

Research

A comparative analysis of the biochemical constituents and nutritional role of the Wild Sour Plum (*Ximenia caffra*) nut with commercial nuts for potential commercialisation

Mdungazi Knox Maluleke¹ · Lerato Isobel Lekhuleni¹ · Mabatho Moreroa²

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Abstract

The Sustainable Development Goals (SDGs) promote universal access to safe, nutritious food. Thus, the “Zero Hunger” campaign’s sustainable efforts to eliminate hunger, by encouraging the cultivation and use of underutilised crops and their value-added products, can improve food systems and community development. Wild sour plum (*Ximenia caffra* subs *caffra*) nuts, an Oleaceae fruit crop native to the Lowveld of Southern Africa, are an underappreciated value-added commodity. In large or small amounts, nuts provide vital nutrients for human consumption. The biochemical components profile of wild sour plum nuts was compared to different commercial nuts to determine their potential role in human nutrition. Wild sour plum, pecan, and macadamia nuts were sampled, each having 24 samples. These samples were tested for various biochemical constituents including total fat and calcium. The study found that pecan nuts and macadamia nuts were superior compared to other nuts, with regards to total fat and calcium content, pecan nuts containing a total fat content of 11.7 g per 100 g dry weight (g/100 g DW), and macadamia nuts containing a total calcium content of 70.5 mg per hundred gram dry weight (mg/100 g DW). The study found that wild sour plum nuts could potentially provide enough nutrients to fulfill the nutritional recommended daily intake for humans. Thus, wild sour plum nuts may be important in human diets, provided crop production is done properly, which includes irrigation, fertilisation, and temperature management of the crop.

Keywords Macademia nuts · Nutrient composition · Pecan nuts · Recommended daily intake

1 Introduction

The discovery of new crops, especially in the twenty-first century has been recognised as a potential and effective strategy towards accelerating the achievement of sustainable global development goals, which includes the eradication of hunger through Zero-hunger initiatives, particularly in areas where accessibility of nutrient-dense food remains a barrier due to affordability [1]. The need for high-quality food is a constant demand in all nations, placing tremendous pressure on the food industry to produce food that is both healthy and of high quality at reasonable prices. Exploring, discovering, and studying “new” crops that have the potential to be commercialised and supplement the current food basket is crucial in the fight against world hunger and food scarcity [2]. It has been noted by several authors that individuals consume

✉ Mdungazi Knox Maluleke, malulm@unisa.ac.za; Lerato Isobel Lekhuleni, lekhuleniil@gmail.com; Mabatho Moreroa, Emorerms@unisa.ac.za | ¹Department of Environmental Sciences, College of Agriculture and Environmental Sciences, University of South Africa, Tshwane 0002, Gauteng, South Africa. ²College of Science, Engineering and Technology, Institute for Catalysis and Energy Solutions, University of South Africa, Roodepoort 1710, Gauteng, South Africa.



different kinds of nuts for different reasons. Traditionally, though, the primary goal of nut consumption has been to provide the daily needed energy and nutrients [3, 4]. Plant value products such as nuts supply people with macro- and micronutrients; therefore, it is important to evaluate their biochemical composition before incorporating them into a daily diet [5]. Various authors such as [6–10] reported a reasonable amount of biochemical components on commercial nut species, such as hazelnut, pecan nut and Macademia, namely; fatty acids, total fiber, total flavanoids, and total phenols. On the other hand, not much research has been done on the nutritional value of wild sour plum (*Ximenia caffra*) nuts, one of the most significant native fruit and nut crops in Central and Southern Africa. The crop is underutilized because people are unaware of its potential as an agronomic crop that can be utilised to address both food and nutritional challenges [11]. Many authors assert that mature wild sour plum fruit is rich in many different mineral elements, including vitamins, macro- and micro minerals [12, 13]. The oil contents of the seed are approximately above 65% [13]. Fruits are best to consume when slightly overripe, but they can also be used to make jam, desserts, and jellies [12]. Wild sour plum nuts are consumed as a source of proteins by rural communities in Lowveld regions of South Africa [11–14]. Nuts are regarded as highly nutritious food due to their; (i) high content of good fat, (ii) good source of dietary fiber and (iii) they contain reasonable amounts of flavonoids [6, 8]. It is important to understand the chemical makeup of Wild sour plum nuts since this will help consumers understand the proper dietary intake linked to such value-based products. Nutrients like vitamins, macro- and micronutrients contained in nuts, which humans require in both smaller and larger quantities to meet their daily nutritional needs, have been reported by researchers such as [15–17]. Research shows that the health effects of eating nuts, directly depend on their nutritional composition and the amount consumed [18]. There seems to be an abundance of literature on the well-known number of nut species, such as almonds, pecans, and macadamia. However, little is known about the biochemical constituent of wild sour plum nuts. Therefore, the objective was to compare the biochemical constituents profile of wild sour plum nuts, with various commercial nuts and the recommended daily intake (RDI), in order to generate a comparative analysis regarding its potential role in human health, nutrition, and possible use for commercial purposes.

