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Nutraceutical and functional food potential of African Elemi (*Canarium schweinfurthii*Engl) fruit pulp from Central Uganda

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Abstract

African elemi (*Canarium schweinfurthii* Engl.) is a native fruit tree species in the tropics that is regarded as underutilized. This study evaluated the nutritional composition, bioactive components, antioxidant activity, and aromatic components of ripe fruits of *C. schweinfurthii* from Central Uganda. Fruit pulp chemical characterization revealed pulp content, titrable acidity, and pH to be 55.5±2.4%, 0.693±0.03, and 5.74±0.01, respectively. The proximate, vitamin and mineral composition that exhibited high values based on their Recommended Dietary Allowance (RDA) above 20% were: total fat (37.5 g/100g, RDA 58%), dietary fibre (28.7mg/100g, RDA 114%), vitamin C (72mg/100g, RDA 121%), β-carotene (0.880±0.034 mg/100g, 704%), selenium (24 mg/100g, RDA 455%), potassium (753 mg/100g; RDA 22%), and magnesium (90.3 mg/100g, RDA 23%). The bioactive compounds: total flavonoids, total phenolic compounds, total anthocyanin pigments, and total antioxidant activity were 27.18±1.36 mg/100g Rutin Equivalent (RE), 807.20±7.21 mg/100g Garlic Acid Equivalent (GAE), 32.33±5.62mg/

100g pigment, and 8.19±0.00 IC_{50} mg/g Ascorbic Acid Equivalent (AAE), respectively. The GC-MS analysis of the pulp identified 27 volatile (aromatic) compounds with Terpinen-4-ol (18.242%), Beta.-Myrcene (11.073%), 2,4-Decadienal,(E,E)-(6.110%),9,12-Octadecadienoic acid, ethyl ester (5.948%), Cyclohexene,4-methylene-1-(1-methylethyl) (5.910%), D-Limonene (5.880%), Benzene, 4-ethyl-1,2-dimethyl-(4.353%),9-Octadecenoic acid (Z)-, methyl ester (3.968%), and L-.alpha.-Terpineol (3.755%) being the dominant compounds. The abundant micro- and macronutrients, as well as bioactive compounds indicate that *C. schweinfurthii* pulp can significantly contribute to the development of nutraceutical products, which warrant its on-farm domestication at a commercial level through vegetative propagation techniques. This is expected to replace the seeds that are destroyed during the parboiling of highly demanded fruits before eating.

Key words: Aromatics, indigenous fruit tree, minerals, phytochemicals, proximate, recommended dietary allowance, vitamins

Introduction

Wild edible fruits are important ingredients for ethnic people worldwide. In Sub-Saharan Africa, wild edible fruits have been incorporated into diets to solve some nutrition-related concerns (Bvenura and Sivakumar, 2017). According to Lal (2016), wild edible fruits are considered dietary and therapeutic solutions for many people who are currently undernourished and are suffering from non-communicable diseases. Indeed, most wild edible fruits are harvested and eaten either raw, cooked, or taken as medicine (Babikir and Ahmed, 2019).

African elemi or Bush candle tree (*Canarium schweinfurthii* Engl.) belongs to Burseraceae family and is a multipurpose tree that produces edible fruits. The tree occurs throughout fifteen countries in East, West, and Central Africa (Anozie and Oboho, 2022). In these countries, the tree is named differently by ethnic groups: *Abel* in Cameroon, *Aiele (*Ivory Coast), *Elemi*, *Atile* or *Odah* (Nigeria), *Bediwunua* or *Eyere* in Ghana (Omeje *et al*., 2022); *Muwafu, Mpafu, Mbafu, Mubafu, Mubani, Nyegye, Mubani,* and *Musanki* in Uganda (Katende *et al*., 1995). Since its fruits are similar in physical shape and black colour to olives from the Mediterranean, *C. schweinfurthii* fruits are also referred to as Schweinfurthii's olives (Nyam *et al*., 2018).

According to Anozie and Oboho (2022), *C. schweinfurthii* tree can grow up to 36-50 m in height with its crown reaching the upper canopy of the forest. The diameter above the heavy root swelling can be up to 4.5 m with branching that begins at 7 m or more (Dawang *et al.*, 2016). The bark has a grey colour. The leaves are pinnate and clustered at the branches (Edou-Engonga *et al*., 2012; Fig. 1). The flowers are

Figure 1. *C. schweinfurthii* fruit tree on a farm with a branch showing maturing green fruits and pinnate leaves.

creamy white, producing ellipsoidal or ovoid greenish fruits when unripe and bluish-purple when ripe (Ehwarieme, 2022; Grant *et al.,* 2024; Fig. 1).

The *C. schweinfurthii* fruits are usually gathered from the wild for eating after parboiling in lukewarm water (at 45 °C) to soften them and improve their palatability. The fruit can also be sold to supplement household income (Dawang *et al*., 2016). According to Olawale (2012), the fruit pulp of *C. schweinfurthii* contains both macronutrients and micronutrients, including trace elements like copper, manganese, iron, and zinc (Tabula *et al.,* 2024). Due to the presence of these nutrients, its fruits can be used in food formulations (Ehwarieme, 2022). The mesocarp has the potential for use in the prevention of diseases, like cancers and oxidative damage-induced diseases (Tcheghebe *et al*., 2016).

Besides food, *C. schweinfurthii* tree is used in folk medicine (Odukoya *et al*., 2022). While the stem bark decoction is used to treat colic, cough, chest pain, venereal diseases, lung and stomach disorders, the leaves of the tree can be used as a stimulant and medicine against fever, constipation, malaria, diarrhea, and sexually transmitted infections (Tcheghebe *et al*., 2016; Tabula *et al*., 2024). Its resin can be used for treating wounds and microbial infections (Edou-Engonga *et al*., 2012).

