

Effect of Processing on Nutrients, Anti-Nutrients and Functional Properties of NCRICAS 1 Variety of Castor Plant Meal

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Abstract

Castor (*Ricinus communis L.*) is a lesser-known crop that remains underutilized despite its potential. The seeds are primarily processed for oil, leaving behind a by-product known as castor seed cake. This residue is often discarded due to its content of harmful substances such as ricin, ricinine, and certain allergens. The present study investigates the nutritional composition of castor seed cake and explores optimal processing techniques that can reduce its anti-nutrient content to safe levels for animal feed inclusion. Proximate and mineral contents were analyzed in accordance with methods established by the Association of Official Analytical Chemists (AOAC), while amino acid profiling was carried out using an automated analyzer. Anti-nutrient and functional characteristics were also assessed using standard protocols. A total of seven different processing approaches—including heat treatment (toasting and boiling), fermentation, and their combinations—were applied to mitigate the anti-nutritional factors. Findings indicated that the NCRICAS 1 variety contains high protein (39.93%) and mineral content (ash 6.24%). Essential amino acids such as leucine (6.18 mg/g), lysine (4.19 mg/g), and methionine (2.08 mg/g) were found in considerable quantities. Ricin and ricinine levels were measured at 3.44 mg/100g and 0.53 mg/100g, respectively. Among the tested methods, the most effective involved boiling at 84°C for 65 minutes followed by fermentation at 40°C for 5 days, which reduced ricin by 99.7% and increased protein to 40.48%. These results suggest that with proper detoxification, NCRICAS 1 seed cake holds significant promise as a nutritious component in animal feed.

Keywords: Castor cake, nutrients, anti-nutrients, functional properties, fermentation, cooking

Introduction

Ricinus communis L., commonly referred to as castor, is a hardy oilseed crop native to Africa and part of the Euphorbiaceae family (Adeboet al., 2022), though globally cultivated, major producers include.

India, China, and Brazil (Adeyemo and Onikoyi, 2012). With the release of improved varieties like NCRICAS 1 by the National Cereals Research Institute (NCRI), castor has gained popularity in Nigeria in recent years (Salihu et al., 2014). After oil extraction, this cultivar produces a significant amount of leftover cake due to its large seeds and high oil output (Chakrabarty et al., 2021).

Castor seed cake is positioned as a possible substitute protein source in animal feeds due to its 25–40% crude protein content (Chakrabarty et al., 2021). However, poisonous components including ricin, ricinine, and CB-1A allergens limit its use; ricin is particularly dangerous (Franke et al., 2019). Because of the dangers these substances offer, the cake is typically thrown out despite its nutritious value (Anosike, 2018). To neutralize these toxins, a number of physical and biological detoxification techniques have been investigated, including fermentation, autoclaving, and roasting (Borja et al., 2017). According to Diarra and Seidavi, (2020) fermentation and heat treatment can greatly lower toxicity, allowing for safe usage in animal feeds. Given the nutritional promise of castor cake and the need to reduce feed costs in animal production (Amoah et al., 2023). This study evaluates the nutritional composition and anti-nutrient levels of the NCRICAS 1 castor variety. It also identifies the most effective processing methods for detoxification, aiming to facilitate its inclusion in poultry feed formulations.

Materials and Methods

Sample Collection

NCRICAS 1 castor seeds were sourced from the castor research program at NCRI, Badeggi, Niger State, Nigeria.

Cake Preparation

One kilogram of seeds was manually decorticated and cold-pressed using a hydraulic press. The resulting cake was collected for further analysis.

Castor cake production

One kilogram of NCRICAS 1 was obtained and decorticated and then cold press in a hydraulic press to obtain the residue which is the cake and use for laboratory analysis.

Design for processing methods

The central composite design at three levels for each independent variable at three center points replicates was employed for the study. Thirty-nine (39)

different processing methods comprising fermentation (30 –45°C and 1 – 5 days), cooking (70 –100°C and 30 – 120 minutes) and toasting (70 –100°C and 30 – 120 minutes) were used to get the best optimal combination of factors. The results of this factors where then combined to generate four more treatments making the methods seven. (toasting, cooking, fermentation, toasting and cooking, toasting and fermentation, cooking and fermentation and toasting, cooking and fermentation).

Nutrients analysis

The nutritional composition was determined according to the (AOAC, 2010).

