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(Research Article)

Mineral composition of the kernel cake from the seeds of five rubber tree clones cultivated in Côte d'Ivoire

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Abstract

The objective of this study was to determine the mineral composition of the kernel cake derived from the seeds of five rubber tree (Hevea brasiliensis) clones commonly cultivated in Côte d'Ivoire (PB217, GT1, IRCA41, IRCA230, and IRCA331). The experiment was conducted at the CNRA Research Center of Bimbresso, Abidjan, from March 2024 to January 2025. Oil extraction was performed using a Soxhlet apparatus with hexane, and mineral profiling was carried out according to AOAC (1990) procedures. Results showed significant variation ($p < 0.05$) in macro- and micronutrient contents among clones. GT1 exhibited the highest levels of magnesium (526.48 mg/100 g) and potassium (2275.86 mg/100 g), whereas PB217 showed the highest phosphorus (1182.21 mg/100 g), sulfur (561.29 mg/100 g), and calcium (270.39 mg/100 g) concentrations. IRCA331 presented the highest sodium (22.40 mg/100 g), copper (4.89 mg/100 g), and iodine (3.24 mg/100 g) levels. These findings demonstrate the nutritional potential of rubber seed kernel cake as a valuable mineral source for animal feeding and as an organic soil amendment in sustainable agriculture.

Keywords: Minerals; Kernel Cake; Hevea Brasiliensis; Côte d'Ivoire

1. Introduction

Hevea brasiliensis is cultivated globally as the primary source of natural rubber. In Africa, Côte d'Ivoire is the leading producer and ranks third worldwide in natural rubber production [1]. Although the latex is economically valuable, the rubber seed — a by-product often discarded — represents an underutilized source of nutrients [2]. Rubber seeds contain around 50 % oil [3,4] rich in unsaturated fatty acids and fat-soluble vitamins (A, E, K) [5], making them suitable for food, cosmetic, and biofuel industries. After oil extraction, the residual cake (kernel meal) remains rich in proteins, fibers, carbohydrates, and minerals [6–8]. Several studies have explored the potential use of rubber seed cake in animal feeding [9–11] and as a bio-fertilizer [12]. However, data on the quantitative and comparative mineral composition of kernel cakes from different clones remain scarce. Genetic and environmental factors may influence mineral uptake and accumulation. Therefore, this study aimed to characterize the macro- and micro-element composition of kernel cakes from five Hevea brasiliensis clones widely cultivated in Côte d'Ivoire to identify their nutritional and agronomic potential.

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2. Materials and Methods

2.1. Plant Material

The plant material used in this study consisted of seeds from five *Hevea brasiliensis* (rubber tree) clones commonly cultivated in Côte d'Ivoire: GT 1, PB 217, IRCA 41, IRCA 230, and IRCA 331. The seeds were collected from monoclonal plots belonging to three plantation entities: the Société Africaine de Plantation d'Hévéa (SAPH) located in the *Grands Ponts* region, the Société Coopérative Agricole du Sud-Ouest in the *Bas-Sassandra* region, and EXAT Agriculture in the *Kouamé Koffikro plantation* situated in the *Prikro* area.

2.2. Methods

2.2.1. Preparation of the Oil Cake

The oil cake was obtained from kernels after chemical extraction using a Soxhlet apparatus according to the AOAC (1990) [16] method, with hexane as the solvent. After defatting, the solid residues were dried at 50 °C, ground, and sieved to obtain a homogeneous powder used for subsequent analyses.

2.2.2. Determination of the Mineral Profile

The mineral profile of the oil cakes was determined by X-ray fluorescence spectrometry (XRF) according to the AOAC (1990) [16] method. The samples were first finely ground, and five (5) grams of the powder were weighed using an analytical balance and mixed with one (1) gram of a binding agent. The mixture (sample powder + binder) was homogenized using a vibro-grinder, then compressed under a pressure of 10 tons with a hydraulic press to form a homogeneous pellet. Sample information was entered into the spectrometer analysis software before starting the measurement. The principle of X-ray fluorescence is based on the excitation of matter by an X-ray beam. Under this excitation, the atoms in the material emit secondary X-rays, known as fluorescence X-rays. The emission spectrum is characteristic of each chemical element and allows for the identification and quantification of the elements present in the sample.

By analyzing this spectrum, the elemental chemical composition can be determined and expressed as mass concentrations (mg/100 g of dry matter) for both macro- and microelements.

