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Josephine Akuba Timtey
Kwame Nkrumah University of Science and Technology

Francis Alemawor
Kwame Nkrumah University of Science and Technology

William Otoo Ellis
Kwame Nkrumah University of Science and Technology

Nana Baah Pepra-Ameyaw
Chapman University, pepraame@chapman.edu

Jacob K. Agbenorhevi
Kwame Nkrumah University of Science and Technology

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Pentadesma butyracea in Ghana – indigenous knowledge, uses, and seed characterization

Josephine Akuba Timtey, Francis Alemawor*, William Otoo Ellis, Nana Baah Pepra-Ameyaw, Jacob K. Agbenorhevi

Department of Food Science and Technology, Faculty of Biosciences, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

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ABSTRACT

This study ascertained the indigenous knowledge and uses of *Pentadesma butyracea* plant through a focus group study. The proximate, mineral, antinutritional compositions, and antioxidant activity of *P. butyracea* seed were also determined using standard analytical methods. The results of the focus group study showed that *P. butyracea* is essentially used for its butter which is prepared by women processors who hand down the skill of butter processing to their children. The butter is used for cooking, frying, and preparing traditional delicacies, and the plant is known to possess some therapeutic potential. The seed recorded the following mean proximate values: fat content of 35.82%, carbohydrate of 50.97%, 1.81% ash, 2.68% protein, 1.34% crude fibre, and moisture of 7.39%. The most abundant mineral in the seed is potassium (32.93 mg/100 g). Calcium, magnesium, phosphorus, sodium, iron, and zinc were at levels of $<$10 mg/100 g. Antinutritional factors found present in *P. butyracea* seed include oxalate (2737.42 mg/100 g), tannins (55.44 mg/100 g), saponins (10.23 mg/100 g), and alkaloids (9.18 mg/100 g). Also, the *P. butyracea* seed recorded mean total phenolics of 725.85 mg GAE/gdw), total flavonoids of 2313.15 μg (QE)/gdw, and DPPH activity of 82.02%. Although rich in fat, carbohydrates, and some minerals that can be exploited in food applications, the high contents of some antinutrients may pose nutritional challenges to its use. The findings from the indigenous knowledge investigation about *Pentadesma butyracea* seeds would partly influence the choice of appropriate processing approaches to maximising its value regarding food security challenges of indigenes in the study areas.

Introduction

Wild edible plants are typical of tropical environments, and indigenous communities greatly depend on these natural resources for survival; thus, they are knowledgeable about their environmental resources. The knowledge emanates from oral traditions, observations, and reluctance to adjust to changing living conditions [1–3]. Rural inhabitants habitually consume food resources that may not be well appreciated by conventional agriculture and/ or health sectors [4]. These food resources

* Corresponding author.
E-mail addresses: inthylight96@gmail.com, falemawor.cos@knust.edu.gh (F. Alemawor).

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are highly nutritious and may enhance food nutrition and security. It is palpable that indigenes acknowledge the health and nutritional benefits of some edible plants that are part of their traditional food systems [5]. They are aware of cultivars' specific differences in agronomic and dietary characteristics. They often describe certain cultivars or indigenous varieties as having nutritional or therapeutic benefits [6].

Traditional knowledge of underutilised plants is diminishing due to several factors, including unfamiliarity amongst the youth with the existence of such crops, inadequate research and extension efforts, the introduction of modern crops with higher yields, and changes in dietary patterns [7]. Though wild edible plants may be low-yielding, indigenous edible plants are tasty and can withstand natural disasters [8].

Oilseed crops are placed fourth after cereals, vegetables and melon, and fruits and nuts. They constitute a major vegetable oil and essential crop for low-income families in the semi-arid tropics contributing about 40% of their total caloric intake [9,10]. Seeds are good sources of micro and macronutrients necessary for healthy living. Also, they are abundant sources of phytochemicals which, at certain critical levels, may have anti-nutritional impacts [11,12].

Pentadesma butyracea sabine seeds is one oilseed crop belonging to the Clusiaceae family, well-distributed in the forest belts and galleries of West Africa from Sierra Leone to the Congo [13]. Available information indicates that various parts of the tree are beneficial to man. The seeds treat ill-defined symptoms, musculoskeletal system disorders, inflammations, and respiratory and digestive system disorders. The roots and barks are used for stomach aches and the regularisation of the menstrual cycle. The pulp is used for pedicures and the treatment of constipation. The leaves are commonly used to treat fever and heal wounds, with the seeds producing edible fats [14,15]. It is imperative to acquire and document more knowledge on *Pentadesma butyracea* to promote the preservation and domestication of the plant species in improving food security and nutrition interventions and policies [3,5] to enhance sustainable forest usage.

The traditional knowledge of *Pentadesma butyracea* was conducted through the focus group discussion method. Focus group discussion involves gathering individuals to talk over a complex topic, seeking to derive from the beliefs, difficult personal experiences, perceptions, and attitudes of the participants through a moderated interaction [16,17]. The technique developed as a qualitative data collection approach and a connecting strategy for scientific research and local knowledge. Focus group discussion is a cost-effective and promising alternative to participatory research, offering a platform for differing paradigms [18].

Despite the economic importance of *Pentadesma butyracea* for food, cosmetic and therapeutic uses, there is a lack of knowledge about the plant in Ghana. The purpose of the study was to assess indigenous knowledge and utilisation of *Pentadesma butyracea* seeds in selected communities in Ghana, as well as to characterise the seeds in terms of proximate, mineral, and anti-nutritive compositions and antioxidant potential.

Materials and methods

Study location

The study was carried out in four (4) communities in the Nkoranza North municipality of the Bono East region of Ghana. Bono East is a mixture of forest vegetation and Savanna woodland with a mean annual rainfall of 750 to 1050 mm (30 to 40 inches) [19]. The communities are Akrudwa No. 1, Akrudwa No. 2, Busunya, and Boabeng Fiema. Nkoronza Municipality lies within longitudes 1° 10‘ and 1° 55‘West, and latitudes 7° 20‘ and 7° 55‘North. Boabeng Fiema is on longitude 1° 40′ 43.9″ west and latitude 7° 43′ 8.7″ north, with an elevation of 369 metres. Akrudwa lies within longitude 7° 41′ 45.6″ and 1° 40′ 43.9″ west latitude, and Busunya, longitude 1° 39′ 35.1″ west, 7° 41′ 16.3″ north and 318 metres above sea level [20,21].