Experimental Design

A central composite design was used to evaluate processing variables. Fermentation (30–45°C for 1–5 days), cooking (70–100°C for 30–120 minutes), and toasting (the same temperature and duration) were all tested. Individual (toasting, cooking, and fermentation) and combined processes (toasting + cooking, toasting + fermentation, cooking + fermentation, and toasting + cooking + fermentation) treatments were created from thirty-nine combinations.

Nutritional Analysis

Using (AOAC, 2010) procedures, the approximate composition (moisture, crude fat, crude protein, ash, crude fibre, and carbohydrate) was ascertained. The thermo-gravimetric method was used to measure moisture, and Soxhlet extraction was used to measure crude fat (AOAC, 2000). The Kjeldahl method was used to measure the protein, and gravimetric analysis was used to measure the ash and crude fibre following digestion and ignition, respectively. Carbohydrates were calculated using the difference method.

Mineral Composition

Macro and microelement contents were determined as per (AOAC,2010) standards.

Amino Acid Profiling

Approximately 200 mg of ground defatted samples were hydrolyzed with 6 M HCl, followed by evaporation and buffering with acetate (pH 2.0). The prepared samples were analyzed using an Applied Biosystems PTH Amino Acid Analyzer.

Anti-nutritional Factors

Levels of phytates, tannins, oxalates, lectins, ricin, and ricinine were determined. Phytates and tannins were analyzed via (AOAC, 2010) and Folin-Denis spectrophotometric methods respectively. Oxalates were measured through titration (Dayand Underwood, (1986). Lectins were

identified by hem agglutination assays (Wang et al., 2009), ricin quantified via ELISA (Baldoniet al., 2010) and ricinine using HPLC-MS (Wang et al., 2009).

Results and Discussion

Proximate and Mineral Composition of Castor Cake (NCRICAS 1)

The analysis of the castor cake's proximate composition revealed that it is notably rich in protein, with a content of 39.93%, highlighting its potential as a protein supplement in animal feeds (Table 1). Ash content was relatively low at 6.24%, indicating moderate mineral availability. These values align with previous findings by (Chakrabarty et al., 2021) and demonstrate that castor cake possesses appreciable nutritive properties.

Macro and microelement evaluations (Table 1) showed that magnesium was the most abundant macro element (4.12 mg/g), whereas calcium had the lowest concentration (0.34 mg/g). Among the microelements, iron registered the highest value (0.19 mg/g), and lead was present in trace amounts (0.03 mg/g). These results support the cake's utility in mineral supplementation, provided heavy metal levels remain within permissible limits.

Table 1. Proximate and mineral content of castor cake from NCRICAS 1 Variety

Parameter	Mean (%)
Proximate	
Moisture	7.86±0.12
Fibre	9.09±0.06
Ash	6.24±0.032
Protein	39.93±0.07
Fat	14.88±0.09
CHO	21.94±0.09
Macro nutrients	(mg/g)
Sodium	0.73±0.03
Calcium	3.40±0.01
Magnesium	4.12±0.10
Potassium	1.75±0.04
Micronutrients	(mg/g)
Manganese	0.04±0.01
Iron	0.19±0.004
Copper	0.12±0.003

Zinc	0.13±0.001
Lead	0.03±0.001

The moisture content recorded in this analysis falls within the standard range of 5–12% established in prior studies (Akande et al., 2016). Moisture serves as a key determinant of microbial stability and shelf life in feed ingredients. The relatively low moisture content observed suggests a reduced risk of microbial spoilage, thereby promoting better storage stability (Edemet al., 2008). Additionally, lower moisture levels can concentrate other nutrients and improve overall storage quality.

The crude protein content (39.98%) aligns with values between 21–48% reported by (Ani, 2009) but surpasses the 17.22–24.84% range cited by (Adebayo et al., 2019), reinforcing the classification of castor cake as a promising plant protein source. These findings are consistent with earlier conclusions from (Akande et al., 2015; Diarra, and Seidavi 2020).

The crude fiber content (9.09%) is lower than the 12.5–24.5% range from (Akande et al., 2016) but higher than values reported by (Onyia, 2015), and it concurs with the results of (Ogunbode and Raji, 2024). Variations may be attributed to genetic or environmental factors. Dietary fiber plays a role in regulating gastrointestinal motility (Oduoret al., 2008) but excessive levels may reduce nutrient utilization due to faster transit times and lower absorption (Jha and Mishra, 2021) (Tejeda and Kim, 2021).