2 Methods and material

2.1 Sample collection

In this investigation, a total of 72 nuts, that were free from physical damage, of which 24 nuts from each species (wild sour plum, macadamia, and pecan nuts), were used for analysis (Fig. 1). The wild sour plum, nuts from mature ripe non-fallen fruit, harvested from random mature trees that were growing in their natural habitat in December 2022, were utilised, specifically in Bushbuckridge, Huntington, South Africa (– 24.91648, 31.41572). It is worth to note that wild sour plum trees (ID number: 0999867) were identified by a qualified botanist (Doctor R. Munyai), a Researcher at the University of South Africa and verified by the National Herbarium at Pretoria National Botanical Gardens (SANBI). Macadamia and pecan nuts were purchased at a local market in Mbombela, South Africa, in 2023. The fruit were transferred to their

Fig. 1 Nuts of different tree species. A=Wild sour plum nut, B=Macadamia nut and C=pecan nut



corresponding sample bags and, thereafter, delivered to the Agricultural Research Council-Vegetable, Industrial Crops and Medicinal Plants facility for analysis. To compare the wild sour plum nuts with other well-known commercial nuts (macadamia and pecan nuts), an analysis of biochemical constituents, such as total carbohydrates, total fat, total fibre, total flavonoids, vitamin E, macro- and micro-nutrients was carried out.

2.2 Biochemical constituents analysis

In order to conduct a comparative analysis, the biochemical composition and several biochemical elements were examined, between wild sour plum nuts and two commercially popular nuts, namely macadamia and pecan nuts. These constituents included total carbohydrates, total fat, total fibre, total flavonoids, vitamin E, macro- and micro-nutrients, which were all measured in triplicates to ensure accuracy and reliability of the results. The analysis was conducted using the following procedures:

Total fat content was determined according to the recommended standard procedure of ISO 12966-2, followed by [8] with a minor modification (triplicate). Briefly, fatty acid glycerides were converted into the appropriate methyl esters, and gas chromatography was used to establish the fatty acid composition. Utilising a flame ionization detector, the analyses were carried out using an Agilent 7890a GC (Agilent 7890A, Santa Clara, CA, USA). Film thickness of 0.25 mm was employed for the separations on a DB-5MS fused silica capillary column (60 m 0.320 mm). A reference mixture (FAMES) of fatty acid methyl esters, were identified by comparing the retention periods of the chromatogram (Supelco 37 component FAME mix). Total fat content was expressed in grams per 100 g dry weight (g/100 g DW).

Regarding total carbohydrate content analysis, expressed in grams per 100 g dry weight (g/100 g DW), a method reported by [8] developed by [19] was used with minor modification (triplicate). In summary, a 50 ml test tube was filled with a sample of ~ 5 g of dried powder of wild sour plum nuts, macadamia nuts, and pecan nuts. About 25 ml of 80% ethanol was then added. The sample was heated for 15 min in a water bath at 100 °C after being vortexed for 3 min. A 50 ml volumetric flask was filled with the filtered material. After the filter cake was cleaned, 80% ethanol was added to the extract. To prepare the extract for high-pressure liquid chromatography (HPLC), a 0.45 mm membrane filter was used to filter the mixture. Every sample was completed in two copies. In the nut samples, sucrose, glucose, and fructose were separated and quantified using HPLC. An Agilent 1100 series liquid chromatograph (Agilent Technologies, Wilmington, Del.) was used to analyse the carbohydrates. A 20 ml sample was injected into the chromatograph, along with premixed HPLC-grade water (25%) and acetonitrile (75%), which served as the mobile phase. The stationary phase was an aminopropylsilane column (Agilent ZORBAX carbohydrate analysis column, 4.6 mm ID 150 mm, 5 mm), which was followed by an Agilent refractive index detector. The column and detector temperatures were set to 30 °C, and a flow rate of 1.4 ml per minute was employed. Prior to usage, the mobile phase was vacuum filtered with a 0.45 mm membrane filter. Carbohydrate peaks of the samples were located using HPLC retention durations in comparison to real standards. Total carbohydrates content was expressed in gram per hundred-gram dry weight (g/100 g DW).

Total fibre content was measured using freeze-dried samples of various nut species, in accordance with the procedures described in [8]. In summary, the complete dietary fibres assay kit K-TDFR (Megazyme Int., Wicklow, Ireland) was used to determine the total fibres by using the enzymatic gravimetric method (AOAC Method 985.29). The enzymes utilized were heat-stable α -amylase, protease, amyloglucosidase, and phosphate buffer with a pH of 6.0. Protease breaks down and dissolves proteins, α -amylase breaks down starch when it is heated, and amyloglucosidase turns starch into glucose. The material was adjusted for potential mineral and nitrogen residue, following the enzymatic treatment. Using gravimetric analysis, the total fibre expressed in gram per hundred grams dry weight (g/100 g DW) was determined.