2.3. Statistical Analysis

Data were subjected to one-way ANOVA using XLSTAT 2019 to assess clone effects on mineral composition. Means were separated using Duncan's multiple range test at the 5 % significance level. Results were expressed as mean ± standard deviation. Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were performed to explore correlations among minerals and to classify clones by mineral profiles.

3. Résults

The macronutrients contained in rubber seed meal showed significant variation ($p < 0.05$) among the studied clones (Table 1). Sodium content ranged from 12.61 ± 0.02 mg/100 g in clone PB 217 to 22.40 ± 0.05 mg/100 g in clone IRCA 331, the latter displaying the highest value. For magnesium, levels varied between 265.80 ± 0.72 mg/100 g in IRCA 230 and 526.48 ± 0.31 mg/100 g in GT 1, which also exhibited the highest phosphorus content (1139.88 ± 1.50 mg/100 g), while the lowest value (785.52 ± 1.20 mg/100 g) was recorded for IRCA 230. Sulfur concentrations showed marked variability, ranging from 326.92 ± 0.97 mg/100 g in IRCA 230 to 561.20 ± 0.96 mg/100 g in PB 217. Clone GT 1 also showed a high sulfur content (532.00 ± 0.45 mg/100 g), indicating good accumulation of this element. Potassium, the predominant mineral element, ranged from 1487.36 ± 1.28 mg/100 g in IRCA 230 to 2275.86 ± 3.21 mg/100 g in GT 1, confirming the strong nutrient absorption capacity of this clone. Finally, calcium concentrations varied between 152.44 ± 0.25 mg/100 g in IRCA 230 and 270.39 ± 0.23 mg/100 g in PB 217, with GT 1 showing an intermediate value of 245.97 ± 0.80 mg/100 g. Overall, these results highlight significant clonal variability for all macronutrients analyzed. Clones GT 1 and PB 217 stand out for their higher levels of major elements (K, Mg, P, Ca, and S), whereas IRCA 230 exhibited the lowest contents, suggesting physiological differences in mineral uptake and accumulation capacity among clones.

Table 1 Macronutrient composition of rubber seed kernel cakes from five *Hevea brasiliensis* clones

Macroelements (mg/100 g)	GT1	PB217	IRCA 41	IRCA 230	IRCA 331
Sodium (Na)	16.84 ± 0.05^{c}	12.61 ± 0.02^{e}	18.32 ± 0.04^{b}	13.50 ± 0.01^{d}	22.40 ± 0.05^{a}
Magnesium (Mg)	526.48 ± 0.31^{a}	518.76 ± 0.09^{b}	369.70 ± 0.43^{d}	265.80 ± 0.72^{e}	410.35 ± 0.70^{c}
Phosphorus (P)	1139.88 ± 1.50^{b}	1182.21 ± 1.80^{a}	943.93 ± 1.10^{d}	785.52 ± 1.20^{e}	1039.50 ± 1.00^{c}
Sulfur (S)	532.00 ± 0.45^{b}	561.20 ± 0.96^{a}	428.40 ± 0.55^{c}	326.92 ± 0.97^{e}	418.40 ± 0.53^{d}
Potassium (K)	2275.86 ± 3.21^{a}	2233.53 ± 4.12^{b}	1657.51 ± 1.30^{d}	1487.36 ± 1.28^{e}	1793.63 ± 1.56^{c}
Calcium (Ca)	245.97 ± 0.80^{b}	270.39 ± 0.23^{a}	169.79 ± 0.35^{c}	152.44 ± 0.25^{e}	164.79 ± 0.79^{d}
Nitrogen (N)	3010 ± 10^{b}	3040 ± 20^{b}	3160 ± 60^{a}	3050 ± 30^{b}	3080 ± 90^{ab}

Note: Means ± standard deviations followed by different superscript letters within a row differ significantly at $p < 0.05$ according to Duncan's multiple range test.