Crude fat content (14.88%) falls within the previously reported range (1.9–20%) (Akande et al., 2016) but is lower than the 23.46% observed by (Adebayo et al., 2019). Differences may result from oil extraction techniques. Lipids in feed provide metabolic energy and enhance palatability (Saleh et al., 2021). Proper storage is necessary to prevent rancidity from lipid oxidation.

Ash content measured at 6.24% was below the 8.1–19.2% range noted by (Anandan, 2005), indicating that raw castor cake may require supplementation with mineral-rich additives.

Macro-elements including magnesium, calcium, sodium, and potassium were consistent with data from (Ramteke et al., 2019) and (Adebayo and Akinyele, 2019), highlighting their relevance for poultry metabolism. Magnesium supports enzyme function and electrolyte balance, while calcium is critical for bone formation (Souza et al., 2023). Calcium supplementation may be necessary due to the low content in castor cake (Marchal, et al., 2024) (Tay et al., 2023). Trace elements such as iron, zinc, copper, and manganese also play metabolic and immunological roles. The mineral composition supports findings by (Adedapo and Babalola, 2017), who safely included 10% castor cake in fish diets. Although lead was detected at a low

level (0.03 mg/g), continuous monitoring is advised due to its toxicity (Aljohani, 2023).

Amino Acid Composition

Amino acid analysis (Tables 2) showed glutamic acid as the dominant amino acid (10.55 mg/g), while asparagine had the lowest concentration (0.09 mg/g). Essential amino acids accounted for 40.3% of the total amino acid content, which included significant amounts of leucine (6.18 mg/g), lysine (4.19 mg/g), methionine (2.08 mg/g), cysteine (1.06 mg/g), and tyrosine (1.93 mg/g). These values reflect the suitability of castor cake as a balanced protein source for livestock.

Table 2. Amino Acids profile of castor cake from NCRICAS 1 Variety

Parameter	Mean (mgg ⁻¹)
Leucine	6.81±0.04
Lysine	4.91±0.06
Phenoline	2.76±0.17
Isoleucine	1.78±0.03
Tryptophan	0.86±0.08
Valine	3.16±0.05
Methionine	2.08±0.02
Proline	3.19±0.03
Arginine	5.23±0.08
Tyrosine	1.93±0.07
Histidine	1.67±0.32
Cysteine	1.06±0.16
Alanine	2.79±0.27
Glutamic acid	10.55±0.46
Glycine	1.34±0.07
Threonine	1.64±0.07
Serine	3.36±0.15
Aspartic acid	8.29±0.05
Glutamine	0.18±0.02
Asparagine	0.09±0.02

This study reveals that raw castor seed cake contains a significant amount of essential and non-essential amino acids, corroborating findings by (Jayant et al., 2021; Mondal et al., 2019) who successfully integrated castor cake into

calf diets at 20% inclusion. The essential amino acids accounted for 40.30%, exceeding values observed in soybean meal (37.42%) and groundnut cake (32.68%) reported by (DiarraandSeidavi,2020).

The sulfur-containing amino acids—methionine and cysteine—were present at 3.14 mg/g, higher than those in soybean meal, where these amino acids are typically limiting ((Jayant et al., 2021). Lysine, methionine, and cysteine levels found in castor cake in this study surpassed those found in conventional protein sources, supporting their essential role in poultry development, including muscle growth and feather formation (Chen et al., 2020). Methionine also plays a vital role in immune responses and protein metabolism (Liu et al., 2022).

The substantial level of glutamic acid further indicates that castor cake can be a viable energy source (Anyiamet al.,2012). However, tryptophan was relatively low, a common limitation in many plant protein sources, suggesting the need for dietary supplementation (VichareandMorya,2024). Tryptophan is important for serotonin synthesis, which regulates feeding behavior and stress response in poultry (Lu et al., 2024).

Arginine, tyrosine, and histidine, also found in appreciable levels, are associated with metabolic support, hormone production, and antioxidant functions (Amoah et al.,2023). Since poultry cannot synthesize arginine, its presence in castor cake is particularly beneficial. Nutritional enhancement can be achieved through fermentation, enzymatic hydrolysis, or amino acid supplementation (Kårlundet al., 2020). Effective detoxification processes are necessary to ensure amino acid bioavailability by reducing anti-nutritional interference.