Phytochemical analyses of the stem bark, leaves, fruit mesocarp and seed of *C. schweinfurthii* revealed the presence of several bioactive compounds with antimicrobial, antioxidant, anti-inflammatory, and antitumor activities (Ehwarieme, 2022). Even then, analyses of nutritional composition, phytochemical and pharmacological properties of *C. schweinfurthii* fruits/kernels in the last decade have focused on samples from West African countries like Cameroon, Nigeria and Ghana (Olaniyi *et al.,* 2018; Tcheghebe *et al*., 2016). In Uganda, Tabula *et al*. (2024) reported zero to very low cytotoxicity in human colon (Caco-2) cell lines treated with 1:50, 1:100, 1:200 and 1:1000 of *C. schweinfurthii* fruit pulp extract. Whereas variation in proximate composition and phytochemical properties of fruits, including those of the *C. schweinfurthii* has been reported in other countries (Olaniyi *et al*., 2018; Ringgit *et al*., 2024), nothing comparable has been reported for *C. schweinfurthii* in Uganda. Previous studies have reported on the nutritional composition, bioactive components, and antioxidant activity of selected Ugandan fruits, including *C. schweinfurthii* fruit (Stangeland *et al.,* 2009; Omujal, 2018). Tabula *et al.* (2024) also reported on the ethnobotany, total polyphenol content, and cytotoxicity of *C. schweinfurthii* fruit extracts.

However, information on the proximate composition, including the Recommended Dietary Allowance (RDA) of the nutrients and minerals, as well as the phytochemical properties of *C. schweinfurthii* fruit pulp, is scarce in Uganda. Thus, assembling data on these key aspects would enhance the economic and nutritional potential of this indigenous fruit tree. Therefore, this study had the aim of determining the proximate composition and phytochemical properties of *C. schweinfurthii* fruit pulp from Central Uganda.

Materials and methods

The study area

This study was conducted in Buikwe sub-county and Wakisi Division of Buikwe District. Buikwe is one of the Lake Victoria Basin (LVB) districts located in the Central Region of Uganda (Fig. 2). It lies 0°20’59.99" N 33°01’60.00" E. The district is characterized by a mixed landscape of both flat and sloping land with a vegetation that varies from dense forests to scattered trees and grasslands. Other trees common in this area are *Pseudospondias microcarpa*, *Mitrogyra* spp, and *Ficus* spp. Its soils are ferralitic/ferrisols. The area is about 1000-1300m above sea level with a mean annual rainfall of 11,000 mm, and a temperature ranging between 16 °C to 28 °C throughout the year. The district has a total land area of about 1209 Km^2 (BDSA, 2016).

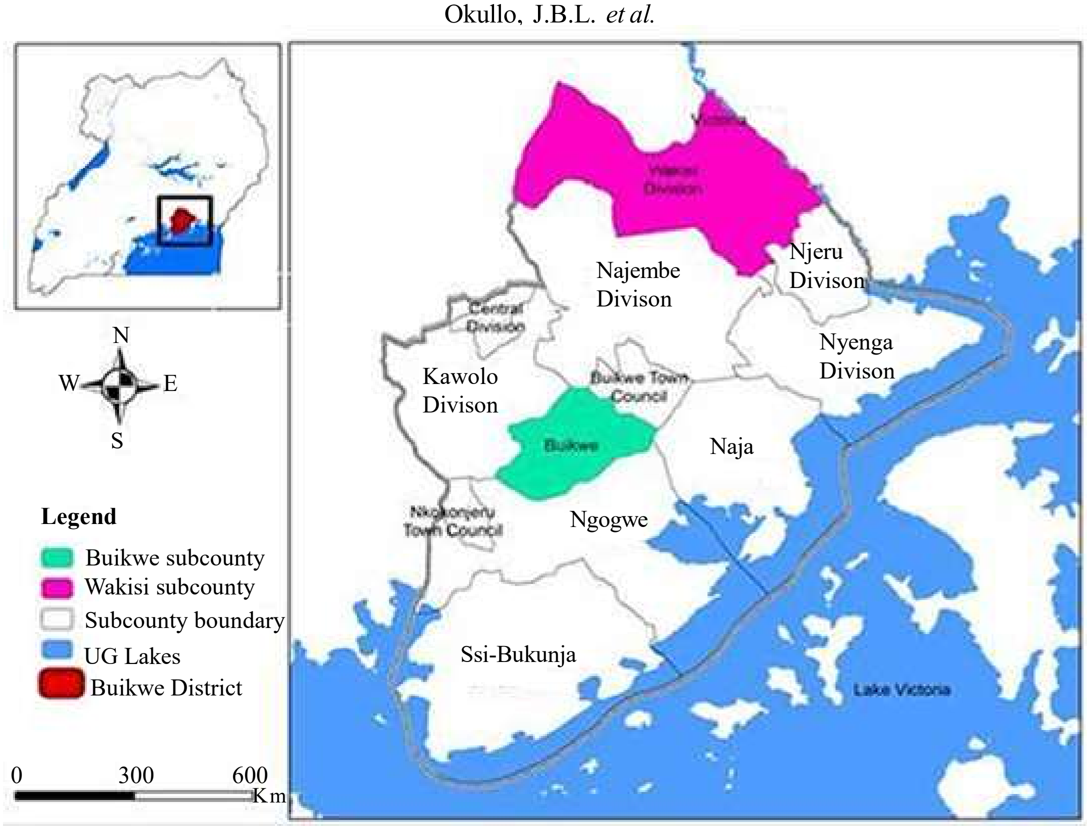

Figure 2. Buikwe district in Uganda showing the Sub counties used for samples collection.