The trace elements determined were manganese, iron, zinc, copper, and iodine (Table 2). The micronutrient contents of the rubber seed meal also showed significant variations ($p < 0.05$) among the studied clones. Manganese (Mn) levels ranged from 3.34 ± 0.01 to 5.27 ± 0.03 mg/100 g, indicating a significant difference between clones. For iron (Fe), values were 31.86 ± 0.44 mg/100 g (GT 1), 21.55 ± 0.13 mg/100 g (PB 217), 15.14 ± 0.09 mg/100 g (IRCA 41), 14.73 ± 0.07 mg/100 g (IRCA 230), and 19.14 ± 0.12 mg/100 g (IRCA 331). Clone GT 1 therefore exhibited the highest iron content, highlighting its superior nutritional potential for this element. Copper (Cu) concentrations ranged from 4.20 ± 0.01 to 4.89 ± 0.00 mg/100 g, with the highest value recorded in clone IRCA 331 (4.89 ± 0.00 mg/100 g) and the lowest in IRCA 41 (4.20 ± 0.01 mg/100 g). Regarding zinc (Zn), the observed levels were 19.31 ± 0.03 mg/100 g (GT 1), 16.26 ± 0.04 mg/100 g (PB 217), 12.12 ± 0.04 mg/100 g (IRCA 41), 10.58 ± 0.06 mg/100 g (IRCA 230), and 13.17 ± 0.09 mg/100 g (IRCA 331). The highest concentration was found in clone GT 1, reflecting its strong ability to accumulate zinc. Finally, iodine (I) contents ranged from 2.22 ± 0.01 to 3.24 ± 0.00 mg/100 g. The lowest value was recorded in clone GT 1 (2.22 ± 0.01 mg/100 g), while the highest was observed in IRCA 331 (3.24 ± 0.00 mg/100 g). Clones PB 217, IRCA 41, and IRCA 230 showed intermediate levels of 2.24 ± 0.02, 2.76 ± 0.02, and 3.01 ± 0.01 mg/100 g, respectively. Overall, the results indicate marked clonal variability for most of the studied micronutrients. Clone GT 1 is distinguished by its high iron and zinc contents, while IRCA 331 shows the highest concentrations of copper and iodine.

Table 2 Trace element composition of rubber seed meal from five clones

Trace elements (mg/100 g)	GT 1	PB 217	IRCA 41	IRCA 230	IRCA 331
Manganese	5.00 ± 0.01^{b}	5.27 ± 0.03^{a}	3.34 ± 0.01^{e}	3.98 ± 0.03^{d}	4.26 ± 0.01^{c}
Iron	31.86 ± 0.44^{a}	21.55 ± 0.13^{b}	15.14 ± 0.09^{d}	14.73 ± 0.07^{d}	19.14 ± 0.12^{c}
Copper	4.52 ± 0.01^{d}	4.76 ± 0.01^{b}	4.20 ± 0.01^{e}	4.63 ± 0.03^{c}	4.89 ± 0.00^{a}
Zinc	19.31 ± 0.03^{a}	16.26 ± 0.04^{b}	12.12 ± 0.04^{d}	10.58 ± 0.06^{e}	13.17 ± 0.09^{c}
Iodine	2.22 ± 0.01^{d}	2.24 ± 0.02^{d}	2.76 ± 0.02^{c}	3.01 ± 0.01^{b}	3.24 ± 0.00^{a}

Means ± standard deviations followed by different letters within a row are significantly different at $p < 0.05$ according to Duncan's test.

3.1. Correlation Matrix between Mineral Elements in the Five Clones

The Pearson correlation matrix illustrates the interrelationships among the mineral elements in the five rubber clones (Table 3). Magnesium showed strong positive correlations with phosphorus (r = 0.99), sulfur (r = 0.97), potassium (r = 0.99), and calcium (r = 0.90), as well as moderate correlations with manganese (r = 0.79) and iron (r = 0.82). However, it was negatively correlated with iodine (r = –0.77). Phosphorus was positively correlated with sulfur (r = 0.96), potassium (r = 0.95), and moderately with calcium (r = 0.87), manganese (r = 0.78), and iron (r = 0.73). Iodine showed negative correlations with magnesium (r = –0.77), sulfur (r = –0.85), potassium (r = –0.83), and calcium (r = –0.92). Sulfur was positively correlated with potassium (r = 0.96), calcium (r = 0.95), manganese (r = 0.77), and iron (r = 0.73). Potassium was positively correlated with calcium (r = 0.95), manganese (r = 0.88), and iron (r = 0.86). Calcium, in turn, was positively correlated with manganese (r = 0.87) and iron (r = 0.72). Zinc displayed strong positive correlations with magnesium (r = 0.93), phosphorus (r = 0.87), sulfur (r = 0.89), potassium (r = 0.96), calcium (r = 0.87), manganese (r = 0.80), and iron (r = 0.96), indicating its close association with these macronutrients in the mineral profile of the clones.