Nkoranza North Municipality is characterised by a tropical wet and dry or savanna climate. The yearly temperature is 29.07 °C, which is 0.21% higher than Ghana's average. Nkoranza North, typically receives about 66.61 mm of precipitation annually. The warmest month is February, with a temperature of 38.88 °C, and the coldest month is January, with a temperature of 20.94 °C. October is the wettest month, with a precipitation of 139.75 mm, and the driest month is January, with a precipitation of 2.82 mm. On average, the area receives 142.8 rainy days representing 39.12% and 222.2 days, representing 60.88%, days with no rain. The humidity of Nkoranza North is 69.93% [22]. The communities have an average high temperature of 26 °C with February, March and April being the hottest months. The communities are characterized by a major rainy season between April and June and a minor rainy season between September and November [23]. The vegetation of the study area is part of the transitional zone between the savannah woodland of Northern Ghana and the forest belt of the South. The soils are mostly savanna ochrosols with some lithosols. The land is low lying and most of the soil is sandy loam and loamy [24].

These communities were selected because of their long-standing history of the use of *Pentadesma butyracea* [25]. Fig. 1 shows the map of selected communities where the study took place.

Method of data collection

Focus group discussion, key informant interviews, and field observations were used in this study. Informed consent was obtained from the participants in these discussions. The interviews aimed to get and document the traditional knowledge of *Pentadesma butyracea* and the ways it has been utilised. Questions asked concerned how the plant is known locally,

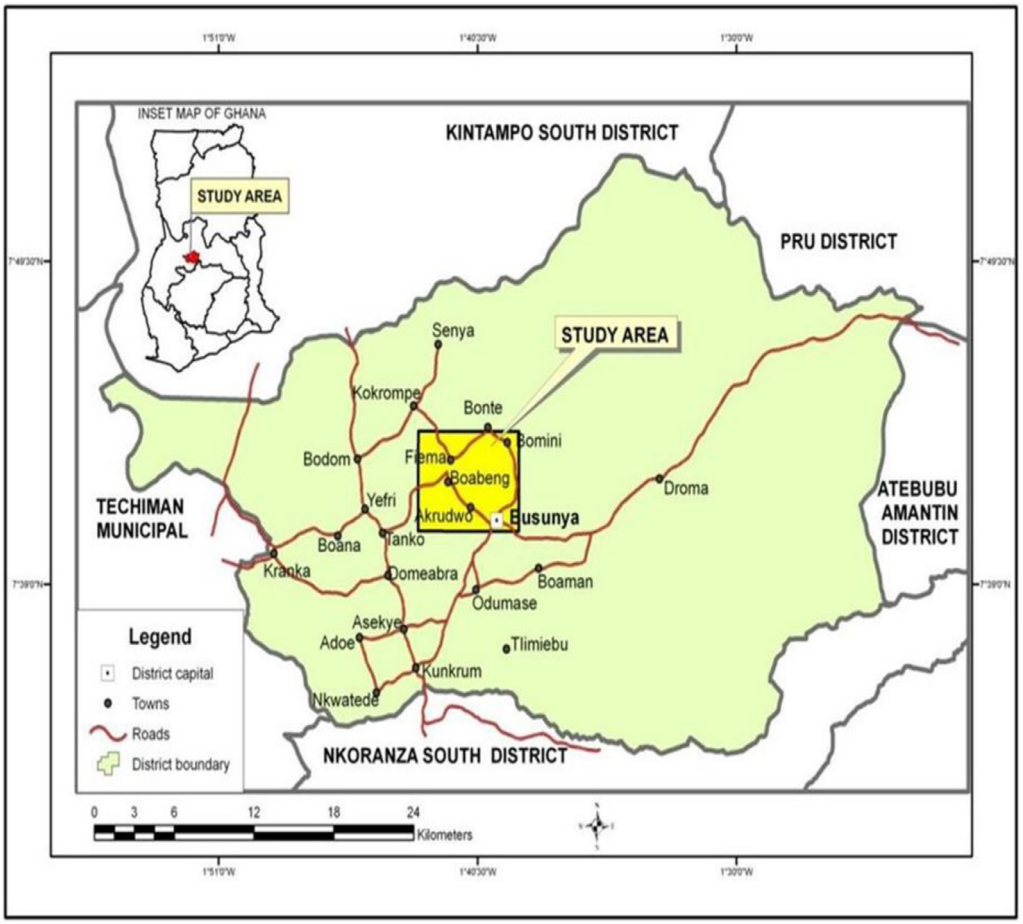

Fig. 1. Map of Bono East region showing study area. (https://www.ghanamissionun.org/map-regions-in-ghana/).

the maturity and harvesting period of the plant, and post-harvest practices employed. Furthermore, traditional uses of the plant, butter processing methods and potential applications of the plant butter aside from its known indigenous uses were also discussed. The discussions were carried out in the Bono language, spoken/understood by both the facilitators and the participants.

Focus group discussions

Focus group discussions were held in each of the four communities Akrudwa No. 1, Akrudwa No.2., Busunya, and Boabeng Fiema. The Single focus group approach was used [26]. Interactive discussions on *Pentadesma butyracea* were done with all the participants and the facilitator as one group in one place. Each session lasted between one and a half to two hours. Two separate discussions were held in all the communities except Akrudwa No. 2. Akrudwa No. 2 is a very small community. The focus group discussion was held in the Chief's palace involving the necessary stakeholders arranged by the community's elders, so only one meeting was held in the community. The outcome of the discussion was not affected in any way by the single discussion held in Akrudwa No.2. Each group was made up of eight to ten participants. The ages of the participants ranged between 24 and 95 years. Fifty-six females and 4 males participated in the focus group discussion. The mode of invitation of participants to the focus group discussions was not biased toward women. However, the processing of *P. butyracea* butter traditionally has been the preserve of women.

Key informants

Two persons served as key informants in this study. The first informant was an exporter of the *Pentadesma butyracea* butter, and the second was an indigene of Akrudwa No. 1. The informants connected the facilitator to the communities and provided details on the collection areas of the plant, traditional processing, and uses of the plant and its butter.

Field observation

Field observation was carried out in the thick forest, where *P. butyracea* plants grow in the company of two experienced farmers. The trees, matured fruits, fermented pods, and dried seeds were identified.