Anti-nutrient Composition and Functional Properties

Table 3 summarizes the anti-nutrient content. Lectins (4.46 mg/100g) and ricin (3.44 mg/100g) were present in the highest amounts, posing toxicity risks. Ricinine (0.53 mg/100g), oxalates (2.11 mg/100g), and phytates (1.48 mg/100g) were also detected, with tannins being the least prevalent (0.13 mg/100g). The presence of these compounds justifies the necessity for effective detoxification methods.

The functional analysis (Table 5) indicated that the raw castor cake had a bulk density of 0.77 g/cm³, water absorption capacity of 1.82 g/g, and oil absorption capacity of 0.76 g/g. It also demonstrated foaming and emulsifying capacities of 8.16% and 28.42%, respectively. Stability values were 62.37% (foam) and 38.55% (emulsion). These characteristics suggest that the cake can perform well in composite feeds with desirable mixing and holding properties.

Table 3 Phytochemical and functional properties of castor cake from NCRICAS 1 Variety

Parameter	Mean
Phytochemical (mg/ 100 g)	
Ricin	3.44±0.03
Ricinine	0.53±0.002
Lectins	4.46±0.03
Oxalates	2.11±0.04
Tannins	0.13±0.004
Phytates	1.48±0.01
Functional Properties	
Bulk density (g/ml)	0.77±0.05
Water absorption capacity(g/g)	1.82±0.03
Oil absorption capacity(g/g)	0.76±0.04
Foaming capacity (%)	8.16±0.12
Foaming stability (%)	62.37±0.33
Emulsion capacity (%)	28.42±0.34
Emulsion stability (%)	38.55±0.26

Anti-nutritional factors were recorded as follows: ricin (3.44 mg/100g), ricinine (0.53 mg/100g), lectins (4.46 mg/100g), oxalates (2.11 mg/100g), tannins (0.13 mg/100g), and phytates (1.48 mg/100g). These values were lower than those reported by (Akande et al., 2016) but aligned with findings from (Bradberry, 2016) and (Adebayo et al., 2019). Genetic variation and environmental factors likely account for discrepancies. Ricin and ricinine, components of lectins, are toxic and can induce symptoms ranging from gastrointestinal distress to organ failure and death. Oxalates and phytates inhibit nutrient absorption by forming indigestible complexes (Ramteke et al., 2019). Oxalates can cause irritation, weakness, and digestive issues (Nateshand Ska, 2018); (Ogunbode and Raji, 2024). Despite this, these anti-

nutrients may offer health benefits like antioxidant activity (Oyeyinka et al., 2013).

The bulk density of raw castor cake (0.77 g/ml) falls within the range reported by (Oyeyinka, 2013) but exceeds the value found in dried beans (Bagireiet al., 2021). Bulk density is influenced by factors such as particle size and initial moisture. Higher values, like those seen here, enhance stability and handling in feed production. Lower densities, such as those in (Falade and Kolawole, 2011), benefit complementary food production.

The bulk density of castor cake is similar to those of cowpea (0.78 g/ml) and pigeon pea (0.69 g/ml), making it suitable for feed pelleting (Butt and Batool, 2010) as (Pekelet et al., 2022) noted, bulk density impacts how easily alternative feed ingredients are stored and transported.

The water absorption capacity (1.82 g/g) aligns with values reported for cowpea (Falade and Kolawole, 2011) and mucunabean flour (Adebowale et al., 2005). High WAC improves dough handling and water retention during feed preparation. Oil absorption capacity (0.76 g/g) was also above reported levels for some cowpea varieties (Chinma et al., 2008), suggesting the protein structure remains largely intact. Oil binding is influenced by the side-chain properties of proteins and determines energy density and palatability in feeds (Akubor and Egbekun, 2017).

Functional properties like WAC and OAC play essential roles in feed hydration and fat binding. The moderate WAC supports good pellet formation and feed texture, while the low to moderate OAC ensures controlled lipid content in feed formulations.

The foaming ability of castor cake indicates its capacity to form stable protein structures, contributing positively to feed texture and appeal (Aljohani, 2023). Good foaming stability points to the surface-active nature of castor cake proteins, which may improve digestion and nutrient bioavailability (Mahaveerchand and Abdulsalam, 2024).

Its emulsion properties further enhance nutrient dispersion within feed, allowing for better fat uniformity and digestion. This was similarly observed in studies (Mahaveerchand and Abdulsalam, 2024), where high-emulsion proteins improved the efficiency of feed formulations.