Table 3 Pearson correlation matrix between mineral elements of the five rubber clones

Variables	Na	Mg	P	S	K	Ca	Mn	Fe	Cu	Zn	I	N
Sodium	1											
Magnesium	−0.02	1										
Phosphorus	0.04	0.99	1									
Sulfur	−0.18	0.97	0.96	1								
Potassium	−0.18	0.98	0.95	0.96	1							
Calcium	−0.45	0.90	0.87	0.95	0.95	1						
Manganese	−0.38	0.79	0.78	0.77	0.88	0.87	1					
Iron	−0.01	0.82	0.73	0.73	0.86	0.72	0.74	1				
Copper	0.06	0.18	0.27	0.07	0.21	0.14	0.56	0.11	1			
Zinc	−0.10	0.93	0.87	0.89	0.96	0.87	0.80	0.96	0.09	1		
Iodine	0.56	−0.77	−0.68	−0.85	−0.83	−0.92	−0.68	−0.69	0.22	−0.82	1	
Nitrogen	0.42	−0.44	−0.38	−0.37	−0.59	−0.57	−0.84	−0.69	−0.56	−0.62	0.45	1

3.2. Hierarchical Cluster Analysis (HCA)

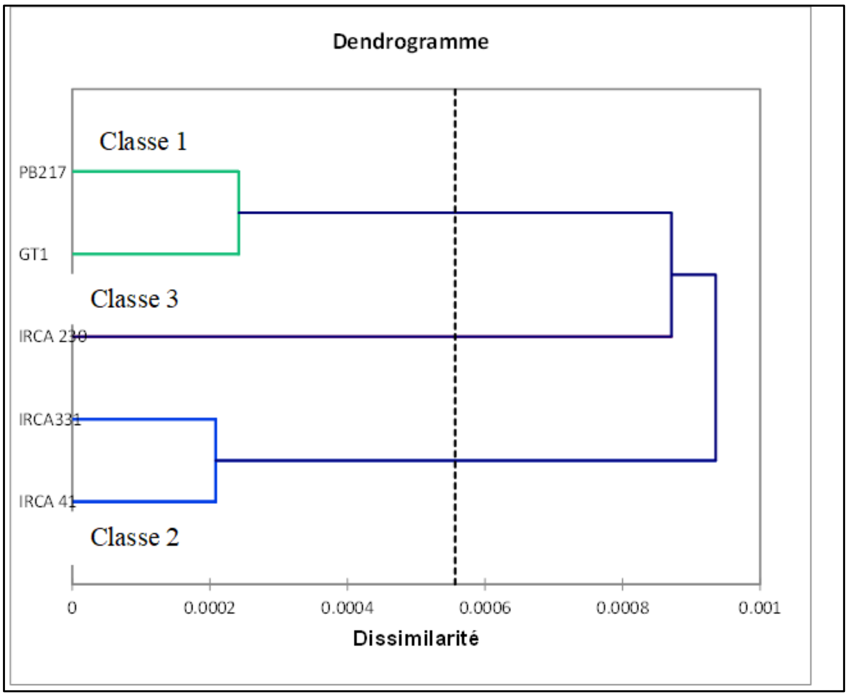

Figure 1 Classification hiérarchique des cinq clones en fonction du profil minéral

The dendrogram (Figure 1) obtained from the hierarchical cluster analysis (HCA) grouped the five clones into three distinct classes. Group 1 consisted of clones GT 1 and PB 217, characterized by their relatively high contents of sodium, magnesium, sulfur, calcium, manganese, iron, copper, zinc, and iodine. Group 2 included clones IRCA 41 and IRCA 331, distinguished by their higher potassium and phosphorus contents. Group 3 was represented solely by IRCA 230, which stood out due to its distinct nitrogen content. These results highlight a clear mineral differentiation among clones, reflecting genetic variability in nutrient absorption and accumulation capacities within Hevea brasiliensis seed meals.