Proximate analysis of P. butyracea *seeds*

The proximate composition of *P. butyracea* seed samples was determined in triplicate, according to standard methods described by the Association of Official Analytical Chemists [27]. The moisture was determined by desiccation of about 5 g sample in a Gallenkamp drying oven at 105 °C to constant weight. The ash by incineration of 3 g of sample in a muffle furnace at 550 °C for 3 h; the nitrogen (N) content was estimated by the Kjeldahl technique and the crude protein content (CP) was calculated as%N x 6.25. The total fat/ lipids (CL) was Soxhlet extracted from a 5-g sample with petroleum ether (boiling range of 40–60 °C) for 8 h. Crude fibre content was determined by treating the sample with 1.25% (w/v) H_2SO_4 and 1.25% (w/v) NaOH. The carbohydrate content (CHO) was determined by difference. The energy was calculated by the equation involving Atwater conversion factors: [Energy (kcal/100 g) = (4 x CP) + (4 x CHO) + (9 x CL)].

Mineral analysis of P. butyracea *seeds*

The amount of the minerals, Potassium. Phosphorus, Magnesium, Manganese, Iron, Calcium, Sodium, and Zinc were analysed using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) method (USEPA method 200.7. U.S. [28]). A 50 g of *P. butyracea* seeds (milled using Amcon high-speed blender, model DT-8110, Japan) was weighed using an analytical balance (model AS260D Ohaus co-operation, USA) and digested in a fume chamber using 30 mL of 69% (w/w) nitric acid and 70 mL of 36% (w/w) hydrochloric acid. The mixture was stirred and heated on a hot plate for 10 min. The mixture was cooled to room temperature and filtered, and the residue was discarded. The filtrate was made to the 100-mL mark with distilled water and analysed using the Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) (Thermo Scientific™ iCAP 7400 Duo ICP-OES Spectrometer equipped with a Teledyne ASX-560 autosampler, Germany).

The standard instrumental operating parameters used were

Parameter Description	Rf power 1.15 kW
Plasma gas flow rate	15.0 L/min
Auxiliary gas flow rate	1.50 L/min
Nebulizer gas flow rate	0.70 L/min
Sample uptake rate	1.8 mL/min
Argon gas (high purity)	99.999%
Torch type	Duo Torch (Axial and Radial)
Nebulizer type	Concentric glass
Nebulizer pressure	200 kPa
Pump rate	50 rpm
Sample uptake delay	30 s

In performing the analysis, the gas supply for the ICP-OES and the ICP was turned on, and the instrument was allowed to optimise for 1 h. The ICP-OES was calibrated by first analysing the calibration blank followed by the calibration standard. The *P. butyracea* seed samples were analysed after calibration was accepted by pouring 10 mL of *P. butyracea* sample into a clean sample tube and inserting it into the sample probe. The results of the analysis were obtained by clicking the analyse button. Determination was replicated three times.

Antinutritient analyses

Saponin determination

The method described by Baburao et al. [29] was used with slight modification. Methanol was used in place of ethanol in this experiment. The technique involved using Soxhlet extraction, using two different organic solvents. The first solvent extracted lipids and interfering pigments, while the second solvent extracted the saponins. About five grams (5 g) of ground *Pentadesma butyracea* seeds were weighed into a thimble and transferred into the Soxhlet extractor chamber fitted with a condenser and a flask. Refluxing was done using petroleum spirit. Extraction was carried out for 3 h to extract the lipids and the interfering pigments. The defatted sample in the thimble was then used for the saponin extraction. A new pre-weighed flask was fitted into the Soxhlet apparatus containing the defatted sample. Methanol was used for refluxing and flushing for 3 h. Saponin extraction was done by heating the flask on a heating mantle. After extraction, the methanol was recovered, leaving the saponins and some little methanol in the flask. The residual methanol was removed by heating the oven by slanting the flask at a temperature of 70 °C. The flask and its content were weighed, and the difference between the flask plus the saponins and the flask alone is the saponin extracted expressed in mg/100 g. The procedure was carried out in duplicate.

Tannin content determination

Tannin was determined using the method described by Schanderi [30]. A 0.25-g powdered sample of *Pentadesma butyracea* seeds was extracted with 37.5 mL distilled water and boiled gently in a flask for 30 min. The sample mixture was centrifuged at 2000 rpm for 20 min, and the volume of the supernatant was finally made up to 37.5 mL with distilled water in a 100 mL flask. An aliquot of 500 µL of the sample was treated with 1 mL of Folin-Denis reagent followed by 2 mL of sodium carbonate and allowed to stand for colour development. The absorbence of the reaction mixture was measured at 700 nm in a spectrophotometer (S Series 711239v1.27, USA). Tannic acid was used as standard. Tannin content was expressed as Tannic acid equivalent (TAE) in gram per gram dry weight.

Oxalate content determination

The titration method, as described by Day and Underwood [31], was used in analysing the oxalate content. One gram of *Pentadesma butyracea* seed sample was weighed into a 100-mL conical flask, and 75 mL of 3 M H_2SO_4 was added, stirred for 1 h with a magnetic stirrer, and filtered using Whatman No.1 filter paper. A 25-mL portion of the filtrate was titrated while hot against 0.05 M $KMnO_4$ solution until a faint pink colour persisted for at least 30 s. The oxalate content was calculated using 1 mL of 0.05 M $KMnO_4$, equivalent to 2.2 mg oxalate.

Alkaloids

Alkaloids were determined using the method described by Harborne [32]. A powdered *Pentadesma butyracea* sample of 2.5 g was weighed into a 250-mL beaker, and 200 mL of 10% acetic acid in ethanol was added and incubated at room temperature for 4 h. The extract was concentrated in a water bath (100 °C) to a quarter of the original volume. Subsequently, concentrated ammonium hydroxide was added dropwise to the extract until the precipitation was complete. After 3 h of mixture sedimentation, the supernatant was discarded, and the precipitates were washed with 20 mL of 0.1 M of ammonium hydroxide and filtered using Whatman No.1 filter paper. The residue, the alkaloid, was weighed using an analytical balance (model AS 260D Ohaus co-operation, USA) after complete dryness, and the percentage of alkaloid was calculated [33].

Antioxidant potentials of P. butyracea *seeds*

Sample preparation

Pentadesma butyracea seeds were coarsely powdered using Amcon high-speed blender (DT-8110, Japan). The pulverised sample (0.5 g) was extracted in 10 mL of 50% hydroethanol by cold maceration for 48 h at room temperature on a Rocking Laboratory shaker (Model MR 12, Latvia). The extract was centrifuged at 8500 g for 10 min, and the supernatant was recovered. An additional 10 mL of the 50% hydroethanol was used to reextract the seeds residue and the supernatants pooled.