Sampling techniques, sample collection and preparation

Both purposive and simple random sampling techniques were used in selecting trees in Buikwe Sub county and Wakisi Division. Five fruiting trees (Fig. 1) were purposively sampled in each Sub-county based on their abundance . The sampled fruiting trees were then tagged and mapped using GPS coordinates. Contact farmers selected from among community members in the respective sub-counties were assigned to monitor the ripening of *C. schweinfurthii* fruits. The contact farmers were trained to monitor the marked *C. schweinfurthii* trees every week until ripe fruits were seen on and harvested.

From each tree, 10kg of ripe fruits were manually harvested. Thereafter, 100 fruits were randomly selected from each tree, pooled, and mixed as a composite sample for the five trees. The samples were kept in a respective cool box containing a separate clean bag (Chew *at al*., 2011) and transported to a laboratory at Makerere University. In the laboratory, the fruits were washed with clean tap water to remove dust and stored at -4 ^{o}C in a cold freezer **(**Okalebo *et al*., 2002).

The average weight of the harvested fruits were determined by weighing 100 randomly sampled fruits using an analytical weighing balance. The fruits were then soaked in warm water at a temperature of 45 ^{o}C for 30 minutes to soften the pulp. The soft fruits were depulped manually, and the pulp weight was determined. The weighted pulp was then pounded into paste (Wahab *et al*., 2015).

The percentage weight of the pulp was determined by the formula in equation (1):

$$\text{Percentage weight or pulp (\%)} = \frac{\text{Weight of pulp}}{\text{Total weight of fruit}} \times 100 \quad \text{.......................... (1)}$$

Determination of the chemical characteristics of extracted fruit pulp

The pH and Titratable acidity (TA) of the pulp were determined using standard methods (AOAC, 2005). A digital pH meter (model Hanner) was used to determine the pH. Titratable acidity (TA) was measured by weighing 10g of the pulp and mixing 60 ml of de-ionized distilled water. Three drops of phenolphthalein indicator were added and then titrated using 0.1 N NaOH until the colour changed to pink (pH=8.1). The volume of the NaOH added to the solution was multiplied by a correction factor of 0.007 to estimate titrable acidity as a percentage of citric acid using the formula in equation (2):

$$\text{Percentage acid} = \frac{\text{Titre x Acid factor}}{\text{10 ml (pulp)}} \times 100 \quad \text{.. (2)}$$

Analysis of fruit pulp nutritional composition

The nutritional composition was assessed for proximate, mineral, and vitamin composition. The proximate parameters of the fruit pulp (moisture content, crude protein, crude fat, crude oil, dietary fibre, total carbohydrates, total ash, and energy) were determined using standard methods (AOAC, 2005). While moisture content was determined using blended-fresh pulp in the oven method at 105 °C (Okullo *et al.* 2010), the other proximate parameters were determined using dry fruit pulp produced by drying the fresh pulp paste in an oven at 40-50^{o}C °C for 72 hours. Fresh pulp was used to determine Vitamin C and Beta-carotene (expressed as mg/100g) using the 2, 6 dichlorophenolindophenol method (Okullo *et al*., 2010), spectrophotometrically with HPLC (Sari and Sari, 2022), respectively.

Mineral composition (Na, K, Ca, P, Mg, Zn, Fe, and Se) of the dry fruit pulp was assessed using an Atomic Absorption Spectrophotometer (AAS), model Shimatzu AA-63000 (Okullo *et al.,* 2010). Two grams (2 g) of dry pulp was weighed and digested in a mixture of 5 ml de-ionized distilled water and 20 ml concentrated nitric acid at a temperature of between 180 °C and 220 °C in a digester for 2 hours. The mixture was allowed to cool, 10 ml of concentrated perchloric acid was added, and heated at the same temperature for 1 hour. The mixture was then cooled, filtered, and 2 ml of concentrated HCl added. The solution was diluted to 100 ml with de-ionized distilled water and analyzed using AAS. A calibration curve was prepared for each mineral using its respective reference standard (AOAC, 2005).

Analysis of the bioactive component of the C. schweinfurthii pulp

The dry fruit pulp was extracted with respective solvents and analyzed qualitatively for the presence of reducing compounds, saponins, tannins, sterols, triterpenes, flavonoids, anthracenoicides, and alkaloids using standard methods (Ogwang *et al.,* 2011). Another portion of the dry fruit pulp was analyzed for total phenolic compounds, total flavonoids, and total anthocyanins using spectroscopic quantitative analysis.

Analysis of total phenolic compounds

Total phenolic compounds values were determined using Folin– Folin-Folin-Ciocalteu reagent standard method with some modifications and expressed as mg Gallic Acid Equivalents (GAE) g^{-1} of dry fruit weight (Premathilaka and Silva, 2016).

A total of 100 mg of fruit was introduced into test tubes, and 10 ml of 50% methanol was added into two portions of 5 ml each. The sample was extracted by manual shaking for 30 minutes and 40 minutes, respectively. The extract was kept at -20 ^oC for 10 minutes and thereafter centrifuged at 300 rpm for 10 minutes. The extracts were decanted into a test tube containing 5.0 ml of Folin-Ciocalteu reagent (2N) and diluted with 5 ml of distilled water. After which 0.1 ml of each sample was diluted with 0.4 ml distilled water and 0.25 ml Folin–Ciocalteu reagent. To each sample, 1.25 ml of 20% sodium carbonate was added and shaken with the help of a vortex. The tubes were vortexed for 15 minutes and then allowed to stand for 35 minutes (Dehbi *et al.,* 2013).

