Discover Food

Review

Quality aspects of marula (*Sclerocarya birrea*) fruit, nutritional composition, and the formation of value-added products for human nutrition: a review

Isobel Lerato Lekhuleni[1] · Ayanda Shabalala[2] · Mdungazi K. Maluleke[1,3]

Received: 24 March 2024 / Accepted: 28 May 2024
Published online: 31 May 2024

Abstract
The review aimed to explore the reported biochemical, nutritional, and quality aspects of marula fruit and its value-added products for enhancement of human nutrition. Marula (*Sclerocarya birrea*) fruit is one of the underutilised indigenous fruits that grows naturally across the northern and eastern regions of Southern Africa. A search on Google Scholar, Scopus, Science Direct, and Web of Science databases was conducted in September and November of 2023. Use the following search "terms" to find relevant literature: "*Marula fruit*, *underutilised African fruit crops*, "*Nutritional composition of marula fruit*", "*biochemical constituents of marula fruit*, "*marula fruit value-added products, function in human health and nutrition*". Available literature shows that almost every part of a tree, namely the leaves, bark, roots, and fruit, have known nutritional benefits for human health and nutrition. The fruit contains valuable biochemical constituents such as vitamin C, carotene, flavonoids, phenols, calcium, magnesium, iron, and zinc. Its value-added products, such as alcoholic beverages, juice, jam, and nuts, contain biochemical constituents with potential enrichment of human health and nutrition, endorsing a compelling case for potential commercialisation globally. The different nutritional and biochemical properties were compared against the human recommended daily intake to determine their potential role in human health and nutrition. The study reveals that the marula fruit and its value-added products may be vital in providing the required nutrients to meet human nutritional daily needs and could play a pivotal role in accelerating the Sustainable Development Goals 1 and 2 (no poverty and zero hunger). Therefore, there is a need for more research on agroprocessing of marula fruit to create nutritious value-added products, for potential commercialisation. As a result, the objective of the study was to examine the literature on the biochemical components of marula fruit and its value-added products, comparing them to the daily recommended intake, while assessing their possible significance in human nutrition for possible commercialisation.

Keywords Biochemical constituents · Marula fruit · Nutritional composition · Recommended daily intake

1 Introduction

Marula (*Sclerocarya birrea*) is one of the underutilised indigenous fruits with potential to contribute to food and nutrition [1–3]. The fruit is appreciated mainly for its nutritious pulp with high vitamin C content and edible nuts [4, 5]. According to [6], marula fruit contains a high amount of vitamin C, claimed to be at the same level as that of well-known commercial

✉ Mdungazi K. Maluleke, malulm@unisa.ac.za | [1]College of Agriculture and Environmental Sciences, Department of Life and Consumer Sciences, University of South Africa, Tshwane 0002, South Africa. [2]Faculty of Agriculture and Natural Sciences, School of Biology and Environmental Sciences, University of Mpumalanga, Mbombela 1200, South Africa. [3]College of Agriculture and Environmental Sciences, Department of Environmental Sciences, University of South Africa, Tshwane 0002, South Africa.

fruits such as orange and mango [5]. Considering its nutritional composition, marula fruit makes a valuable contribution to nutrient intake and fulfilment of the recommended daily intake (RDI) in disadvantaged communities, thus playing a paramount role in the diet due to its nutritional value [7]. By 2030, the Sustainable Development Goals (SDGs) hope to eradicate all types of hunger and malnutrition and guarantee that everyone has access to enough wholesome food throughout the year (SDG 2, zero hunger). According to the Food and Agricultural Organisation [8, 9], availability and access to nutritionally balanced foods are a fundamental principle for human life. Marula fruit is freely available for harvest during summer to autumn in Southern Africa and meets the nutritional needs of rural to semi-urban communities due to its high nutrient content, subsequently contributing to nutritional security in most developing countries [9]. However, malnutrition typified by deficiency in either essential nutrients (carbohydrates, proteins and fats) or mineral elements (vitamins, magnesium, phosphorus, zinc and iron) is still prevalent in these areas [10, 11]. In addition, it is claimed that micronutrient deficiencies affect over two billion people globally and their effects can lead to poor health or even death due to chronic diseases [12, 13]. The role of micronutrients in the body is to facilitate physiological reactions as co-enzymes and contribute to the natural antioxidant pool [14]. Antioxidants help the body to increase its resistance to infections [14]. In addition, micronutrient deficiencies can hold back socioeconomic development, particularly in rural communities where access to commercial food seems to be a challenge [10]. Consumption of marula fruit and its value-added products could be beneficial for human health and can aid in mitigating malnutrition, thus meeting the RDI requirements (Fig. 1) [13]. In this review the biochemical properties of marula fruit and its value-added products (alcohol, jam, juice, and nuts) and their potential contribution to human health and nutrition in the fulfilment of RDI were compared for possible commercialisation.