Total flavonoid determination

The aluminium chloride colourimetric assay method described by Zhishen, Mengcheng, and Jianming [34] was used to analyse the total flavonoid content (TFC) in *Pentadesma butyracea* samples using quercetin as standard. A 500-µL aliquot of each extract was mixed with 1500 µL of 99.9% ethanol (EtOH), 100 µL of 1 M potassium acetate, 100 µL of 10% aluminium chloride, and 3000 µL of distilled water. The mixture was shaken vigorously and left to stand in the dark at room temperature. The resulting mixtures were incubated for 30 min at room temperature, and the corresponding absorbence was measured at 415 nm. A standard calibration curve was constructed using quercetin standard solutions of 12.5 µg/mL, 25 µg/mL, 50 µg/mL, 75 µg/mL and 100 µg/mL. Five hundred (500) µL of each standard was treated similarly to the samples above, and a linear calibration regression was generated. The flavonoid content of each extract was determined from the curve, and the final results were recalculated and expressed as microgram quercetin equivalent per gram of dry *Pentadesma butyracea* sample (µg QE/gdw).

Total phenolic content

Determination of total phenolic content was carried out by Folin-Ciocalteu (FC) method using gallic acid as standard with modifications [35]; i.e. Folin-Ciocalteu (FC) solution was prepared using 1 in 10 dilution instead of an undiluted FC solution. Briefly, a 50-µL portion of each ethanol and aqueous extract was mixed with 3 mL of distilled water (dH_2O) and 250 µL of FC reagent. The mixture was allowed to stand for 5 min, and then 750 µL of 20% Na_2CO_3 was added. The resulting mixture was vigorously vortexed for two minutes. After incubating the resulting reaction mixtures for 30 min at room temperature, absorbence values were measured at 760 nm using a UV-VIS Spectrophotometer (Shimadzu 1201, Japan). All determinations were performed in triplicate. A calibration curve was prepared using freshly prepared 1 mg/mL gallic acid dissolved in water and serially diluted to the following concentrations, 0.2 mg/mL, 0.4 mg/mL, 0.6 mg/mL, 0.8 mg/mL, and 1 mg/mL. The polyphenolic content in each extract was determined from the calibration curve, and the final results were recalculated and expressed as gallic acid equivalents per gram of dry *Pentadesma butyracea* kernel (mg GAE/gdw).

Determination of antioxidant activity

The free radical scavenging ability of *Pentadesma butyracea* against DPPH free radical was evaluated as described by Oliveira et al. [36] with slight modification. Extracts (200 µL) were added to 3800 µL of 0.004% DPPH methanolic solution. Instead of measuring the absorbence of the resulting mixture periodically until a constant absorbence was obtained, the

Table 1
Demographics of participants involved in the focus group discussion on indigenous knowledge of *Pentadesma butyracea*.

Variable	Number of respondents	Percentage (%)
Gender		
Male	4	9.33
Female	56	66.67
Total	*60*	*100.0*
Age (years)		
15–25	10	16.67
26–35	13	21.67
36–45	16	26.67
46–55	11	18.33
56–100	10	16.67
Total	*60*	*100.0*
Occupation		
Farming	39	65
Market woman/Trading	13	21.66
Hairdressing	3	5
Seamstress	4	6.67
Corn milling	1	1.67
Total	*60*	*100*

mixture was incubated at room temperature in the dark for 60 min and the absorbence was measured at 517 nm. A blank sample containing only methanol was used to zero the spectrophotometer (Shimadzu 1201, Japan). Ascorbic acid was used (as positive control) for comparison. Each experiment was performed in triplicate.

Data analysis

Data entry and analysis were done using Statistical Package for Social Sciences (SPSS version 26.0). Frequencies and percentages were generated for the variables assessed. Mean values for analytical parameters determined were presented either as mean±*S*.D. or plotted in graphs with error bars.

Results and discussion

Demographics of respondents

Sixty participants were involved in the focus group discussion, drawn from Busunya, Boabeng Fiema, Akrudwa No.1. and Akrudwa No.2. The participants were made up of 93.33% women and 6.67% males (Table 1). This observation correlates with a report from Avocèvou-Ayisso [7] stating that *Pentadesma butyracea* butter is processed by women in the various processing communities [7]. These women have in-depth knowledge of *P. butyracea* and butter processing from the plant's seeds.

The age range of the participants was fairly distributed amongst the various age brackets. The highest age bracket for the focus group discussion was 36–45 years, with a percentage of 26.67%. The age brackets indicate that the youth are knowledgeable about *Pentadesma butyracea*. The knowledge is acquired from the oral tradition and through the work or support they offer to their mothers while processing the seeds into butter for cooking. Most participants were farmers, with 65% indicating familiarity with the plant and 21.66% traders or market women. Hairdressers made 5%, dressmakers 6.67%, and 1.67% corn mill attendants. The varied occupation of the participants confirms how well *Pentadesma butyracea* is known amongst the inhabitants of the communities.

Indigenous knowledge, therapeutic and socio-economic uses of Pentadesma butyracea

The indigenes in the various communities expressed their thoughts on *Pentadesma butyracea*. Locally, the plant is called" Paa" or "Agya Paa". Badoussi et al. [37], stated that different sociocultural groups have different local names for *P. butyracea* and its various parts (tree, kernels, and fruits). These names may cover useful information. For example, the local name "soiluku" given to the *P. butyracea* tree by the Boo socio-cultural group in Benin means 'shea tree of the river' indicating its similarity to the shea tree and habitat. The Otamari socio-cultural group in Benin calls the *P. butyracea* kernel "Yêkotchêpouo" which means 'hard kernels like coconuts', which probably shows not only the hardness of the kernels but also the phenotypic characteristics of the resource. The name "Agya Paa" given to the tree by the Bono people may indicate the mighty nature of the tree.

The plant is known to the communities right from birth. A tall forest tree about 30 metres tall bears an ellipsoidal berry with a yellow pulp and some embedded kernels. The seeds are very similar to kola. Sinsin and Sinadouwirou [15], stated that the fresh kernels of *P. butyracea*, are consumed like kola. The plant takes about 7 to 8 years to reach maturity. Adomako [25], detailed that *P. butyracea* can be cultivated from the seeds, growing up to 30 m high, and under natural conditions reaching

maturity between 7 and 8 years. *Pentadesma butyracea* flowers around November and fruits are harvested between March and June. In Gabon, *P. butyracea* flowers from March to September and fruits are produced from October to December. In Benin, harvesting of *P. butyracea* occurs in April to June [38]. It has a similar season to mangoes and 'dawadawa' (*Parkia biglobosa;* African locust bean). The communities observe a discontinuous harvesting pattern. Usually, a plentiful harvest is followed by a meagre harvest in the following season. The fruits fall to the ground when fully ripe and are handpicked. Handpicked seeds are well-dried and either kept in cane baskets or jute bags or spread on the kitchen floor for storage. Well-dried seeds can be stored for over a year and yield butter of good eating quality. Ayegnon et al. [39], produced *P. butyracea* butter of acceptable quality using *P. butyracea* seeds that has been stored for 12 months.