4. Discussion

The analyses highlighted the presence of seven essential macronutrients required for animal nutrition: calcium (Ca), phosphorus (P), magnesium (Mg), sulfur (S), sodium (Na), chlorine (Cl), and potassium (K). These minerals showed significant differences ($p < 0.05$) among the studied clones, differences that could be attributed both to clonal variability and to the oil extraction process. Indeed, oil extraction leads to a concentration of nutrients in the solid residue, explaining the higher mineral contents found in the seed cakes. The most abundant macronutrients were magnesium (265.80 ± 0.72 – 526.48 ± 0.31 mg/100 g), phosphorus (785.52 ± 1.20 – 1139.88 ± 1.50 mg/100 g), sulfur (326.92 ± 0.97 – 561.20 ± 0.96 mg/100 g), and potassium (1487.36 ± 1.28 – 2275.86 ± 3.21 mg/100 g). These values are higher than those reported by Rokiatou et al. [17] for agricultural by-products used in poultry feed, and by Pousga et al. [18] for shea (Vitellaria paradoxa) cake, cottonseed (Gossypium spp.) cake, and sorghum beer residue (Sorghum bicolor) in Burkina Faso. These results reflect the mineral richness of Ivorian soils and confirm the high nutritional potential of rubber seed cakes. The presence of sodium in the cakes is beneficial because it enhances flavor, improves texture, and inhibits bacterial activity [19]. Sodium plays a key role in plasma volume regulation and acid–base balance while maintaining muscle excitability. Sodium deficiency leads to growth retardation in chicks and, in laying hens, to a decrease in egg production and hatchability [20]. Calcium and phosphorus are interdependent elements. Calcium contributes to bone and teeth formation, nerve and muscle function, and blood clotting. Phosphorus, in turn, is involved in ATP, phospholipid, and phosphoprotein synthesis and in the formation of bone structures [21–24]. The high phosphorus content (up to 1139.88 mg/100 g) observed in the seed cakes is markedly higher than that found in raw rubber seed kernels (225.74 mg/100 g), soybean meal (0.57–0.76 mg/100 g), and palm kernel meal (0.046 mg/100 g) [21–23]. These values demonstrate the high phosphorus richness of rubber seed cakes, making them suitable for both animal feed and plant fertilization. Potassium levels, ranging from 1487.36 to 2275.86 mg/100 g, represent nearly half of the recommended daily intake for humans (4700 mg/day) [26]. Potassium is known for its role in blood pressure regulation and enzyme activation in plants, contributing to tolerance against water and oxidative stress [25, 27]. Therefore, rubber seed cakes can serve as a natural source of potassium for both animal nutrition and organic fertilization. Magnesium acts as a cofactor for many enzymes involved in energy metabolism and bone formation [28]. The levels observed (265.80–526.48 mg/100 g) far exceed the recommended values for livestock: 400 mg/kg for pigs, 500 mg/kg for broilers, and 100 g/day for laying hens [30–31]. These results confirm that rubber seed cakes are an excellent source of magnesium, comparable to oilseed cakes (3.0–5.8 g/kg DM) and fish meals (1.7–2.5 g/kg DM) [32]. The nitrogen content (3.01–3.16%) reflects the protein richness of the cake. These levels are higher than those of neem cake (1.09% DM) and copra cake (1.73%) [33–34], and close to those of safou seed cake (1.81–2.14%) [35]. Nitrogen plays an essential role in amino acid, protein, and nucleic acid synthesis and is a key element for plant growth and productivity [36–37]. Regarding micronutrients, the main ones observed were iron (Fe), zinc (Zn), copper (Cu), iodine (I), and manganese (Mn). Zinc levels (10.58–19.31 mg/100 g) are crucial for muscle growth, protein synthesis, and reproduction in animals [38–40]. The concentrations observed exceed the recommended levels for broilers (60–70 mg/kg feed) [38]. Iron levels, reaching up to 31.86 mg/100 g, are higher than those found in sunflower meal (5.26 mg/kg) [44]. Iron is essential for hemoglobin synthesis and oxygen transport, and its deficiency causes anemia [45–46]. Beyond their nutritional importance, these seed cakes can also be used as organic soil amendments. Their incorporation into soils improves physicochemical properties (organic matter content, water retention capacity, pH) and stimulates beneficial microbial activity. Thus, they offer an ecological and economical alternative to chemical fertilizers, promoting the sustainability of agricultural systems [47]. According to [48], incorporating oilseed cakes (soybean, cotton, flax, sesame, olive) into tomato cultivation can also reduce nematode populations while improving soil structure and fertility.