Concerning total flavonoids content, expressed in milligram per hundred-gram catechin equivalent of dry weight (mg/100 g CE DW), as per the method reported by [16] and [20] with slight modification (triplicate) was utilised. Freeze-dried samples of varying nut species (wild sour plum, macadamia, and pecan nuts) were quantified by using the aluminium chloride colorimetric method. In a nutshell, 50 mg of nut powder was dissolved in 1 mL methanol, combined with 4 mL distilled water, and then 0.3 mL of 5% NaNO_2 solution; after 5 min of incubation, 0.3 mL of 10% AlCl_3 solution was added, and the combination was left to stand for 6 min. The final volume of the combination was brought to 10 mL with double-distilled water after adding 2 mL of 1 mol/L NaOH solution. After allowing the mixture to sit for 15 min, the absorbance was measured at 510 nm. Catechin was used as a standard for the calibration curve and total flavonoids content was expressed in mg catechin equivalents (CE) gram per hundred dry weight (mg/100 g DW).

Regarding vitamin E content, expressed in milligrams per hundred grams dry weight (mg/100 g DW), the method of [11, 20] was adopted by [21] with minor modification (triplicate). The wild sour plum nut samples that underwent freeze-drying was used for analysis of vitamin E. The verified protocol described by [11] was used to prepare the samples. In glass

screw-cap test tubes (Supelco, Bellefonte, PA, USA), about 600 mg of finely powdered nut species samples were properly weighed. Subsequently, about 150 μL of tocol solution was used as the internal standard, and 100 μL of BHT solution was applied as the antioxidant. After adding the following reagents, the sample was homogenized for 1 min by vortex mixing: 2 mL of ethanol, 4 mL of *n*-hexane for the extraction solvent, and 2 mL of saturated NaCl solution. The clear upper layer of the sample was transferred to a second screw-cap test tube after the sample was centrifuged for 2 min. *N*-hexane in the volume of 2 mL was used twice to extract the sample. A 1.5 mL volume of *n*-hexane was used to reconstitute the residue after the mixed extracts were dried under a nitrogen stream on a (Pierce, Rockford, IL, USA) Reacti-Therm module running at room temperature. The extract was transfer into the HPLC programmable autosampler after being dried with anhydrous sodium sulphate, centrifuged, and moved into a 2.0 mL vial.

Macro- and micro-nutrients, which were expressed in milligrams per 100 g dry weight (mg/100 g DW), were determined following the procedure of [22], adopted by [1, 11, 20] with minor modification (triplicates). In short, a dispersed microwave system (MLS 1200 Mega; Milestone S.r. L, Sorisole, Italy) was utilized to digest samples of freeze-dried nuts. Adjustments involved introducing 2 mL of HNO_3 (67% anaphur) and 1 mL of analytical-grade H_2O_2 into polytetrafluoroethylene vessels prior to measuring samples in triplicate (ranging from 15 to 25 mg) for each treatment. After digestion, each solution was diluted to a 15 ml volume in a test tube filled with deionized water, and ICP-MS was employed for result analysis. The ICP-MS apparatus (Agilent 7700; Agilent Technologies, Tokyo, Japan) featured a quadrupole mass analyser and an octapole reaction system (ORS 3). The calibration solution was prepared by appropriately diluting the single-element certified reference material (Analytika Ltd, Czech Republic; 1.000 0.002 g/L for each element) with deionized water (18.2 M Ω cm, Direct-Q; Millipore, France). The accuracy of measurements was validated using certified reference material of water TM-15.2 from the National Water Research Institution in Ontario, Canada. The analysis covered nutrient elements, such as calcium (Ca), magnesium (Mg), phosphorus (P), copper (Cu), manganese (Mn), iron (Fe) and zinc (Zn).

2.3 Statistical analysis

A one-way analysis of variance (ANOVA) was used to analyse and compare data on the nutritional content of different nut tree species (wild sour plum nut, pecan nut and Macadamia nut). The measured variables included total carbohydrates, total fat, total fibre, vitamin E, total flavonoids, macro- and micro-nutrients. Fundamental statistical analysis included grand mean, list significant difference (LSD), and standard deviation. Statistical software (TIBCO Software Inc, CA, USA) was utilised for all statistical analysis.