The seeds are essentially used in producing plant butter. The butter is yellow and smells just like shea butter. Butter from the seeds is used in frying and cooking in various communities. Traditionally it is used in preparing meals like "nkeiseinke-sei" (traditional bean delicacy)," abom," which is a sauce, and for frying fish. In conventional medicine, the butter is applied to wounded skin and boils for healing. One of the key informants who happened to be an exporter of the butter stated that the butter is a potent scar remover, tightens the skin, and serves as an anti-ageing cream. The tree bark is pounded, boiled with salt, and drunk to alleviate stomach ulcers and improve appetite in nursing mothers. A concoction of the roots is used in fighting malaria and serves as an analgesic. Stems of the tree are also used in building and roofing. *P. butyracea* has versatile uses for seeds, leaves, flowers, bark, and roots. These organs are used extensively in food, traditional medicine, and therapeutic, and cosmetic purposes [39]. The butter of *P. butyracea* is used as a massage oil, in skin and hair care, and in the soap manufacturing because it possesses softening, lubricating and healing qualities [40]. The butter of *P. butyracea* was used to retard the ageing of skin in patented cosmetic preparation [41]. The respondents believe the butter can be used for processes like breadmaking, pastries, and body creams, which could help improve their livelihoods.

Traditional processing of P. butyracea *seeds into butter*

According to the community folks interviewed, the butter processing of *P. butyracea* seeds involves the pretreatment and extraction stages. Depulping of the seeds is the first step in butter processing. The seeds are depulped from the ripened *P. butyracea* fruits that fall to the ground. The fallen fruits go through natural fermentation, which makes seed removal from the fruits easy. In Northern Benin, seed depulping of *P. butyracea* goes through a similar process. The fallen fruits are either made to undergo natural fermentation and the seeds removed, or the ripened fruits are cracked with a stone to remove the seeds [37]. After depulping, the seeds are pre-treated. The pre-treatment involves sun drying the seeds to reduce the moisture content. The sun drying can last up to a month, depending on the weather, according to the indigenes. In Northern Benin, 3 major pre-treatments are done in processing *P. butyracea* butter. First, the seeds are boiled for 1 to 2 h and sun-dried for 14 days to 1 month. The second method involves sun drying the seeds between 4 and 14 days, whiles with the last method, the seeds are smoked in a traditional oven for 36 to 48 h [37].

Extraction of *P. butyracea* butter consists of heating, crushing, milling, kneading and churning, decanting, boiling, cooling, and filtration. In Ghana, we found that *P.butyracea* seeds are either roasted whole before cracking or cracked into pieces before roasting. Roasting becomes complete when seeds break easily upon cracking with mortar and pestle, or a stone. The cracking is to reduce the sizes of the seeds for finer milling. In Northern Benin, heating is done by roasting or frying the *P. butyracea* seeds [37].

The roasted seeds are milled using an attrition mill (corn mill) to obtain *Pentadesma butyracea* seed paste or slurry. The slurry is taken through the kneading and churning procedures. In these processes, hot water of about 85 °C is added to the slurry. It is then kneaded and churned by hand. Water at room temperature is added as the kneading and churning occur. The process continues until the surface of the mixture is filled with creamy droplets starting from the sides of the mixing bowl. Water at room temperature is again added, and the droplets float on the surface. The floating droplets are collected and washed severally into a saucepan. It is then boiled, cooled to room temperature, and filtered through 8 layers of white polyester material lining a funnel to obtain the *Pentadesma butyracea* fat. In Northern Benin, churning is done by kneading and adding hot water without cooking or by adding cold water followed by cooking [37].

In Ghana, we identified variations in the slurry processing before kneading and churning: some processors add salt to the slurry before the kneading and churning procedures, whiles other processors mix the *P. butyracea* paste with water into a dough and allow it to ferment overnight with or without salt. Some processors believe that adding salt to *P. butyracea* butter extraction reduces the yield of the butter. Other processors also believe that adding salt to the butter extraction process improves the quality of the butter. The women processors combine any pre-treatment, heating, and churning and kneading methods for butter extraction, depending on the know-how of the processor. Badoussi et al. [37], also commented that processors combine any of the pre-treatment, heating and churning procedures for *P. butyracea* butter extraction based on the know-how of the processors.

Nutritional composition of Pentadesma butyracea *seeds*

Proximate composition

Table 2 shows the moisture content of *Pentadesma butyracea* seeds on a wet matter basis. The moisture content was 7.39%, which falls in the range of legumes with moisture contents of between 7.0 and 11.0% [42,43]. Food moisture content is an index of a food's water activity and indicates the susceptibility and stability of the food to microbial spoilage and

Table 2
Proximate composition and Energy of *Pentadesma butyracea* seeds.

Parameter	*Mean Value ± Standard Deviation*
Moisture (%)	7.39 ± 0.093
Ash (%)	1.81 ± 0.025
Protein (%)	2.68 ± 0.036
Fat (%)	35.82 ± 0.060
Crude fibre (%)	1.34 ± 0.112
Carbohydrate (%)	50.97 ± 0.299
Energy (Kcal/100 g)	536.79 ± 0.293

insect infestations [44]. It is reported that dried seeds with moisture content lower than 8% have longer storage potentials [45,46]. The moisture content of sun-dried *Pentadesma butyracea* has been reported to be 7.41% which agrees with the value obtained in this study [47]. Low moisture content shows *Pentadesma butyracea* is high in dry matter and highly likely that seeds will have reduced algae and fungal growth and other microbial activities and prevent oxidation–reduction reactions [44].

Ash measures the total mineral content of a sample. Ash content of 1.83% was obtained for the *Pentadesma butyracea* seeds (Table 2). The low ash content of *Pentadesma butyracea* seeds shows it is low in mineral composition. Similar results have been reported for the ash content of *P. butyracea* seeds (1.82%) by Kouadio et al. [48] and in allanblackia seeds (1.98%) by Adubofuor [49]. Ash contents of 4.26%, 3.71%, and 3.93 also have been reported for sun-dried, roasted, and sundried, and in boiled and sundried *Pentadesma butyracea* seeds, respectively [47]. Defatted *Pentadesma butyracea* seeds have a reported ash content of 4.1% [50]. Variation in the value obtained relative to the reported ash figures may be due to varietal differences and the effect of geographical location [49,48].