5. Conclusion

The kernel cake derived from five *Hevea brasiliensis* clones in Côte d'Ivoire contained substantial macro- and micronutrient levels, with significant inter-clone variability. Clones PB217 and GT1 were the richest in phosphorus, calcium, magnesium, and potassium, while IRCA331 accumulated more copper and iodine. These results confirm the high nutritional and agronomic value of rubber seed kernel cakes, supporting their use as alternative protein-mineral feed ingredients and as organic amendments promoting sustainable agriculture.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Ruf F. (2012). *The adoption of rubber in Côte d'Ivoire: Prices, copying effect, ecological and social change.* CIRAD Working Paper. https://doi.org/10.13140/RG.2.1.4932.1522

[2] Koffi E. N., Niamketchi L. G., Koffi U. K., Guéi J. F., Konan M. K., & Anin L. (2022). Chemical analysis and antifungal activity of rubber seed oil (*Hevea brasiliensis*) from southern Côte d'Ivoire. *Journal of Materials and Environmental Science*, 13(4), 382–390. https://doi.org/10.26872/jmes.2022.13.4.40

[3] Mary A. C., Ehijie A. A., Chidinma N. E., & Ogechi S. A. (2020). Evaluation of proximate and functional properties of rubber seed meal. *African Journal of Food Science*, 14(11), 407–413. https://doi.org/10.5897/AJFS2020.2020

[4] Bamba S., Diomandé G. G. D., Sanou S. F., & Adima A. A. (2024). Omega-3 enrichment of refined palm oil using detoxified rubber seed oil (*Hevea brasiliensis*). *Afrique Science*, 24(3), 17–32. https://doi.org/10.5281/zenodo.12687289

[5] Okoma D. M. J., Koffi L. B., Kouadio E., Elabo A., & Obouayeba S. (2018). Valorization of rubber seed through oil and poultry feed production in Ivory Coast. In *International Rubber Conference (IRCC 2018)*, Abidjan. https://doi.org/10.13140/RG.2.2.24179.48167

[6] Cheng T., Huang H., Mi H., Zhang L., Deng J., Zhang S., Dong X., Chi S., Yang Q., Liu H., … Tan B. (2024). Effects of replacing fish meal with rubber seed cake on growth, digestive, antioxidant, and protein metabolism of juvenile Asian red-tailed catfish (*Hemibagrus wyckioides*). *Animals*, 14(21), 3149. https://doi.org/10.3390/ani14213149

[7] Sylla A., Konan R. K. B., Okoma D. M. J., Soro P. A. D., & Konan J. L. K. (2025). Use of rubber seed cake as a biofertilizer on agro-morphological and biochemical characteristics of plantain (*Musa paradisiaca L.* "Big Ebanga"). *Journal of Experimental Agriculture International*, 47(8), 581–589. https://doi.org/10.9734/jeai/2025/v47i83699

[8] Sugebo B., Demrew Z., Feleke S., & Biazen M. (2025). Evaluation and characterization of rubber seed oil for biodiesel production. *Biomass Conversion and Biorefinery*, 15(15), 22125–22135. https://doi.org/10.1007/s13399-024-04851-7

[9] Sultana R., Banik U., Nandy P. K., Huda M. N., & Ismail M. (2023). Bio-oil production from rubber seed cake via pyrolysis: Process parameter optimization and physicochemical characterization. *Energy Conversion and Management: X*, 20, 100429. https://doi.org/10.1016/j.ecmx.2023.100429

[10] Trirahayu D. A., Abidin A. Z., Putra R. P., Hidayat A. S., Safitri E., & Perdana M. I. (2022). Process simulation and design considerations for biodiesel production from rubber seed oil. *Fuels*, 3(4), 563–579. https://doi.org/10.3390/fuels3040030

[11] Pousga S., Boly H., Lindberg J. E., & Ogle B. (2007). Evaluation of traditional sorghum beer residue, shea-nut cake, and cottonseed cake for poultry in Burkina Faso: Availability and amino-acid digestibility. *International Journal of Poultry Science*, 6(9), 666–672. https://doi.org/10.3923/ijps.2007.666.672

[12] Heaney R. P. (2006). Role of dietary sodium in osteoporosis. *Journal of the American College of Nutrition*, 25(Suppl 3), 271S–276S. https://doi.org/10.1080/07315724.2006.10719574

[13] Soetan K. O., Olaiya C. O., & Oyewole O. E. (2010). The importance of mineral elements for humans, domestic animals and plants: A review. *African Journal of Food Science*, 4(5), 200–222. https://doi.org/10.5897/AJFS.9000119

[14] Azizi M. N., Loh T. C., Foo H. L., & Chung E. L. T. (2021). Is palm kernel cake a suitable alternative feed ingredient for poultry? *Animals*, 11(2), 338. https://doi.org/10.3390/ani11020338

[15] Dei H. K. (2011). Soybean as a feed ingredient for livestock and poultry. In *Soybean: Biochemistry, Chemistry and Physiology.* IntechOpen. https://doi.org/10.5772/14497

[16] Hays V. W., & Swenson M. J. (1985). Minerals and bones. In *Dukes' Physiology of Domestic Animals* (10th ed., pp. 449–466). Cornell University Press.