3 Results and discussion

3.1 The contribution of the required daily intake of nutrients from nuts

In this investigation, recommended daily intake (RDI) of biochemical elements necessary for an adult human being are presented in Table 1, as standard reference against those of three different nut types (wild sour plum nut, macadamia nut and pecan nut). The nutritional/mineral content of various nuts, as shown in Table 1, was used as a benchmark for comparison. The primary focus was to assess the availability of nutrients in commercially accessible nuts and the less commonly utilised wild sour plum nut, for potential commercialisation purposes. The nutrient components required by an adult human being, outlined in Table 1, include manganese, total flavonoids, magnesium, phosphorus, zinc, iron, calcium, dietary fibre, fat, and carbohydrates. Based on the biochemical composition of nuts studied in this investigation, their nutritional contribution towards meeting the RDI, especially the wild sour plum nuts show a promising possibility for commercialisation.

4 Comparison of biochemical constituents of nuts and their potential role in human nutrition, with a special focus on wild sour plum nut

4.1 Biochemical constituents

4.1.1 Total carbohydrates

Table 2 presents the biochemical constituents of nuts of different tree species (macadamia, pecan nut and wild sour plum). The study results showed that there was a significant ($P \leq 0.01$) difference in the biochemical constituents (total

Table 1 Average recommended daily intake of various biochemical constituents of nuts

Biochemical/nutrient elements	Average RDI* (mg/person/day)	Wild sour plum		Macadamia		Pecan		References
		RDI content	%RDI	RDI content	%RDI	RDI content	%RDI	
Manganese (mg/100 g)	2.05	3.70	180	3.60	176	3.80	185	[35]
Total flavonoids (mg/100 g)	60.3	37.3	61.9	44.2	73.3	40.1	66.5	[12]
Magnesium (mg/100 g)	365	99.7	27.3	71.1	19.5	111	30.3	[11]
Phosphorus (mg/100 g)	625	168	26.9	196	31.4	167	26.7	[20]
Zinc (mg/100 g)	11.5	2.07	18.0	3.50	30.4	3.96	34.4	[12]
Iron (mg/100 g)	13.0	2.26	17.4	3.26	25.1	2.23	17.2	[36, 37]
Copper (mg/100 g)	10.0	0.64	6.37	0.617	6.17	0.88	8.80	[1]
Calcium(mg/100 g)	1100	53.3	4.85	70.5	6.41	64.9	5.90	[33]
Dietary fibre (mg/100 g)	50,000	7.24	0.02	7.61	0.02	8.90	0.03	[30]
Fat (g/100 g)	34,000	60.76	0.18	70.83	0.14	67.4	0.13	[12]
Carbohydrates (g/100 g)	275,000	9.73	0.0035	12.5	0.005	11.7	0.0043	[38]

carbohydrates, total fat, total fibre, and total flavonoids) in the nuts of the three tree species analysed. According to study findings, the total carbohydrate content ranged between 9.7 and 12.5 g/100 g DW. The findings additionally showed that the wild sour plum nut had the lowest carbohydrate level (9.7 g/100 g DW), followed by pecan nut (11.7 g/100 g DW). Macadamia nut demonstrated the highest carbohydrate content (12.5 g/100 g DW). The human body uses carbohydrates as an energy source, aids in the metabolism of insulin and blood sugar, and participates in the metabolism of triglycerides absorption process [23]. The variation between wild sour plum carbohydrates content (9.7) and average daily recommended intake (275) is 265.3 g. Values obtained from the study implies that the percentage contribution of wild sour plum nut, in terms of carbohydrates for human nutrition, is around 3.5%. Even though the carbohydrates percentage contribution of wild sour plum nut to recommended daily intake is low, values obtained from this study could mean that wild sour plum nuts have the potential to assist in curbing diseases such as constipation, nausea, and constant fatigue, which are conditions associated with low carbohydrates intake in human diets [24]. These findings regarding the potential contribution of indigenous species, especially nuts, are in line with those of [23], who suggest that consumption of indigenous fruits may potentially assist in curbing symptoms of conditions affecting rural communities where food accessibility might be a challenge due to cost implications.

4.1.2 Total fat

Concerning total fat, study results depicted that it ranged from 60.8 to 70.8 g/100 g DW. Furthermore, the results showed that the wild sour plum nut had the lowest total fat content (60.8 g/100 g DW), followed by the pecan nut (67.4 g/100 g DW). When compared to other nut tree species, macadamia nuts were found to have the highest total fat content (80.8 g/100 g DW). The human body uses fat as a molecule to help absorb vitamins A, D, and E [23]. Due

Table 2 Biochemical constituents of three different nut tree species

Sample	Total carbohydrates (g/100 g DW)	Total fat (g/100 g DW)	Total fibre (g/100 g DW)	Total flavonoids (CE mg/100/g DW)
Macadamia nut	12.5 (1.2) ^a	70.83 (4.5) ^a	7.614 (1.9) ^b	44.2 (6.6) ^a
Pecan nut	11.74 (0.7) ^b	67.41 (1.3) ^b	8.9 (2.1) ^a	40.1 (3.7) ^b
Wild sour plum	9.73 (1.5) ^c	60.76 (3.1) ^c	7.243 (0.2) ^c	37.3 (7.9) ^c
Grand mean	11.28	6.42	7.99	25.5
LSD0.05	0.61	2.00	0.68	8.61
P value	0.001	0.001	0.001	0.001