Effect of Processing on Nutritional Quality

The influence of different processing treatments on the cake's proximate composition (Table 4) showed significant ($p < 0.05$) changes. Moisture content increased with boiling and fermentation, while toasting reduced it. Ash, crude fiber, and fat decreased under most processing conditions, except for a slight fiber retention under boiling. Notably, protein content increased under fermentation (40.02%) and combined boiling + fermentation (41.69%), demonstrating that microbial and thermal breakdown may enhance protein

availability. Carbohydrates also increased, particularly in the toasting + boiling combination (50.77%).

Table 4. Effect of processing methods on proximate composition of castor cake (%)

carboh ydrates	Fat	Protein	Ash	Crude Fibre	Moisture	Treatm ent
21.94± 0.09 ^d	7.88±0. 09 ^a	39.93± 0.07 ^b	6.24±0. 03 ^a	9.09±0. 06 ^{ab}	7.86±0. 12 ^c	Raw
44.40± 0.19 ^b	3.61±0. 07 ^d	33.42± 0.15 ^d	5.05±0. 05 ^{bc}	8.59±0. 18 ^b	5.01±0. 08 ^f	Toasting g(90°C for 35minu tes)
32.42± 2.03 ^c	5.16±0. 15 ^{bc}	38.57± 0.32 ^c	5.78±0. 26 ^{ab}	9.72±0. 18 ^a	10.01± 0.14 ^a	Cookin g(84°C for 65minu tes)
32.44± 0.16 ^c	5.62±0. 08 ^b	40.02± 0.12 ^b	4.84±0. 13 ^{cd}	7.75±0. 24 ^c	9.33±0. 19 ^b	Fermen ting (40°C for 5days)
50.77± 0.35 ^a	3.54±0. 16 ^d	28.50± 0.21 ^e	4.10±0. 10 ^e	7.38±0. 10 ^c	5.71±0. 16 ^e	toasting /cookin g
45.60± 0.41 ^b	3.65±0. 28 ^d	33.13± 0.28 ^d	4.49±0. 17 ^{cd}	6.12±0. 09 ^d	7.04±0. 10 ^d	toasting /ferme nting
35.32± 0.19 ^c	3.48±0. 27 ^d	41.69± 0.15 ^a	4.12±0. 20 ^{de}	7.21±0. 13 ^c	8.18±0. 07 ^c	cookin g/ferme nting
46.39± 0.36 ^b	4.72±0. 09 ^c	34.06± 0.07 ^d	3.86±0. 11 ^e	4.68±0. 25 ^e	6.29±0. 07 ^e	toasting /cookin g/ ferment ing

The findings reveal that different processing techniques significantly influenced the proximate composition of castor seed cake, particularly with respect to moisture, protein, fat, fiber, ash, and carbohydrate levels. These changes are consistent with earlier studies on the impact of heat and microbial treatment on oilseed meal composition (Saleh et al 2021).

Toasting notably reduced the moisture content due to direct exposure to heat, while cooking and fermentation led to higher moisture retention, likely caused by water absorption during processing. Dry heat methods, such as

toasting, are known to evaporate water, whereas wet methods allow water uptake and retention.

Crude fiber, fat, and ash contents generally declined across most treatments, likely because heating and microbial breakdown facilitated leaching and degradation of structural components. In contrast, the retention of fiber in cooking treatments suggests that high-moisture heat does not always degrade fiber significantly, a trend also observed in legume-based feed ingredients (Shekade, et al., 2023).

Protein content showed varying responses: it decreased following cooking and toasting, probably due to protein denaturation and Maillard reactions that impair protein digestibility. However, fermentation—especially when combined with cooking—improved protein content. This may be due to microbial action that breaks down anti-nutrients, thereby enhancing protein availability, as demonstrated by (Vichare and Morya, 2024)

Carbohydrate concentration increased most significantly in the cake processed by both toasting and cooking. The relative rise is likely due to reductions in other proximate components, making carbohydrates proportionally higher. Cooking alone resulted in the least carbohydrate content, which could be attributed to incomplete breakdown of polysaccharides or sugar leaching into the cooking medium.

Overall, the findings show that processing alters nutrient profiles in castor cake. Fermentation appears most effective in increasing protein digestibility, while toasting and cooking enhance carbohydrate availability. Selecting the right processing method is essential for balancing detoxification and nutritional quality when formulating poultry feed.