The absorbance was measured at 725 nm (Genesys 10 UV spectrophotometer, model 2G21144001, Thermo Electron Corporation, Cambridge, United Kingdom). Different concentrations of garlic acid (0.001-0.0060 mg ml^{-1}) were prepared in methanol for the preparation of a standard curve with equation (3)

$$\textit{Absorbance (y)} = 68.62 \text{ Concentration of garlic acid } \textit{(x)} - 0.0024,\ R^2 = 0.9983 \ .... \quad (3)$$

Analysis of total flavonoids

Total flavonoids were determined spectrophotometrically using a method reported by Borkataky *et al.* (2013). In this method, 2 ml of the fruit pulp methanol extract sample was poured into test tubes, and equal volume (2 ml) of 2% $AlCl_3$ ethanol solution added to each. The solution was incubated at room temperature for 1 hour, and the absorbance was measured at 420 nm using Genesys 10 UV spectrophotometer, model 2G21144001. A yellow color indicated the presence of flavonoids. Total flavonoids were quantified based on a rutin compound calibration curve (Bhagat *et al.,* 2021).

A calibration curve was prepared from concentrations of 0.01-0.08 mg/ml using the equation (4)

$$\textit{Absorbance (y)} = 7.782 \text{ Concentration of rutin } \textit{(x)} - 0.003,\ R^2 = 0.999 \quad \text{.........} \quad (4)$$

Analysis of total anthocyanins

Total anthocyanins were extracted from 1 g of fruit pulp using 30 mL of 95% ethanol/ 1.5 M HCl (85:15, v:v) stored at 4 °C overnight to allow for complete extraction of pigments from the cells (Moo-Huchin *et al.*, 2015). The extracts were centrifuged, decanted, transferred to a 50 mL volumetric flask, and topped up with 95% ethanol/ 1.5 M HCl. Since fruits contain a few compounds that absorb energy in the anthocyanin range of 500 to 535, the absorbance for the samples was measured at 535 nm using Genesys 10 UV spectrophotometer, model 2G21144001 (Omujal *et al*., 2020).

The total anthocyanin content was determined by applying the Lambert–Beer law, calculated as mg/100 g of fresh weight, through the formula in equation (5):

$$\text{Total anthocyanin} = \frac{\text{a x 50}}{98.2 \text{ mg/g}} \quad \text{...} \quad (5)$$

Sample size: 1.0 g; original fruit extract = 50 ml and absorbance measurement at 535 nm = a

A_{535}: a dilution factor/E1%1cm; 535 A_{535} is the absorbance in the diluted sample, and E 1%1cm; 535 is the value factor (98.2) of molar absorptivity of cyanidin-3-glucoside, a common anthocyanin found in many fruits and vegetables (Francis, 1982).

Analysis of volatile compounds using GC-MS

Following Gillij *et al*. (2008), 100 g of fresh pulp was mixed with 500 ml of distilled water and extracted by hydro-distillation in a Clevenger-type apparatus for 4 Hr. The distillate obtained (50 ml) was extracted with n-hexane (10 ml each) twice in a separating funnel. The organic layer dried over anhydrous sodium sulphate was then analyzed with a Gas Chromatography-Mass Spectrometry (GC-MS), Shimadzu, model TQ 8040 triple quadruplets. One micro-litre of the mixed organic extracts was injected split-less in GC-MS with the column (ZB-5SMi, 30 m x 0.25 mm x 0.25 μm).

The helium mobile phase was set at an average linear velocity of 44.5 cm/sec and prime pressure of 500-900. The injector and detector temperatures were set at 260 °C and 330 °C, respectively. The oven temperature was programmed as 90 °C for 4 minutes and then held for 20 minutes, followed by a temperature increase at 5 °C min/min to 180°C, that was held for another 5 minutes to 250 °C, and 15 minutes to 310 °C. The essential components were identified by comparing their mass spectra and retention times with the built-in National Institute of Standards and Technology (NIST) library in the GC-MS computer (Vallarino *et al.,* 2018).

Analysis of anti-oxidant activity

Anti-oxidant activity was determined by extracting the dry pulp sample with methanol, and 2,2-Diphenyl-1-1picrylhydrazyl (DPPH) free radical scavenging standards (Seal, 2012). In this method, aliquots (20 - 100 μl) of the tested sample were placed in test tubes, and 3.9 ml of freshly prepared DPPH solution (25 mg L^{-1}) in methanol was added in each test tube and mixed. Thirty minutes later, the absorbance was measured at 517 nm (UV-visible spectrophotometer).

Following Gulcin and Alwasel (2023), the capability to scavenge the DPPH radical was calculated, using the equation in formula (6):

$$\text{DPPH scavenged (\%)} = \frac{Ac - At}{Ac} \times 100 \quad \text{......} \quad (6)$$

Where: *Ac* is the absorbance of the control reaction, and *At* is the absorbance in the presence of the sample of the extracts.

The antioxidant activity of the extract was expressed as IC_{50}. The IC_{50} value was defined as the concentration in mg of dry material per ml (mg/ml) that inhibits the formation of DPPH radicals by 50%.