The standard deviations of the mean are shown by numbers enclosed in brackets. Lower than 0.05 P values are in bold. The least significant difference between means, or LSD0.05, is used

Means with different letters (a, b, c) are significantly different at $P \leq 0.05$

to their fat-soluble nature, these vitamins can only be absorbed in the presence of fats [1, 23]. The variation between wild sour plum fat content (60.8 g) and the average recommended daily intake (61 g) is 0.2 g. Values obtained from this study indicates that wild sour plum nut contribute (99.6%) of fat content recommended by human daily consumption. Moreover, the study findings could mean that consumption of wild sour plum nuts may potentially assist in prevention of conditions such as dermatitis, alopecia, and intellectual disability, which are symptom diseases associated with low fat intake in the human diet [25]. These findings are in harmony with those of Maluleke et al. who suggested that fat content of wild sour plum fruit may potentially assist in the enhancement of human health and nutrition due to their ability to boost the immune system.

4.1.3 Total fibre

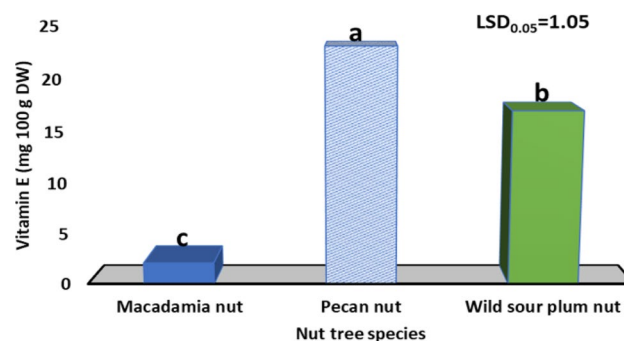
For total fibre content, study results depicted that it ranged from 7.2 to 7.6 g/100 g DW. Moreover, results illustrated that wild sour plum nuts contain lower fibre content (7.2 g/100 g DW), followed by macadamia (7.6 g/100 g DW). When compared to other nuts, pecan nuts exhibited the highest total fibre content (8.9 g/100 g DW). Dietary fibre is important for human nutrition and health because it controls the functions of the digestive system [26]. Due to its capacity to absorb water and contribute solid material to the digestive system, dietary fibre helps to solidify the food that has been digested, facilitating the passage of that material through the system, and lowering the risk of constipation [27]. The variation between the wild sour plum nut fibre content (7.2) and average recommended daily intake (29.5) was 22.3 g, which implies that wild sour plum nut could contribute about (24.4%) of the fibre required by humans daily. Even though value obtained from the study is lower in terms of percentage contribution to daily intake, consumption of wild sour plum nut has a slight potential to curb conditions such as constipation, haemorrhoids, obesity, heart related diseases, diabetes, and bowel cancer, which are symptom diseases associated with low fibre intake in the human diet [23]. These results support those of [11, 12], who concluded that eating wild sour plum fruit, particularly in places where access to fruits and nuts is limited due to costs, may potentially help provide the dietary fibre needed to prevent conditions like inflammation and constipation, which are linked to a low-fibre diet in human nutrition.

4.1.4 Total flavonoids

For total flavonoids content, study results showed that it ranged from 37.3 to 44.2 CE mg/100 g DW. In addition, study results observed lower flavonoids content in wild sour plum nuts (37.3 CE mg/100 g DW, followed by pecan nuts (40.1 CE mg/100 g DW). When compared to other nuts, Macadamia nuts contained the highest flavonoid content (44.2 CE mg/100 g DW). Several health advantages of flavonoids include their antiviral, anticancer, antioxidant, and anti-inflammatory qualities [1]. Additionally, they offer cardio- and neuroprotective benefits [20]. The variation between the total flavonoids content of wild sour plum (37.3) and the average recommended daily intake (150) is 112.7 mg. Values obtained from this study suggests that wild sour plum nuts could potentially contribute about 25.5% of total flavonoids required by human daily intake. This implies that consumption of wild sour plum nuts may potentially assist in the curbing of heart related diseases and diabetes and inflammation, which are symptom diseases associated with low flavonoids intake in the human diet [28]. These results concur with those of [11, 12, 20], who suggested that eating fruits high in flavonoids could help improve human nutrition and health since they can prevent several conditions like excessive bruising and haemorrhoids, which are linked to a diet low in flavonoids.