Effect on Mineral Composition

Processing significantly ($p < 0.05$) reduced several macro elements (Table 5). However, microelements remained relatively stable, with some (e.g., iron) showing increased values under fermentative and combined methods. This trend may be attributed to the concentration effect and breakdown of anti-nutritional factors that bind these minerals

Table 5. Minerals contents of raw and processed castor cake (mg/g)

Treatment	Raw	Toasting	Cooking	Fermenting	toast/cook	toast/ferm	cook/ferm	toast/cook/ferm
Pb	0.03±0.0 0a	0.01±0.0 0c	0.02±0.0 0bc	0.02±0.0 0ab	0.02±0.0 0c	0.02±0.0 0ab	0.02±0.0 0ab	0.02±0.0 0ab
Zn	0.13±0.0 0a	0.15±0.0 0a	0.15±0.0 2a	0.14±0.0 0a	0.13±0.0 0a	0.13±0.0 0a	0.13±0.0 0a	0.13±0.0 0a
Cu	0.12±0.0 0	0.17±0.0 2	0.15±0.0 1	0.13±0.0 1	0.14±0.0 1	0.12±0.0 1	0.13±0.0 1	0.13±0.0 0
Fe	0.19±0.0 0	0.14±0.0 1	0.15±0.0 1	0.22±0.0 1	0.15±0.0 0	0.15±0.0 0	0.30±0.1 5	0.11±0.0 1
Mn	0.04±0.0 0	0.03±0.0 0	0.03±0.0 0	0.03±0.0 0	0.03±0.0 0	0.03±0.0 0	0.03±0.0 0	0.04±0.0 0
Mg	4.12±0.1 0a	2.89±0.2 7d	3.85±0.1 0ab	3.48±0.0 2bc	3.18±0.0 1cd	3.43±0.0 1bc	3.37±0.0 4bcd	3.13±0.0 4cd
Ca	0.34±0.0 1a	0.29±0.0 1abc	0.29±0.0 1ab	0.30±0.0 2ab	0.26±0.0 1bcd	0.22±0.0 1d	0.25±0.0 1bcd	0.23±0.0 1cd
Na	0.73±0.0 3a	0.60±0.0 1bc	0.62±0.0 1bc	0.56±0.0 1c	0.64±0.0 1b	0.59±0.0 1bc	0.62±0.0 1bc	0.64±0.0 1b
K	1.75±0.0 4a	1.56±0.0 2c	1.64±0.0 2abc	1.69±0.0 2ab	1.59±0.0 1bc	1.58±0.0 3c	1.66±0.0 2abc	1.70±0.0 2ab

The use of different processing techniques influenced the mineral composition of castor cake, especially for key macronutrients such as calcium, potassium, sodium, and magnesium. Losses were evident, particularly with heat and microbial-based treatments, due to leaching and structural breakdown (Yusuf et al., 2021).

Calcium and magnesium levels were significantly reduced during toasting and fermentation. High heat and enzymatic activity from microbes are known to degrade or leach minerals from plant materials, consistent with prior research on leguminous feed ingredients (Sarkar et al., 2021).

Decreases in sodium and potassium may affect electrolyte balance and muscle function in animals. While these losses are not extreme, dietary supplementation is recommended to prevent deficiencies in poultry diets.

Interestingly, iron content increased in cakes subjected to fermentation and cooking. This could result from microbial degradation of anti-nutrients, such as phytates, that normally bind iron and hinder its bioavailability (Salimet al., 2023) meanwhile, copper levels remained relatively stable, indicating some micronutrients are less affected by processing. Lead content, a heavy metal of concern, showed a marked reduction—especially through toasting. This supports the safety potential of processed castor cake for animal consumption. The decline may be linked to microbial degradation during fermentation or thermal volatilization during toasting.

These results confirm that while some mineral losses are inevitable during processing, the reduction in harmful elements like lead supports the feasibility of using treated castor cake in livestock feed.

Anti-nutrient Reduction

As shown in Table 6, all treatments substantially reduced anti-nutrient levels, particularly ricin, which dropped from 3.44 mg/100g to 0.01 mg/100g under both cooking + fermentation and the combined three-step method (toasting + cooking + fermentation). Ricinine and lectins were also drastically lowered, with tannins nearly eliminated. These reductions confirm the effectiveness of combined thermal and microbial detoxification strategies.