Each value was determined from the regression equation (7)

$$y = 10320x + 4.840,\ R^2 = 0.999 \quad \text{......} \quad (7)$$

Statistical analysis

The pulp nutritional and bioactive composition values were entered into Microsoft Excel (Microsoft Office 2024) to generate descriptive statistics expressed as means ± Standard Deviation (SD) of three replicates (Uzoekwe *et al*., 2021). The proximate and mineral contents per 100g of pulp were also calculated according to the Recommended Dietary Allowance (RDA), based on a 2,000-kcal/day diet (Wahal *et al*., 2015).

Results

Pulp yield, chemical characteristics, proximate and vitamin composition of the fruit pulp

The pulp yield of *C. schweinfurthii* was 55.46±3.19 % of the fruit weight. The chemical characteristics of *C. schweinfurthii* pulp, including TA and pH were 0.693±0.03 mg/100g and 5.74±0.01, respectively.

The proximate values for moisture content, crude proteins, dietary fibre, and crude fat were 44.39g/100g, 5.06g/100g, and 28.57g/100g, and 37.50g/100g, respectively. The dietary fibre and crude fat were exceptionally high. This is reflected by their 114% and 58% RDAs, respectively, when an individual consumes 100g of the fruit pulp (Table 1).

Table 1. Proximate and vitamin composition of *C. schweinfurthii* fruit pulp and % RDA contributions of each nutrient for an adult person of >30 years

Parameter (Proximate/ vitamin)	*C. schweinfurthii* pulp/100g	RDA for each nutrient based on a 2000 kcal diet*	RDA contribution of 100g of *C. schweinfurthii* fruit pulp for an adult person >30 years in a 2000 kcal diet (%)
Moisture content (g)	44.39±2.44	na	na
Total ash (g)	2.21±0.01	na	na
Crude protein (g)	5.06±0.42	50.0	10.0
Dietary fibre (g)	28.57±0.04	50.0	114.0
Crude fat (g)	37.50±0.71	65.0	58.0
Total Carbohydrates (g)	10.85±1.89	270.0	4.0
Energy (Kcal)	405.08±3.56	2000.0	20.0
Vitamin C (mg)	72.50±3.54	60.0	121.0
β-carotene (mg)	0.880±0.034	0.125	704.0

* based on Drewnowski *et al*., 2009; na = not applicable

The fruit pulp samples had a vitamin C content of 72.50mg/100g and an RDA over 100%. The β-carotene of the pulp samples was found to be 0.880mg/100g (RDA, seven-fold over 100%) based on 0.125mg daily consumption on a 2000 kcal/day diet (Table 1).

Mineral composition of C. schweinfurthii fruit pulp

The mineral composition values of the pulp were: Fe (2.32mg/100g), Cu (0.34mg/100g), and Zn (1.11mg/100g). The RDA contribution of the 100g dry pulp samples was highest for Se (455%), followed by magnesium (23%) and potassium (22%). The Na/K ratio of the fruit pulp was found to be 0.005 (Table 2).

Table 2. Mineral composition of *C. schweinfurthii* fruit pulp and % RDA contributions of each nutrient for an adult person of >30 years

Mineral	*C. schweinfurthii* pulp (mg/100g)	Standard RDA for each nutrient for an adult person >30 years (mg)*	RDA contribution of 100g of *C. schweinfurthii* fruit pulp for an adult person >30years(%)
Sodium	18.30±0.12	1800.0	1.0
Potassium	752.75±114.20	3400.0	22.0
Calcium	24.09±0.06	1200.0	2.0
Iron	2.32±0.24	18.0	13.0
Copper	0.34±0.05	2.0	17.0
Selenium	0.24±0.03	0.05	455.0
Zinc	1.11±0.15	15.0	7.0
Magnesium	90.34±1.13	400.0	23.0
Na/K ratio	0.005		

*Adapted from Wahab *et al.* (2015)

Bioactive components and antioxidant activity

Qualitative phytochemical ingredient screening of the *C. schweinfurthii* fruit pulp showed an abundance of tannins, reducing compounds, anthocyanins, and sterol & triterpenes. However, saponins were not detected in the fruit pulp of *C. schweinfurthii* (Table 3).

Quantitative analysis of Bioactive components in C. schweinfurthii fruit pulp

Total flavonoids, total phenolic compounds, total anthocyanins and total antioxidant activity in the fruit pulp were found to be 27.18mg/100g RE, 807.20mg/100g GAE, 32.33mg/100g pigment and 8.19(IC_{50} mg/g AAE), respectively (Table 4).

Volatile compounds in the fruit pulp

Analysis of aromatic compounds revealed *C. schweinfurthii* fruit pulp to have 27 components with Terpinen-4-ol constituting up to 18.24 % of the total area followed by β-myrcene (11.07%), 2,4-Decadienal,(E, E)- (6.11%), 9,12-Octadecadienoic acid, ethyl ester (5.95%), and Benzene, 4-ethyl-1,2-dimethyl- (4.35%), respectively (Table 5).