[17] Falkner B. (2017). Does potassium deficiency contribute to hypertension in children and adolescents? *Current Hypertension Reports*, 19(5), 37. https://doi.org/10.1007/s11906-017-0733-9

[18] Johnson R., Vishwakarma K., Hossen M. S., Kumar V., Shackira A. M., Puthur J. T., … Alqarawi A. A. (2022). Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. *Plant Physiology and Biochemistry*, 172, 56–69. https://doi.org/10.1016/j.plaphy.2021.12.008

[19] Murray R. K., Granner D. K., Mayes P. A., & Rodwell V. W. (2000). *Harper's Biochemistry.* McGraw-Hill Health Professions Division.

[20] Lipiński K., Żuk-Gołaszewska K., Purwin C., & Stasiewicz M. (2011). Effects of magnesium on pork quality. *Journal of Elementology*, 16(2), 249–260. https://doi.org/10.5601/jelem.2011.16.2.09

[21] Pinotti L., Manoni M., Ferrari L., Tretola M., Cazzola R., & Givens I. (2021). The contribution of dietary magnesium in farm animals and human nutrition. *Nutrients*, 13(2), 509. https://doi.org/10.3390/nu13020509

[22] Lekadou T. T., N'Goran A., Konan J. L., Allou K., Zakra N., & Assa A. (2008). Decomposition of copra and palm kernel cakes and effects on coconut seedling growth and mineral nutrition in Côte d'Ivoire. *Sciences & Nature*, 5(2), 155–166. https://doi.org/10.4314/scinat.v5i2.42163

[23] Ano A. A. R. R., Koffi E. N., Adima A. A., N'da P. K., & Anin L. A. (2018). Biochemical and phytochemical composition of safou (*Dacryodes edulis*) fruit cakes from Côte d'Ivoire. *International Journal of Biological and Chemical Sciences*, 12(6), 2535–2546. https://doi.org/10.4314/ijbcs.v12i6.15

[24] Smithson P. C., & Sanchez P. A. (2001). Plant nutritional problems in marginal soils of developing countries. In N. Ae, J. Arihara, K. Okada, & A. Srinivasan (Eds.), *Plant Nutrient Acquisition* (pp. 32–68). Springer, Tokyo. https://doi.org/10.1007/978-4-431-66902-9_2

[25] Adesehinwa A. O. K. (2007). Utilization of palm kernel cake as a replacement for maize in diets of growing pigs: Effects on performance, serum metabolites, nutrient digestibility and cost of feed conversion. Bulgarian Journal of Agricultural Science, 13(5), 591–600. https://doi.org/10.13140/RG.2.2.32147.17445

[26] Bao Y. M., & Choct M. (2009). Trace mineral nutrition for broiler chickens and prospects for organically complexed trace minerals. Animal Production Science, 49(4), 269–282. https://doi.org/10.1071/EA08248

[27] Gupta A., Sharma R., Sharma S., & Singh B. (2018). Oilseed as potential functional food ingredient. In P. Kumar, M. K. Mahawar, W. Abobatta, & P. Panja (Eds.), Trends & Prospects in Food Technology, Processing and Preservation (pp. 25–58). Apple Academic Press. https://doi.org/10.1201/9780429465579

[28] Nollet L., Huyghebaert G., & Spring P. (2008). Effect of different levels of dietary organic (Bioplex) trace minerals on live performance of broiler chickens by growth phases. Journal of Applied Poultry Research, 17(1), 109–115. https://doi.org/10.3382/japr.2006-00117

[29] Huang L., Li X., Wang W., Yang L., & Zhu Y. (2019). The role of zinc in poultry breeder and hen nutrition: An update. Biological Trace Element Research, 192(2), 308–318. https://doi.org/10.1007/s12011-019-01916-y

[30] Njuguna D. G., Wanyoko J. K., Kinyanjui T., & Wachira F. N. (2013). Mineral elements in the Kenyan tea seed oil cake. International Journal of Research in Chemistry and Environment, 3(1), 253–261.