Table 6. Anti-nutrients concentrations of unprocessed and processed castor cake (mg/100g)

Treatment	Phytates	Tannins	Oxalates	Lectins	Ricinine	Ricin
Raw	1.48± 0.01 ^a	0.13± 0.00 ^d	2.11± 0.04 ^a	4.46± 0.03 ^a	0.53± 0.00 ^a	3.44± 0.03 ^a
Toasting (90°C for 35min)	0.47± 0.03 ^{cd}	0.91± 0.02 ^a	0.95± 0.05 ^{cd}	0.44± 0.01 ^{cd}	0.00± 0.00 ^{de}	0.23± 0.01 ^c
Cooking (84°C for 65min)	0.60± 0.04 ^c	0.88± 0.03 ^a	1.50± 0.09 ^b	1.10± 0.12 ^b	0.19± 0.01 ^d	0.37± 0.01 ^b
Fermentation (40°C for 5days)	0.34± 0.01 ^d	0.01± 0.00 ^e	0.73± 0.03 ^{de}	0.57± 0.06 ^c	0.03± 0.00 ^{cd}	0.13± 0.01 ^d
Toasting /cooking	0.37± 0.03 ^d	0.51± 0.02 ^c	0.81± 0.04 ^{de}	0.29± 0.02 ^d	0.05± 0.01 ^c	0.19± 0.01 ^{cd}
Toasting /fermentation	0.75± 0.06 ^b	0.68± 0.02 ^b	1.13± 0.07 ^c	0.41± 0.01 ^{cd}	0.02± 0.00 ^{de}	0.19± 0.01 ^{cd}
Cooking /fermentation	0.17± 0.01 ^e	0.01± 0.00 ^e	0.60± 0.02 ^{ef}	0.27± 0.02 ^{de}	±0.00 ^e	0.01± 0.00 ^e
Toasting /cooking /fermentation	0.09± 0.00 ^e	0.00± 0.00 ^e	0.41± 0.02 ^f	0.03± 0.00 ^e	±0.00 ^e	0.01± 0.00 ^e

Processing proved to be highly effective in reducing the anti-nutritional factors in castor cake. Ricin content, while reduced, was not eliminated entirely by any single method, reinforcing the conclusion of (Oliveira et al., 2010) that multi-step treatments are more effective.

The lowest ricin levels were recorded in samples subjected to a combination of toasting, cooking, and fermentation, suggesting that sequential processing offers the most thorough detoxification. Fermentation was particularly effective in lowering levels of ricinine, lectins, oxalates, tannins, and phytates. Microbial enzymes play a significant role in degrading these anti-nutrients and improving the nutritional value of plant feed ingredients (Manzoor et al., 2021).

Lectins, being protein-based toxins, were denatured by heat treatment, which disrupts their structure and reduces their toxicity. Toasting and

fermentation reduced oxalates substantially, while the combined method was even more efficient, likely due to prolonged exposure to degradative conditions.

Tannins were almost entirely eliminated through fermentation, while heat treatments brought about substantial reductions. Tannins are known to bind with proteins and minerals, reducing their availability during digestion. Their removal improves overall feed efficiency.

Phytates, which bind essential minerals like phosphorus, calcium, and zinc, were significantly decreased in the combined processing methods. The enzymatic activity during fermentation effectively dismantled phytate complexes, enhancing nutrient availability.

These findings confirm that proper processing—particularly combinations of toasting, cooking, and fermentation—can effectively reduce toxic compounds in castor cake and make it suitable as a feed ingredient for livestock.

Changes in Functional Properties

Post-processing evaluation (Table 7) showed a marked reduction in bulk density (from 0.79 g/cm³ to 0.55 g/cm³), foaming capacity (from 5.16% to 2.34%), and foam stability. In contrast, water and oil absorption capacities improved, indicating better hydration and lipid-binding potential. Emulsion capacity increased significantly in samples processed by boiling alone (43.98%), while fermentation boosted emulsion stability to 45.85%. These results indicate that appropriate processing not only detoxifies the cake but also enhances its functional performance, making it more suitable for feed formulation