Table 3. Qualitative phytochemical ingredients in *C. schweinfurthii* fruit pulp

Phytochemical Ingredient	Test method	Result
Alkaloids	Mayer's reagent	(+)
Tannins	Iron III chloride	(++)
Reducing compounds	Fehling solution	(++)
Anthracoenosides	Ammonia solution	(++)
Saponins	Froth	(-)
Coumarins	UV light	(+)
Sterols and triterpenes	Libermann	(++)
Volatile oils	Steam distillation/ether	(+)
Steroid glycosides	Chloroform & sulphuric acid	++
Higher fatty acids	Ether extract	(+)
Anthocyanins	Ammonia solution	(+)
Flavonosides	Methanol & Mg ribbon	(++)

Note: The phytochemicals in the sample were represented as (-) Not detected (absent), (+) Slightly present, and (++) Present in abundance

Table 4. Bioactive components and antioxidant activity of *C. schweinfurthii* fruit

Parameter	Value
Total Flavonoids (mg/100g RE)	27.18±1.36
Total Phenolic compounds (mg/100g GAE)	807.20±7.21
Total Anthocyanins (mg/100g pigment)	32.33±5.62
Total antioxidant (IC_{50} mg/g AAE)	8.19±0.00

Discussion

Chemical characteristics

Results of the chemical characteristics, nutritional composition, and bioactive components of *C. schweinfurthii* fruit pulp indicate that the fruit pulp yield is high (55%), making the fruit suitable for food production of juices, jam, and wine (Omujal *et al*., 2023). The pH and titratable acidity characteristic values are also essential. For instance, pH (a measure of acidity or alkalinity) is useful in identifying the type of fruit, its edibility, and quality, in addition to supporting fruit preservation (Adumanya *et al.,* 2021). In this study, the pH (5.7) of *C. schweinfurthii* fruit showed a medium acidity, like other tropical fruits such as avocado with pH 6.3-6.6 (Shiferaw and Kibret, 2018) and pawpaw with pH 5.5 to 5.9 (Brannan, 2025). According to Ravisankar *et al.* (2016) and Langella *et al.* (2018), fruits with such medium acidity,

Table 5. Selected Volatile compounds in the *C. schweinfurthii* fruit pulp

RT	Compound name	CAS	Area	% Area
4.1226	Cyclohexene,4-methylene-1-(1-methylethyl)-	99-84-3	811650442.1	5.910
4.1881	Beta.-Myrcene	123-35-3	1520608365	11.073
4.4460	(+)-4-carene	29050-33-7	70717312.2	0.515
4.5130	Benzene, 4-ethyl-1,2-dimethyl-	934-80-5	597737062.7	4.353
4.5506	D-Limonene	5989-27-5	807446421.4	5.880
4.7973	.gamma.-Terpinene	99-85-4	283874806.5	2.067
5.0383	2-Carene	554-61-0	163629917.4	1.192
5.4626	Bicyclo[3.1.1]heptan-3-ol,6,6-dimethyl-2-methylene-, [1S-(1.alpha.,3.alpha.,5.alpha.)]-	547-61-5	232047838.8	1.690
5.6830	Bicyclo[3.1.0]hex-3-ene-2-one,4,6,6-trimethyl-,(1S)-	24545-81-1	143764065.7	1.047
5.7597	Terpinen-4-ol	562-74-3	2505208544	18.242
5.8400	L-.alpha.-Terpineol	1048-56-1	515644208.9	3.755
5.9017	.alpha.-Thujenal	576129-54-1	264979960.4	1.930
6.3689	Cis-p-mentha-1(7),8-dien-2-ol	1000374-16-8	85742135.9	0.624
6.8959	2,4-Decadienal,(E,E)-	25152-84-5	531167543.4	6.110
7.4257	Tricyclo[5.4.0.0(2,8)]undec-9-ene,2,6,6,9-tetramethyl-, (1R,2S,7R,8R)-	18252-44-3	94735641.8	0.9110
7.6303	Ylangene	14912-444-8	85125417.9	0.620
7.6863	Copaene	3856-25-5	177557179.7	1.646
8.1180	Cis-.alpha.-Bergamotene	18252-46-5	109183592	1.043
8.2974	Bicyclo[5.2.0]nonane,2-methylene-4,8,8-trimethyl-4-vinyl-	242794-76-9	82128689.2	0.598
9.2318	Aromandendrene	489-39-4	163055569.6	1.187
10.8988	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1,7 (ranapa,+a,apya, .beta,7 a. beta, 7b, alpha.)]-	6750-60-3	105676540.2	0.770
11.0352	Diethyl Phthalate	84-66-2	155598782.5	1.133
12.3919	2-Naphthalenemethanol, decahyaro- alpha.,alpha., 4a-trimethyl-8-methylene-, [2R-(2.alpha., 4a.alpha., 8a.beta.)]-	473-15-4	139824502.7	1.018
23.9156	9,12-Octadecadienoic acid (ZZ)-, methyl ester	112-63-0	381704902.4	2.779
24.1118	9-Octadecenoic acid (Z)-, methyl ester	112-62-9	544926223.2	3.968
26.0087	9,12-Octadecadienoic acid, ethyl ester	01/08/7619	816890268	5.948
26.2087	Ethyl Oleate	111-62-6	316849452.9	2.307

RT- Retention time

which include *C. schweinfurthii* should not cause digestive discomfort or acid reflux when eaten.

On the other hand, TA, a chemical parameter in fruit, measures organic acids such as acetic, tartaric, malic, citric, formic, and succinic as part of its overall pH. The TA (0.693 %) of the pulp revealed in the study can be considered low when compared to 1.174% in olive fruits (Rosca *et al.*, 2023). Even then, such TA value in *C.*

schweinfurthii fruit makes it acceptable for processing into consumable products (Omujal *et al*., 2023)

Proximate composition and RDA contribution

Proximate analyses results revealed that the moisture content of *C. schweinfurthii* (44.39%) from Central Uganda was comparable to that from West Africa *(*Monanu *et al.*, 2014) but lower than the 50-70% moisture content of olive fruits (Evangelou *et al.,* 2018). The crude fat content (37.5%) revealed in this study was lower than the value of 53.7% reported by Omeje *et al*. (2022) in Nigeria, but higher than that for avocado pulp (15-20%), soybean (17.9%), and olive fruit pulp (18%). This makes the crude fat of *C. schweinfurthii* to be considered high for cold pressing when compared with the value of 30% recommended for industrial oil extraction (Olawale, 2012). Such values of the proximate composition of foods are relevant to food product development, quality control, and regulatory purposes (Hait *et al*., 2023). Even then, variations in moisture content and crude fat can be attributed to the ecological locations of the trees (Chew *et al.*, 2011).