4.1.5 Vitamin E

Regarding vitamin E, results delineated that there was significant vitamin E ($P \geq 0.01$) in nuts of different tree species (Fig. 2). Furthermore, results showed that it ranged from 2.1 to 23.1 mg/100 g DW. Additionally, results illustrated that Macadamia nuts (2.1 mg/100 g DW) contained lower vitamin content, followed by wild sour plum nuts (19.9 mg/100 g DW). When compared to other nut species, pecan nuts (23.1 mg/100 g DW) exhibited higher vitamin E content. In human health and nutrition, vitamin E supports the immune system by acting as a natural defence against disease and infection [20]. Additionally, it strengthens the immune system and keeps blood clots from developing in the heart arteries [1]. The variation between the wild sour plum nut vitamin E content (19.9 mg) and recommended daily intake (1 mg/100 g DW)

Fig. 2 Vitamin E content of nuts of different tree species**Table 3** Macro-nutrients content (mg/100 g DW) of nuts of different tree species

Sample	Calcium (mg 100/g DW)	Magnesium (mg 100/g DW)	Phosphorus (mg 100/g DW)
Macadamia nut	70.5 (4.1) ^a	71.1 (15.5) ^c	169.4 (20.5) ^a
Pecan nut	64.9 (3.7) ^b	110.7 (7.9) ^a	166.7 (10.4) ^c
Wild sour plum	53.3 (6.8) ^c	99.7 (4.2) ^b	168.05 (11.8) ^b
Grand mean	63.3	96.1	156
LSD0.05	5.07	12.50	15.23
P value	0.001	0.001	0.001

The standard deviations of the mean are shown by numbers enclosed in brackets. Lower than 0.05 P values are in bold. The least significant difference between means, or LSD0.05, is used

Values with different letters (a,b,c) are significantly different at $P \leq 0.05$

was 2.9 mg/100 g. This suggests that the wild sour plum nuts may potentially provide about twice the daily amount of vitamin E needed by humans. Values obtained from the study suggest that consumption of wild sour plum nuts could assist in curbing conditions such as skin inflammation, night blindness, infertility, and respiratory infections, which are symptom diseases associated with low vitamin E intake [20]. However, authors such as [20], cautioned that consuming too much vitamin E may lead to symptoms including internal bleeding of the brain. Findings reported by [1] state that, to avoid occurrences related to an excess of vitamin E, it is imperative to determine the real content required in a particular food product. These results corroborate those of [11], who hypothesized that consumption of native fruits like wild sour plum fruit, nuts and their value-added products, could help prevent ailments like persistent fatigue and muscle weakness, which are signs of insufficient vitamin E intake.

4.1.6 Macro-nutrients

Table 3 illustrate the macro-nutrient content of nuts of different tree species. The study results showed that there was a significant ($P \geq 0.01$) difference on macro-nutrients such as calcium, magnesium, and phosphorus. For calcium content, results showed that it ranged from 53.3 to 70.5 mg/100 g DW. Furthermore, results delineated that wild sour plum nuts contained a low calcium content (53.3 mg/100 g DW), followed by pecan nuts (64.9 mg/100/DW). The highest calcium content was observed in macadamia nut (70.5 mg/100 g DW). The most crucial mineral that the human body needs in greater amounts is calcium [23]. Calcium is stored by the body in teeth and bones, giving them hardness and structure [20]. In addition, the human body needs calcium for nerves to transmit messages from the brain to every region of the body and for muscles to contract [28]. The variation between the wild sour plum nut calcium content (53.3) and average recommended daily intake (1100) is 1045 mg/100 g. This implies that wild sour plum nuts contribute about 4.8% of the calcium required by humans daily. Even though the wild sour plum nuts' daily calcium contribution is low, values obtained from this study could mean that consumption of the wild sour plum could potentially assist in the curbing of conditions such as muscle aches, and weak bones, which are symptoms linked to low calcium intake in the human diet [28]. Our findings are consistent with those of [11, 12], who suggested that eating indigenous fruits could potentially help prevent conditions like cramping of muscles and problems related to the bones that are caused by insufficient calcium in the diet.

Regarding magnesium content, study results showed that it varied from 71.1 to 110.7 mg/100 g DW. Additionally, the study results revealed that Macadamia nuts contained a lower magnesium content (71.1 mg/100 g DW), followed by wild sour plum nuts (99.7 mg/100 g DW). Pecan nut magnesium content (110.7 mg/100 g DW) was the highest compared to other nuts. Magnesium is essential for the healthy operation of the heart, bones, muscles, and nerves, among other vital organs [29, 30]. It also maintains a strong immune system, stabilizes heartbeat, helps maintain proper nerve and muscle function, and keeps bones strong [31]. Moreover, it aids in regulating blood sugar levels [20]. The variation between wild sour plum nuts' magnesium content (99.7) and average recommended daily intake (365) is 265.3 mg. This implies that wild sour plum nuts contribute about (27.3%) of the magnesium required by humans daily. Values obtained from this study suggest that consumption of wild sour plum nuts could potentially assist in curbing conditions such as low appetite, nausea, fatigue, muscle pains and abnormal heartbeat, which are symptoms linked to low magnesium intake in the human diet [20]. The findings of our investigation align with the findings of [11, 12], who postulated that consuming fruits and nuts, from native fruits that are rich in magnesium, could potentially aid in preventing disorders like irregular heartbeat, which are signs of low magnesium intake. This is particularly true in rural communities where food access is still difficult because of financial concerns.

