins are not a major anti-nutritional factor in FYSM.

The sequential use of water-based and chemical treatment methods was effective in reducing some anti-nutritional factors in false yam seed meal, which can enhance its usefulness for diet formulation in monogastric animals, particularly poultry. However, sequential treatments also induced losses of crude protein, essential amino acids and macro- as well as micro-minerals. Therefore, other ingredients rich in the lost nutrients need to complement the use of treated false yam seed meals in such diets. Since the treated FYSM still contain residual anti-nutritional factors, the nutrient digestibility and metabolisability of treated false yam seed meal by poultry needs to be assessed before recommendations for diet formulation can be given.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

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Authors' contributions

ES, RR and AM coordinated the project design and were in charge of writing the manuscript. WA and HKD were in charge of supervising the implementation of the study at UDS Nyankpala. All co-authors participated in calculation of results, statistics and interpretation. All authors have approved the final article.

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