Proteins are large complex molecules composed of various amino acids. Proteins play critical roles in cellular functions, structure, and regulations of metabolic activities in all living organisms [51]. Proteins are needed to repair worn-out tissues and are used as an alternative energy source in the absence of carbohydrates and fat [52]. *Pentadesma butyracea* seeds had a protein content of 2.680%. The protein content of 7.3% was recorded on a defatted sample of *Pentadesma butyracea* [50]. Oilseeds like shea, cocoa, and *Allanblackia* have protein contents of 7.7%, 13%, and 4.27%, respectively, on a dry weight basis [49]. Garcinia Cola (Bitter Cola) and *Aframomum melegueta* (Alligator pepper) have protein contents of 2.48% and 2.60%, respectively, on a dry weight basis [53]. *Pentadesma butyracea* has a relatively low protein content and may not be considered a good protein source for humans and animals.

Pentadesma butyracea is an oil-rich seed. The fat is solid at room temperature. The fat content of *Pentadesma butyracea* in this study was 35.82%. This agrees with work done by William (1950), which stated the fat content of *P. butyracea* to be 35–54%. However, other researchers have reported ranges of 41.9 to 53% [15,25,40,48,54]. These differences in fat content may be due to ecological factors. Adubofour et al. [49] reported 67.59%, 58%, and 31.7% as fat levels for allanblackia, cocoa, and shea butter, respectively.

A crude fibre value of 1.34% indicates that *Pentadesma butyracea* is low in fibre. Fibre helps in digestion by providing roughage. It is used as an index of poultry and stock feeding [55]. Crude fibre values of 5.7%, 6.2%, and 10% have been reported for Allanblackia, shea, and cocoa, respectively [49]. The lower crude fibre values of 1.26, 1.14, and 1.13 have been reported respectively for sun-dried only; boiled & sun-dried; and roasted & sun-dried *Pentadesma butyracea* seeds [47]. Other nuts have been reported to provide carbohydrates. Adubofuor et al. [49] reported carbohydrate levels of 46.6%, 11%, and 17.06% for Shea, cocoa, and allanblackia, respectively.

Carbohydrate provides energy to the cells, brain, muscles, and blood. Carbohydrates contribute to fat metabolism, sparing protein as an energy source, and are the raw material for many industries [51]. *Pentadesma butyracea* is a good source of carbohydrate and energy, 50.97% and 536.79 KJ/100 g, respectively. The carbohydrate content of shea is reported to be 46.6%, cocoa 11%, and Allanblackia 17.06% [49].

Mineral composition of Pentadesma butyracea *seeds*

Minerals are vital for their pro-oxidant and health benefits [56]. Malnutrition is inextricably linked to micronutrient status of an individual. Thus attempting to improve protein-energy status, without addressing micronutrient deficiencies will not result in optimal growth and function [57]. *Pentadesma butyracea* seeds contain both macro and microelements in various amounts. Minerals are required in relatively small quantities, between 1 and 2500 mg per day [58,59]. Macro and microelements are needed as they play essential roles in bone formation, neurotransmissions, and the maintenance of general health [60]. The mineral composition is affected by ecological and climatic factors [45,61]. The mean mineral levels of *P. butyracea* seed are shown in Fig. 2.

Potassium was the element with the highest concentration of 32.93 mg/100 g in *P. butyracea* seeds. This trend agrees with the work done by Aissi et al. [47]. They reported potassium as the highest mineral in sun-dried, boiled and sun-dried, roasted, and sun-dried *Pentadesma butyracea* seeds. The recommended minimum daily potassium intake is 2 g [62]. *Pentadesma butyracea* seeds have high potassium compared to Allanblackia, 8.41 mg/100 g and 1.55 mg/100 g [50,63]. Differences in the potassium amounts could be due to climatic and soil nature. Sodium is needed for maintaining a proper

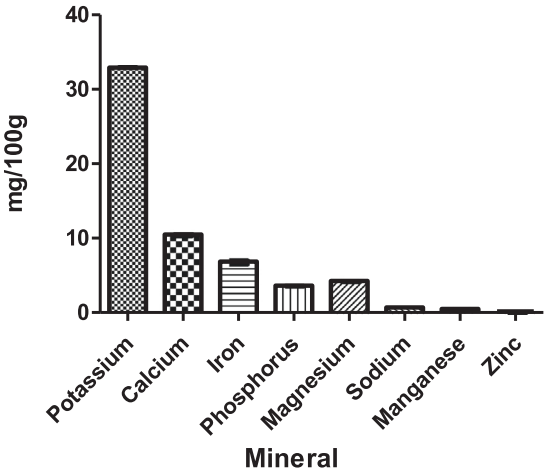

Fig. 2. Mean ($n = 3$) Mineral composition of *Pentadesma butyracea* seeds.

balance of water, body fluid, and blood pH. It is essential for nerve transmissions and muscle contractions [64]. *Pentadesma butyracea* in this study contained 0.7 mg/100 g of sodium. Allanblackia and shea have 5.24 mg/100 g and 12.17 mg/100 g, respectively [49]. The ratio of sodium to potassium in this study is 0.021, which is less than 1. Diets high in potassium and low in sodium encourage lower blood pressure [65]. Also, the low sodium content observed agrees with the generally low sodium encountered in unprocessed foods [66].

Iron is essential for oxygen transport, cellular growth, and division processes and vital to producing neurotransmitters required for healthy immune systems. Iron is also needed to transfer electrons in the electron transport chain to form ATP [67]. The amount of iron was 6.86 mg/100 g which is lower than the recommended daily intake (RDI) of 10 mg/100 g for males and 19 mg/100 g for females [68].

Manganese is needed for the metabolism of carbohydrates, fats, and proteins. It is also essential for brain and nerve nourishment. Manganese in *P. butyracea* was very low, 0.490 mg/100 g, compared to that of shea, 4.15 mg/100 g but higher than Allanblackia, 0.13 mg/100 g [49]. The daily recommended intake for an adult male is 2.3 mg/100 g and 1.8 mg/100 g for females [69]. The concentration in the seed kernels was lower than the recommended daily intake of 2 to 5 mg, making the seeds poor sources of manganese [60].