Table 7. Functional properties of raw and processed castor cakes

Treatments	Bulk Density (g/cm ³)	Water Absorption Capacity (g/g)	Oil Absorption Capacity (g/g)	Foaming Capacity (%)	Foaming Stability (%)	Emulsion Capacity (%)	Emulsion stability (%)
Raw	0.79±0.0 1 ^a	2.96±0.0 8 ^c	1.75±0.0 3 ^b	5.16±0.1 4 ^a	54.97±1.7 70 ^{ab}	31.37±0.3 36 ^d	40.06±0.1 12 ^d
Toasting	0.59±0.0 1 ^{bcd}	4.24±0.0 4 ^b	1.97±0.0 6 ^a	3.71±0.0 4 ^b	53.92±0.1 15 ^a	27.07±0.1 16 ^c	30.03±0.1 18 ^c
Cooking	0.57±0.0 3 ^{cd}	3.98±0.0 6 ^{cd}	2.09±0.0 7 ^a	2.98±0.1 9 ^{cd}	52.12±0.1 60 ^{bc}	43.98±0.1 18 ^a	43.59±0.1 23 ^b
Ferment	0.61±0.0 2 ^{bcd}	3.89±0.0 3 ^d	1.94±0.0 3 ^{ab}	3.19±0.1 4 ^{bcd}	51.63±0.1 42 ^{bcd}	43.93±0.1 15 ^a	45.85±0.1 14 ^a
toast/cook	0.64±0.0 1 ^{bc}	4.62±0.0 2 ^a	1.99±0.0 2 ^a	3.41±0.0 1 ^{bc}	52.01±0.1 17 ^{bc}	41.42±0.1 55 ^b	41.62±0.2 3 ^c
toast/ferment	0.67±0.0 1 ^b	4.18±0.0 2 ^{bc}	2.06±0.0 4 ^a	2.69±0.0 9 ^{de}	50.71±0.1 25 ^{cd}	40.59±0.1 47 ^{bc}	40.72±0.1 26 ^{cd}
cook/ferment	0.58±0.0 2 ^{cd}	4.21±0.0 3 ^b	2.11±0.0 1 ^a	2.94±0.1 3 ^{cd}	49.17±0.1 57 ^{cd}	39.63±0.1 31 ^{bc}	40.42±0.1 35 ^d
toast/cook/ferment	0.55±0.0 1 ^d	4.58±0.0 4 ^a	1.94±0.0 3 ^{ab}	2.34±0.0 8 ^e	48.12±0.1 77 ^d	39.14±0.1 60 ^c	42.96±0.1 24 ^b

Effect of Processing on Functional Properties of Castor Cake

Processing altered key functional characteristics of castor cake, making it more suitable for feed manufacturing. All treatment methods contributed to improvements in handling and formulation compatibility, particularly by enhancing mixing and flow properties. A lower bulk density, as observed

here, supports better aeration and ease of transport in feed production systems (Nkurikiyeet al., 2023). Similar improvements have been noted in other processed legume meals (Ohanenyeet al., 2022).

The highest water absorption capacity (WAC) was recorded in samples subjected to a combination of toasting, cooking, and fermentation. Enhanced WAC may improve feed texture, moisture retention, and digestion in animals (Avramovicet al.,2025). Hydrated feeds are more palatable and support better growth performance (Zhou et al., 2023).

Oil absorption capacity (OAC) increased notably in fermented samples, with or without cooking. This suggests improved lipid-binding potential, contributing to feed energy value and taste. Feed with high OAC can improve weight gain and growth in animals (Grasso et al., 2022).

Processing led to a reduction in foaming capacity and stability, especially with thermal and microbial treatments. This is consistent with protein denaturation and loss of surface-active properties during heat application (Sarvaniet al., 2020) Since foaming is not critical in animal feeds, this reduction is not a drawback (Ramteke et al., 2019).

Emulsion capacity and stability improved considerably, particularly with fermentation followed by cooking. These properties help ensure uniform distribution of lipids and nutrients in feed, enhancing feed quality and digestion efficiency (Ancuța and Sonia, 2020). Fermentation-induced protein modification likely contributed to the increased emulsifying ability, as noted by (Lonchamp et al., 2019).

These findings demonstrate that processing can enhance the functional usability of castor cake, making it more adaptable and efficient in animal feed applications.

Conclusion

The nutritional composition of NCRICAS1 castor cake has demonstrated that castor has the potential to be used in animal feeds. Processing the cake at 84°C for 65 minutes and fermenting it for five days at 40°C significantly reduced castor anti-nutrients likericin, ricinine lectins, tannins, etc to a level that was safe while preserving its nutrients. The biological significance of the nutrients found in castor cake should be investigated further.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

A.B.O.: Conceptualization, formal analysis, writing – original draft Investigation, resources, validation, A.H.O.: supervision, writing review and editing E.E.C.: Conceptualization, Data curation, formal analysis, validation, writing – review and editing. A.A.: data curation, validation, writing – review and editing. O.F.I.: Conceptualization, methodology, project management, investigation, data curation, writing – original draft, validation, formal analysis, writing – review and editing. All authors read and approved the final version.

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