Concerning phosphorus content, results depicted that it ranged from 166.7 to 169.4 mg/100 g DW. Moreover, study results evinced that pecan nuts contained low phosphorus content (166.7 mg/100 g DW), followed by wild sour plum (168.1 mg/100 g DW). At 169.4 mg/100 g DW, pecan nuts' phosphorus content was the highest compared to other nuts. Phosphorus is mostly needed by the human body for the development of teeth and bones [20]. It plays a crucial role in the way in which the human body metabolizes fats and carbohydrates [32]. The variation between wild sour plum nuts' phosphorus content (168.1) and the average recommended daily intake (900) is 731.9 mg. This indicates that wild sour plum nuts could potentially contribute about 26.9% of phosphorus required by humans daily. Even though the wild sour plum nuts' phosphorus content is low, values obtained from this study could suggest that consumption of wild sour plum nuts could potentially assist in prevention of conditions such as a loss of appetite, anxiety, bone pain, stiff joints, fatigue, and weight loss, which are symptoms linked with low phosphorus intake [12, 20]. The study findings are consistent with those of [12], who suggest that eating fruits and nuts from native species may help prevent conditions like breathing difficulties and bone pains, which are symptoms of low phosphorus in the diet. This is especially true in rural areas where food access and affordability are still issues.

4.1.7 Micro-nutrients

Table 4 depicts the micro-nutrient content of nuts of different tree species. The study results showed that there was a significant ($P \geq 0.01$) difference on micro-nutrients such as copper, iron, manganese, and zinc. Regarding copper content, results showed that it ranged from 0.62 to 0.88 mg/100 g DW. The study results further illustrate that phosphorus content was low in macadamia nuts (0.62 mg/100 g DW), followed by wild sour plum nuts (0.64 mg/100 g DW). When compared to other nuts, the highest phosphorus content (0.88 mg/100 g DW) was observed in pecan nuts. Copper is used by the human body for a variety of vital processes, such as the synthesis of blood vessels, connective tissues, and energy [1]. Moreover, copper activates genes and supports the health of the immune and neurological systems [20, 28]. The human body also need copper for the development of the brain [12]. The variation between wild sour plum nuts' copper content (0.64) and average recommended daily intake (10) is 9.36 mg. This suggests that wild sour plum nuts contribute about 6.37% of copper required by humans daily. Although lower, values obtained from the study could mean that consumption of wild sour plum nuts has a slight potential to assist in curbing conditions such as anaemia, bone fractures, osteoporosis, irregular heartbeat, skin related challenges, and thyroid problems, which are symptoms linked to low copper intake in the human diet. The findings of this study are consistent with those of [1], who suggested that eating native fruits and their value-added products may help prevent deficiencies such skin colour problems and anaemia, which are connected to low copper content in the diet.

Concerning manganese, results showed that it ranged from 3.6 to 3.8 mg/100 g DW. Furthermore, results evinced that macadamia nuts had a lower manganese content (3.6 mg 100/g DW), followed by wild sour plum nuts (3.8 mg/100 g DW). Pecan nuts illustrated higher manganese content at 3.8 mg/100 g DW, when compared to other nuts. Manganese is essential for human nutrition and health since it aids in the formation of bones, connective tissue, and sex hormones [11]. In addition, it helps the body absorb calcium at the best possible rate, controls blood sugar levels, and aids in the metabolism of fat and carbohydrates [20]. The variation between wild sour plum nuts' manganese content (3.8) and average recommended daily intake (2.1) is 1.7 mg. This suggests that wild sour plums nuts may contribute nearly twice as much manganese as is needed by humans daily. In addition, values obtained from

Table 4 Micro-nutrient (mg/100 g DW) of three different nut tree species

Sample	Copper (mg 100/g DW)	Manganese (mg 100/g DW)	Iron (mg 100/g DW)	Zinc (mg 100/g DW)
Macadamia nut	0.617 (0.1) ^c	3.6 (0.3) ^c	3.257 (0.2) ^a	3.5 (0.7) ^b
Pecan nut	0.88 (0.3) ^a	3.8 (0.6) ^a	2.229 (0.5) ^c	3.957 (0.3) ^a
Wild sour plum	0.637 (0.1) ^b	3.7 (0.4) ^b	2.257 (0.1) ^b	2.071 (0.4) ^c
Grand mean	0.716	3.34	2.58	3.17
LSD0.05	0.111	0.24	0.212	0.318
P value	0.001	0.001	0.001	0.001

The standard deviations of the mean are shown by numbers enclosed in brackets. Lower than 0.05 P values are in bold. The least significant difference between means, or LSD0.05, is used

Values with different letters (a, b, c) are significantly different at $P \leq 0.05$

the study could mean that consumption of wild sour plum nuts could potentially assist in prevention of conditions such as bone demineralisation, poor growth in children, skin rash, hair depigmentation and abnormal mood swings, which are symptoms associated with low manganese intake in the human diet. Our study findings are consistent with those of [12], who proposed that consumption of native fruits and their value-added products, such as nuts high in manganese, especially in rural communities, may help prevent diseases like skin rashes and hair-related issues, which are linked to low manganese diets.