Magnesium is essential to many cell functions. It is needed for energy production, growth, repair, and nerve and muscle function [70]. The RDIs for males, females, and children between the ages of 1 and 3, are 400 mg, 310 mg, and 80 mg per day [71]. The magnesium content in *Pentadesma butyracea* of 4.26 mg/100 g is below the RDI. From his work on defatted kernels of *P. butyracea*, Tchobo [50] reported a magnesium value of 0.35%, which is 350 mg/100 g. which is higher than that reported in the present study. The difference in the values may be attributed to the ecological factors, treatment methods, and storage conditions before analysis [63]. Phosphorus is vital in metabolic processes, membrane structure, and the production of ATP [72]. In balance with calcium, phosphorus is needed for teeth and bone building. The RDI for phosphorus is 700 mg for male adults [73]. The phosphorus content of *P. butyracea* is 3.63 mg/100 g and is lower than that of Allanblackia, which is 8.84 mg/100 g [49]. Defatted kernels of *P. butyracea* contain 0.21% (210 mg/100 g) of phosphorus [50]. The variation may be due to the source of the seeds and treatment methods employed before analysis.

Pentadesma butyracea contains 5.24 mg/100 g of calcium, which is very low compared to the RDI for adults 19 years of age and above, which is between 1000 and 1300 mg per day [74]. Defatted kernels of *P. butyracea* contained 0.14% (140 mg/100 g) of calcium [50]. Ecological factors and pretreatment methods could account for differences in calcium values [63]. Calcium is vital for teeth and bone formation, heart function, blood coagulation, and muscle contraction [75]. Allanblackia and shea both contain lower concentrations of calcium than *P. butyracea*. Their values are 0.10 mg/100 g and 0.28 mg/100 g respectively [49]. The amount of zinc in *Pentadesma butyracea* is very low, 0.135 mg/100 g. Zinc is a key component in the synthesis, storage and release of insulin. It aids in wound healing, sexual development, and tissue repair [76]. Generally, it can be observed from the results of the study that some of the mineral elements have low levels relative to findings from other studies as carried out by Tchobo [50] and Adubofour et al. [49]. The variations in values relative to the other studies also indicate that the source of *P. butyracea*, the ecological conditions, post-production practices, and the pre-treatment methods before analysis affect the mineral content [63].

Antinutritional factors in Pentadesma butyracea *seeds*

Seeds of *P. butyracea* contain tannins, oxalates, saponins, and alkaloids in varying amounts. Oxalate is found to be in the highest concentration, followed by tannins, saponins, and then alkaloids. Dietary anti-nutritional constituents are known to negatively influence protein digestibility, the bioavailability of amino acids, and foods' protein quality [77,78].

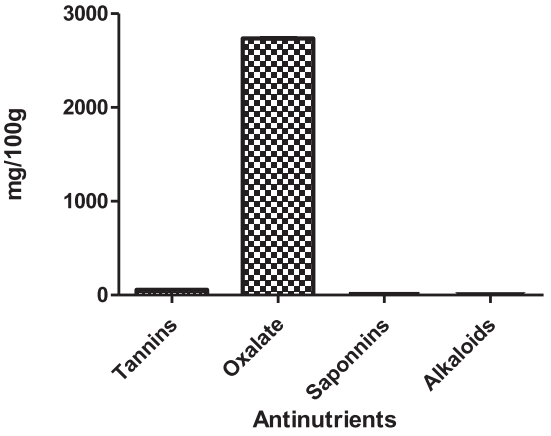

Fig. 3. Mean ($n = 2$) antinutrient levels in *P. butyracea* seeds.

The tannin content of 55.44 mg/100 g for *Pentadesma butyracea* was high compared to the tannin content of shea kernel 14.03 mg/100 g and 5.46 mg/100 g for shea pulp. Tchobo et al. [50] reported the tannin content of *P. butyracea* seeds to be 1.06% (1060 mg/100 g), which is higher than that recorded in the present study. Higher tannin levels have been recorded for moringa leaves, 21.19% [79]. Tannins affect protein bioavailability, reducing protein and amino acid digestibility. Phenolic groups of tannins bind very tightly to proteins by forming hydrogen bonds with the -NH groups of peptides and these bonds cannot be cleaved by digestive enzymes; thus, leading to the reduction of amino acid bioavailability, as well as affecting the protein digestibility [80,81]. Furthermore, tannins are associated with bitterness and astringency, explaining the astringent taste of *Pentadesma butyracea* seeds. Tannins are characterised by properties that speed wound healing and inflamed mucous membrane. This explains the use of *Pentadesma butyracea* in treating wounds, burns, and haemorrhoids in traditional medicine [82,83]

Alkaloids in high concentrations are reported to adversely affect human physiological and neurological activities such as paralysis, rapid heartbeat, and even death. On the other hand, lower concentrations of alkaloids are beneficial for pharmacological applications for their bactericidal and analgesic effects [53,84]. It stimulates circulation and respiration, reduces blood pressure, and destroys cancer cells. Alkaloid levels of 0.38% and 1.13% have been reported for shea kernel and shea pulp, respectively, 9.6% (lima bean) and 8.6% for scarlet runner bean [85]. *Pentadesma butyracea* has an alkaloid content of 9.18 mg/100 g, as shown in Fig. 3, which depicts the antinutrient levels in *P. butyracea* seeds. *Pentadesma butyracea* seeds can be used to produce analgesics and antibacterials.

Saponins offer several biological importance, such as antidiabetic, anti-inflammatory, antiatherosclerotic, and protective functions like gastro-protective, hypolipidemic, and hepatoprotective activities [86]. On the other hand, dietary saponins are reported to undesirably affect protein digestibility by impeding various digestive enzymes like chymotrypsin and trypsin. This lessens nutrient utilisation and conversion effectiveness [87–89]. The amphiphilic nature of saponins makes them useful as a surface-active compound with wetting, emulsifying, and foaming properties and can be used in the cosmetic and beverage industry [90]. A 10.23 mg/100 g of saponin was recorded for *Pentadesma butyracea*, contributing to the bitter taste as saponins are characterised by bitterness. Other researchers have reported higher levels of saponins: *Phaseolus lunatus*, 3.2%; *Phaseolus coccineus,* 4.1%; and 8.15 for shea kernels [85,86].

Oxalates were the highest antinutrient found in *Pentadesma butyracea* seeds, with a 2737.42 mg/100 g oxalate concentration, high above the allowable value of 50 mg per day [85]. Higher oxalate values of 22,5740 mg/100 g have been reported for red kidney beans and 166,890 mg/100 g for black turtle beans [85]. Lower values of 649.00 and 221.50 mg/100 g have been reported for shea kernels and pulp, respectively [78,85].

Oxalates are chelating agents that can chelate toxic metals like lead and mercury and trap heavy metals making their elimination difficult in living organisms. Oxalates in the form of oxalic acid may form crystals with divalent cations, which may be excreted in urine as minute crystals. These crystals could damage tissues due to their physical structure and sharpness [86].