The protein content of *C. schweinfurthii* pulp (5.06 g/100g) is of high quality due to the presence of amino acids that include: Glu, Gly, Ala, Cys, and Tyr (Anyalogbu *et al.* 2014). The dietary fibre values of *C. schweinfurthii* pulp make it a good source of fiber (Omeje *et al*., 2022). Although the total carbohydrate value (10.85 g/100g) of *C. schweinfurthii* pulp is considered low, it can be recommended for consumption by patients with diabetes who require a lower carbohydrate in their diet (Wahab *et al.,* 2015).

Since RDA values represent the average daily amount of nutrients needed to meet the nutritional requirements of most healthy people in a specific age group and gender, they were calculated based on an adult individual aged 30+ years who consumes 100g of the fruit pulp. The dietary fibre content (28 g/100g) of *C. schweinfurthii* pulp contributes RDA of 114% which can be considered significant. This is because dietary fibre can help facilitate digestion and prevent constipation, thereby contributing to a reduction in the risk of colon diseases (Alissa and Ferns, 2017).

Vitamin composition and RDA contribution

The concentration of vitamin C in the pulp (72 mg/100g) is exceptionally high, with a RDA value for 100g pulp of above 100%. According to Wahab *et al.* (2025), vitamin composition is essential for maintaining the overall health and well-being of people. For instance, in the human diet, vitamin C, a water-soluble vitamin, is recognized for its antioxidant properties and its role in reducing the risk of diseases like cancer, arteriosclerosis, and cardiovascular (Monanu *et al*., 2014). Since the vitamin C content of the fruit pulp obtained is higher than the value reported by

Monanu *et al*. (2014) for the same fruit species from W. Africa, it makes *C. schweinfurthii* fruit a good source of vitamin C (Maduelosi and Angaye, 2015**).** Similarly, β-carotene in *C. schweinfurthii* fruit pulp (0.880 mg/100g) can be regarded as exceptionally high with RDA of 704%, that is twice that of orange juice of 0.345mg/100g (Velázquez-Estrada *et al*. 2016) and six times that of mango juice with 0.150mg/100g (Chang and Ismail, 2016).

It should, however, be noted that data on β-carotene content in *C. schweinfurthii* fruit pulp are currently scarce in other studies to make a comparison with the values obtained in this study. Even then, carotenoids have recently received increased interest due to their ability to convert to retinal (vitamin A) in humans (Eggersdorfer and Wyss, 2018). According to Omeje *et al.* (2022); high carotenoid intake is associated with decreased risk of cancer, age-related macular degeneration, cataracts, cardiovascular diseases, and protective effects on vision. This implies that consumption of *C. schweinfurthii* can provide a valuable alternative source of vitamin A for the population in the study area and beyond.

Mineral composition

Analysis of micro (e.g. Fe, Zn, Cu) and macro (e.g. K, Ca, Mg, P) minerals is essential in food because it guides nutritionists in dietary recommendations, informs scientists on fortification strategies, and ensures compliance with proper food regulations. In this study, iron content in *C. schweinfurthii* fruit pulp (2.3 mg/100g) was higher than (0.76 mg/100g) reported for the same species in West Africa (Monanu *et al*., 2014). The value of iron revealed in this study is a vital amount in the human body because iron constitutes part of hemoglobin, which carries oxygen in the blood, thereby supporting energy metabolism and immune function (Ifijen *et al*., 2020). Consumption of *C. schweinfurthii* fruit pulp can be recommended as an excellent source of micronutrients for diabetic patients (Abobatta, 2021); including feeding programs for menstruating/gestating women and lactating mothers (Dreher, 2018).

Zn content in *C. schweinfurthii* (1.11mg/100g) was quite substantial as it facilitates the functioning of many enzymes in animals, the immune system, and the maintenance of healthy skin (Mocchegiani *et al*., 2013). On the other hand, copper is a micronutrient essential for the formation of connective tissue and red blood cells (Cheng *et al.* 2022). In this study, copper content (0.34±0.05 mg/100 g) was more than that (0.19 mg/100 g) reported for the same fruit species in W. Africa (Monanu, *et al*. (2014). With a copper RDA of 17%, *C. schweinfurthii* fruits can be considered a good source of copper for children.

Determining the ratio of sodium and potassium (Na/K) is very important in maintaining various body functions (Pohl *et al.*, 2013). While increased consumption of potassium can help in lowering blood pressure, a lower sodium-potassium ratio is associated with reduced risks of cardiovascular diseases and inflammation associated with various chronic diseases (Ayoade *et al.,* 2017). In this study, the sodium content (18.30mg/100g) was much lower than the potassium content (752.75 mg/100g), giving a ratio of 0.005. The low Na/K ratio in this study makes *C. schweinfurthii* fruit a desirable fruit for hypertensive patients. The potassium RDA value of 22% in *C. schweinfurthii* fruit is considerably good because potassium is a major cation required for the proper functioning of cells, tissues, and organs in the body (Tabula *et al*., 2024).