[31] Tebe U., Tangka J., Kamdem B., & Abioye K. (2024). Characterization of oils and solid residues obtained from Bauhinia variegata L. and Pachira glabra seeds through solvent extraction. Asian Journal of Environment & Ecology, 12(3), 53–61. https://doi.org/10.9734/ajee/2024/v12i3310

[32] Petraru A., Ursachi F., & Amariei S. (2021). Nutritional characteristics assessment of sunflower seeds, oil and cake: Perspective of using sunflower oilcake as a functional ingredient. Plants, 10(11), 2487. https://doi.org/10.3390/plants10112487

[33] Abbaspour N., Hurrell R., & Kelishadi R. (2014). Review on iron and its importance for human health. Journal of Research in Medical Sciences, 19(2), 164–174. https://doi.org/10.4103/1735-1995.128179

[34] Vallée L. (2017). Iron and neurodevelopment. Archives de Pédiatrie, 24(5 Suppl), S18–S22. https://doi.org/10.1016/S0929-693X(17)30110-1

[35] Singh T. B., Ali A., Prasad M., Yadav A., Shrivastav P., & Goyal D. (2020). Role of organic fertilizers in improving soil fertility. In M. Naeem, A. A. Ansari, & S. S. Gill (Eds.), Contaminants in Agriculture (pp. 61–77). Springer International Publishing. https://doi.org/10.1007/978-3-030-41552-5_3

[36] Radwan M. A., El-Maadawy E. K., Kassem S. I., & Abu-Elamayem M. M. (2009). Oil cakes soil amendment effects on Meloidogyne incognita root-knot nematode infecting tomato. Archives of Phytopathology and Plant Protection, 42(1), 58–64. https://doi.org/10.1080/03235400601018616

[37] Council N. R. (2012). Nutrient requirements of swine (11th rev. ed.). National Academies Press. https://doi.org/10.17226/13298

[38] Johnson J. L., Hall C. A., & Wolfe R. R. (2023). Amino acid and mineral nutrition in animal production. Annual Review of Animal Biosciences, 11, 313–340. https://doi.org/10.1146/annurev-animal-030422-024248

[39] FAO. (2020). Animal Nutrition and Feeding Practices: A Global Review. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cb1040en

[40] Falkner B. (2017). Potassium deficiency and hypertension in children and adolescents. Current Hypertension Reports, 19(5), 37. https://doi.org/10.1007/s11906-017-0733-9

[41] Hossain M. M., Islam M. A., & Rahman M. T. (2021). Comparative assessment of mineral profiles in oilseed cakes and their effects on animal feed quality. Animals, 11(8), 2352. https://doi.org/10.3390/ani11082352

[42] FAO & WHO. (2019). Human Vitamin and Mineral Requirements (2nd ed.). World Health Organization. https://doi.org/10.4060/ca8488en

[43] Adima A. A., Kassi B. A. B., & Yao J. C. N. (2024). Chemical and nutritional characterization of detoxified rubber seed kernel cake (Hevea brasiliensis) from Côte d'Ivoire. Food Research International, 181, 113123. https://doi.org/10.1016/j.foodres.2024.113123

[44] Joelle O. D. M., Ardjouma S., Roger K. B., & Louis K. K. J. (2025). Vitamin and fatty acid profile of almond oil from the seeds of five rubber tree clones commonly used in Ivory Coast. European Journal of Nutrition & Food Safety, 17(9), 232–240. https://doi.org/10.9734/ejnfs/2025/v17i93137

[45] Murray R. K., Granner D. K., & Rodwell V. W. (2018). Harper's Illustrated Biochemistry (31st ed.). McGraw-Hill Education.

[46] Merck W. (1896). Die Wirkung der gleichen Tarifierung von Mehl und Getreide auf unserer Landwirtschaft. J. Mayer'sche Buchdruckerei.

[47] Johnson R., Vishwakarma K., Hossen M. S., Kumar V., Shackira A. M., Puthur J. T., … Alqarawi A. A. (2022). Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. Plant Physiology and Biochemistry, 172, 56–69. https://doi.org/10.1016/j.plaphy.2021.12.008

[48] AOAC. (1990). Official Methods of Analysis (15th ed.). AOAC International, Washington D.C.a