Iron oxalate crystals cause oxidative damage and reduce iron stores needed for red blood cell formation, whereas many kidney stones result from calcium crystals. These oxalates can form larger kidney stones that can hinder the kidney tubules. Higher oxalate levels in the human diet can increase the risk of renal calcium absorption [91,92]. On the other hand, oxalates are used in chelating shampoos to remove dirt build-up in the hair [93,94]. This suggests that *P. butyracea* seeds and pressed cakes may not be suitable for dietary and animal feed but could be useful in the cosmetic industries for chelating shampoos.

Antioxidant potential of Pentadesma butyracea *seeds*

Polyphenolic compounds are linked with antioxidant activities, which are vital in stabilising lipid peroxidation and possess scavenging capacities due to the hydroxyl groups [95]. Natural phenolics exhibit their antioxidant activities in processes

Table 3
Total phenolics, total flavonoid, and DPPH contents of *P. butyracea* seed (hydroethanolic extract).

Parameter	Mean value±SD; $n = 3$
Total Phenolic Content (mg GAE/gdw)	725.85 ± 0.26
Total Flavonoid Content (μg (QE)/gdw)	2313.15 ± 0.36
% DPPH Scavenging	82.02 ± 0.04

like preventing constant hydrogen abstraction from substances, breakdown of primary oxidation products, and interception of singlet oxygen [96,97]. Diets rich in phenolic compounds positively affect cancer prevention and retardation of atherosclerosis by reducing the risk of heart diseases due to their antioxidant activity [98,99]. The total phenolic content of *P. butyracea* was 725.85 mg GAE/gdw, shown in Table 3. This value is high compared to values reported by other works on *P. butyracea* kernel, 108.49 to 251.95 mg GAE/gdw, with an average value of 164.03 mg GAE/gdw [39].

The differences in the total phenolic values of *P. butyracea* kernels may be due to genotypical and geographical factors [100]. Raw cocoa beans are reported to have total phenolic content ranging from 76.14 mg GAE/gdw to 173.58 mgGAE/gdw [100]. Black rice has an entire phenolic content of 0.8–6.9 mgGAE/gdw and red onion of 15.56 mgGAE/gdw [101]. *P. butyracea,* with its high phenolic content, can be incorporated into diets for its beneficial antioxidant activities on human health.

Flavonoids are phenolic compounds with biological actions like anti-inflammatory, antiatherosclerotic, and antioxidative properties. The antioxidative properties of flavonoids are achieved through inhibiting enzymes liable for free radical generation, chelation of metal ions, and scavenging free radicals [102]. Flavonoids can scavenge active oxygen molecules, including hydrogen peroxide, peroxyl radicals, hydroxyl, singlet oxygen, and superoxide. They are also active scavengers of peroxynitrite, a highly reactive oxidant formed when superoxide reacts with nitric oxide [103]. The results showed that *P. butyracea* had a low flavonoid content of 2313.15 μg (QE)/gdw. Higher levels of flavonoids have been reported for Ajwain oilseed 5343.5 mg QE/100 g, 987.3 mg QE/100 g for mustard seed, 580.5 mg QE/100 g for fenugreek, and 676.3 mg QE/100 g for poppy seeds [104]. Stem barks of shea tree have a reported total flavonoid content of 3.98 mg QE)/gdw [105]. From this study, the concentration of flavonoids is lower than the concentration of total phenols in the seeds. Thus, it can be inferred that flavonoids may not be the major phenolic compounds in *P. butyracea* seeds. Total phenolics contribute to over 90% of the antioxidant activity of the extracts of various herbs [106,107], the relatively high content of total flavonoids and total phenolics makes *P. butyracea* a good source of natural, free radical scavengers.

Free radical scavenging activity is a means by which antioxidants impede lipid oxidation. The antioxidant capacity is linked with the actions of free radical scavenging enzymes (superoxide dismutase, catalase, peroxidase) and antioxidant substances like phenolic compounds, ascorbic acids, tocopherols, and carotenoids [96,108]. The antioxidant effect of phenolic acids is associated with the number and position of hydroxyl groups in the molecule; the higher the number of hydroxyl groups on the phenyl radical of an acid, the higher the antioxidant potential [109,110]. The DPPH percentage inhibition was 82.022% in this study, indicating *Pentadesma butyracea* seeds have the potential to scavenge free radicals. Lower DPPH inhibition values of 36.52 - 60.00% have been reported for *P. butyracea* seeds using methanolic extraction [39]. The differences in the DPPH inhibition could be attributed to the extraction medium used. Black rice is reported to have DPPH inhibition of 16.0 - 30.3% and red rice 13.0 - 62.8% [101]. The high percentage DPPH value could be attributed to the structural features of the phenols present, ensuring maximum scavenging activity [103,111]. It is stated that the phenolic compounds of most oilseeds comprise phenolic acids, coumarins, flavonoids, and tannins [112].

Conclusion

The indigenous knowledge from the selected communities indicated that *Pentadesma butyracea* is used for butter processing, cooking, and traditional medicine. The study established that this indigenous knowledge was handed from generation to generation through oral tradition, especially from mothers to children, during the processing of the butter and the use of the plant in traditional medicine. Through this process, much of the indigenous knowledge of *P. butyracea* is preserved and transferred from generation to generation. *Pentadesma butyracea* was high in fats and low in protein and minerals, making it a potential oil crop to be harnessed. The anti-nutritional factors in *P. butyracea* seeds can affect the bioavailability of nutrients. Thus, its direct inclusion in both the human diet and animal feed may lead to some nutrient deficiencies. However, pre-treatment options may be considered in future studies for improving the nutritional and functional values of defatted *P. butyracea* seed meal for food/feed applications The low mineral content of the seeds makes them a poor source of micronutrients. Seeds of *Pentadesma butyracea* are rich sources of antioxidants. Its free radical scavenging activity, offering the seeds anti-inflammatory, anti-carcinogenic, and anti-atherosclerotic potential, may not be mainly due to flavonoids.

CRediT authorship contribution statement

J.A. Timtey: Conceptualization; Methodology; Funding; Resources; Investigation & Acquisition of data; Formal/Statistical Analysis & Interpretation of data; Writing – Original Draft Preparation. **F. Alemawor:** Conceptualization; Methodol-

ogy; Project Administration; Supervision; Formal/Statistical Analysis & Interpretation of data; Validation; Visualization; Writing – Original Draft Preparation; Writing – Review & Editing. **W.O. Ellis:** Supervision; Writing – Review & Editing. **N.B. Pepra-Ameyaw:** Writing – Review & Editing. **J.K. Agbenorhevi:** Supervision; Writing – Review & Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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