Regarding iron content, study results showed that it ranged from 2.2 to 3.3 mg/100 g DW. Additionally, study results revealed lower iron content (2.2 mg/100 g DW) on pecan nuts, followed by wild sour plum nuts (2.3 mg/100 g DW). The highest iron content (3.3 mg/100 g DW) was observed in macadamia nuts. Mineral iron is necessary for the body's growth and development [1, 20]. The human body requires iron to generate myoglobin, a protein that supplies oxygen to muscles, and haemoglobin, a protein found in red blood cells that transports oxygen from the lungs to every part of the body [1, 33]. The variation between wild sour plum nuts' iron content (2.2) and average daily recommended daily intake (13) is 10.8 mg. This indicates that wild sour plum nuts could potentially contribute about 17.4% of the iron required by humans daily. Although, the iron value of wild sour plum nuts obtained from the study was low, the study findings suggest that consumption of wild sour plum nuts could potentially assist in curbing conditions such as fatigue, pale skin, chest pain and inflammation, which are symptoms associated with low iron content in the human diet [11]. The findings of this study corroborate those of [23], who concluded that eating native fruits and their value-added products may help prevent ailments like chronic fatigue, chest pains, and irregular heartbeats, which are associated with a low iron diet.

For zinc content, results showed that it ranged from 2.1 to 3.9 mg/100 g DW. Furthermore, results showed that wild sour plum nuts (2.1 mg/100 g DW) had lower zinc content, followed by wild macadamia nuts (2.3 mg/100 g DW). Compared to other nuts, pecan nuts had superior zinc content (3.9 mg/100 g DW). Although the human body only needs small amounts of zinc, it has essential enzymes which depend on it to carry out critical chemical reactions [1]. It is essential for the synthesis of proteins, the development of new DNA, the expansion of cells, the repair of damaged tissue, and the maintenance of a robust immune system [20, 24, 34]. The variation between wild sour plums' zinc content (2.1) and the average recommended daily intake (11.5) is 9.4 mg. This implies that that wild sour plum nut could potentially contribute about 18% of zinc required by humans daily. Although lower, values obtained from the study mean that consumption of wild sour plum nuts could potentially assist in curbing conditions such as hair loss, eye related challenges, and diarrhoea, which are symptoms associated with low zinc content in the human diet [12]. The present study findings are consistent with those of [11, 23], who proposed that the consumption of indigenous fruits and their value-added products, especially in rural communities, could potentially mitigate conditions like poor wound healing and eye-related issues that are associated with low zinc content in human diet.

5 Conclusion

When compared to other popular commercial nuts, like macadamia and pecan nuts, this study showed that wild sour plum nuts are relatively rich in nutrients. Furthermore, the possible contribution of wild sour plum nuts to daily recommended intakes of several biochemical elements, including manganese, total fat, and vitamin E, have been demonstrated in this study. Even though other biochemical components, like total carbohydrates, total flavonoids, phosphorus,

magnesium, copper, iron, and zinc were found to be below the daily recommended intake, findings depict that these elements could be increased if the crop is cultivated under agronomical practices, such as suitable soil type, optimum irrigation, fertilizers and temperature. Given the nutritional data and their significance to human health presented in this study, it is clear that wild sour plum nuts, which is currently underutilized due to a lack of nutritional baseline data, public awareness and which is only consumed in a small number of rural communities in South Africa, mainly in the Lowveld, could be counted on to help achieve one of the SDGs (SDG1 Zero-hunger), which promotes the idea that everyone, including the underprivileged and members of vulnerable societies, should have year-round access to enough food that is both safe and nutritious. However, prior to commercializing of this underutilized value-added product (wild sour plum nuts), a toxicological study should be carried out to identify the biological aspects and substances which might lead to injurious situations, such as allergies, which are important aspects of food safety that might arise from consumption of wild sour plum nuts.

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Author contributions Dr. M.K.M. was involved in study design, data collection, analysis, interpretation and write-up. Ms. L.I.L. was involved in data collection, analysis and write-up. Dr. M.S.M was involved in data interpretation and write-up.

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Data availability Data generated for this study is available from the corresponding author on formal request.

Declarations

Competing interests Authors declare that they have no conflicts of interest.

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