The magnesium content (90.34 mg/100g) obtained in this study was higher compared to 30.0 mg/100g for the same species in W. Africa. Apart from playing a key role in the synthesis of proteins, blood sugar control, and regulating heartbeat, Mg is also responsible for controlling the flow of calcium, potassium, and sodium across cell membranes (Faryadi, 2012**).** With Mg RDA of 23% in this study, *C. schweinfurthii* fruit pulp can be considered a good source of Mg for the population that consumes it. This is so because Mg is a macro mineral connected with circulatory diseases, as well as calcium metabolism and the transmission of nerve impulses (Ishida *et al.*, 2000).

Calcium is another macro mineral essential in bone and teeth health (Uzoekwe *et al*., 2021), besides blood clotting and muscle contraction. In this study, the calcium content (24.09 mg/100g) in *C. schweinfurthii*. was higher than for the same species in W. Africa. The RDA of 2% reported in this study makes *C. schweinfurthii* fruit a poor source of calcium. This implies that *schweinfurthii* fruit should be consumed together with other fruits to obtain the recommended calcium dietary requirements.

Bioactive components and antioxidant activity

Bioactive compounds do not only impact on physiological or cellular activities in humans/animals that consume such compounds (Tabula *et al.,* 2024), but also can offer health benefits to humans due to their antioxidant and anti-inflammatory properties (Walia *et al*., 2019). According to Atawodi *et al*. (2014), the world health organization recommends that an individual should consume at least 400 g of fruits and vegetables a day to prevent heart disease, cancer, type-2 diabetes, and obesity, in addition to increasing their protection against various diseases and metabolic disorders. Such beneficial effects make *C. schweinfurthii* and other fruits an important ingredient for the development of new functional foods with potential protective and preservative properties (Tabula *et al.,* 2024).

The presence of alkaloids, tannins, flavonoids, and anthocyanins phytochemicals in *C. schweinfurthii* fruit makes it a good source of antioxidant compounds essential for the prevention of several human diseases (Tcheghebe *et al.,* 2016). The total phenolic compound content of the fruit was higher than the values reported for the same fruit samples from West Africa (Chew *et al*., 2011). This indicates that the Ugandan *C. schweinfurthii* fruit is a good source of antioxidants.

Similarly, the total flavonoids in this study were much higher compared to those reported for the same species in West African samples**.** According to Abugri *et al.* (2013), flavonoid compounds such as quercetin, kaempferol, catechins, and epicatechin can provide a range of health benefits, including protection against coronary heart disease/cancer, maintaining healthy blood glucose, and improving insulin sensitivity.

Anthocyanins are bioactive compounds in fruits and vegetables responsible for their red, purple, and blue pigments (Deis *et al*., 2021). Since *C. schweinfurthii* fruits have purple to black colour, it was essential to determine their total anthocyanin content. Much as the total anthocyanin content in purple to black colour *C. schweinfurthii* pulp could not be compared with other studies on the same species, the value of total anthocyanin content obtained in this study was higher than in olive fruits with black colour (Aprile *et al*., 2019). This is quite important since coloured compounds are secondary metabolites of plants that are generally involved in protection against ultraviolet radiation or pathogens (Deis *et al*., 2021). Further analysis, however, needs to be conducted to establish the specific anthocyanins found in *C. schweinfurthii*

A report by Walia *et al*. (2019) indicates that bioactive compounds, including total phenolic compounds, total flavonoids, and total anthocyanins, can determine the antioxidant activity of a fruit. The total antioxidant activity of C. *schweinfurthii* revealed in this study was higher than that reported for the same species in the African fruits (Tcheghebe *et al.,* 2016). Accordingly, *C. schweinfurthii* fruits from Uganda are a valuable source of antioxidant compounds offering protection against various health conditions, including cardiovascular diseases and cancer (Tcheghebe *et al.,* 2016).

Analysis of aromatic compounds in the fruit pulp is a prerequisite for determining their flavor and aromatic profile, and antibacterial properties (Pinto *et al*., 2022). Understanding the aromatic profile can also inform product development and sensory characteristics of the fruit (Chang *et al.,* 2017). The presence of Beta.-Myrcene, 2,4-Decadienal, (E,E)-, ethyl ester and other compounds with antioxidant/anti-inflammatory properties and flavor characteristics in this *C. schweinfurthii* fruit pulp, makes it a fruit pulp to be explored as a flavoring in food and beverage products.

Based on the nutritional composition and bioactive components, *C. schweinfurhii* fruit can be processed into various nutraceutical products. The high anthocyanin and phenolic compound content makes *C. schweinfurthii* fruits suitable for the development of high-value products, such as wine (Omujal *et al*., 2023), and jam, which can offer potential health benefits, including reduction in cardiovascular disease, cancer, and diabetes (Abobatta, 2021). The potential to develop nutraceutical products from the fruits of *C. schweinfurhii* warrants promoting its conservation on farms, including growing the *Schweinfurthii* trees on a commercial scale through stem cutting propagation techniques. This is expected to replace the seeds (planting material) that are destroyed during the parboiling of highly demanded fruits for eating.

Conclusions

The study has established that *C. schweinfurthii* fruits contain essential food nutrients in amounts that meet RDA specifications (dietary fibre, fat, vitamin C, β-carotene, Se, Fe , Cu and Zn), total phenolic compounds, flavonoids, and anthocyanins with nutritional, antioxidant, and therapeutic applications as well as the aromatic Beta.-Myrcene, 2,4-Decadienal, (E,E)-, ethyl ester and others that make *C. schweinfurthii* fruit pulp to be explored as a flavoring in food and beverage products. There is therefore a need to promote not only local consumption of *C. schwenfurthii* fruits but also their industrial use in the formulation and production of nutraceutical products.

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