2 Materials and methods

Databases searched between September and November of 2023 were Google Scholar, Scopus, Science Direct and Web of Science, as adopted by [15]. Key phrases used were marula fruit, underutilised African fruit crops, nutritional composition of marula fruit, biochemical components of marula fruit, marula fruit value-added products, function in human health and nutrition. Works released between 1982 and 2023 were selected for this review. About 38 articles that were found through the search engines were cited in this review. Information was selected based on its relevance to the manuscript's title, literature, and discussion. The following research questions were formulated to assist with the manuscript formulation: (i) What body of knowledge is available regarding the biochemical components and nutritional composition of marula fruit? (ii) What are the botanical characteristics of the marula fruit tree? (iii) What are the biochemical, nutritional composition and health benefits of marula fruit and its value-added products such as alcoholic beverages, jam, juice and nuts? (iv) How is marula fruit used in the biotechnology and food industry? The review was prepared strictly in

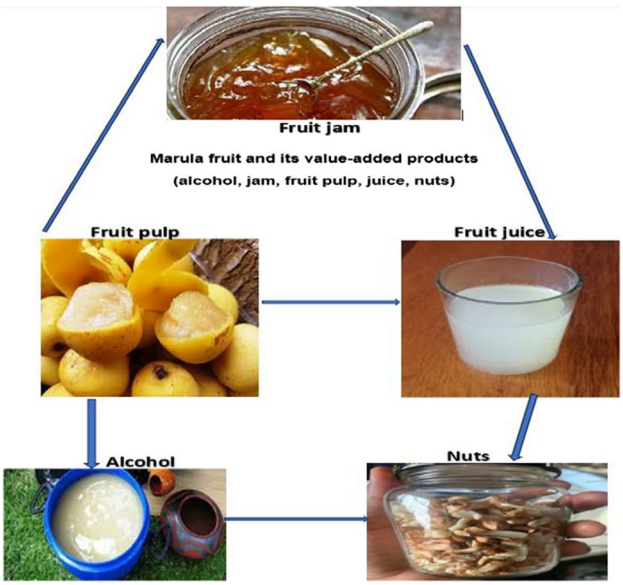

Fig. 1 Marula fruit and its value-added products (jam, juice, nuts, alcohol, pulp)

compliance with Unisa's College of Agriculture and Environmental Sciences Research and Higher Degree Committee, and other relevant local and global regulations.

3 Results and discussion

3.1 Biochemical constituents of marula fruit, its value-added products, and their significant role in human nutrition

Table 1 illustrates the proximate composition (carbohydrates, protein, fibre, and lipids) of marula fruit and its value-added products. Published literature found that marula fruit pulp has a carbohydrate content ranging from 25,300 to 61,700 mg/100 g. For marula nuts, the carbohydrate content ranges from 6400 to 7300 mg/100 g. Additionally, the results show that the fruit pulp (61,700 mg/100 g) has the highest carbohydrate content compared to the nuts (7300 mg/100 g). The difference between the highest marula fruit pulp carbohydrate content (61,700 mg) and average recommended daily intake (130,000 mg) is 68,300 mg. Regarding marula nuts, the difference between marula nut carbohydrate content (7300 mg/100 g) and average recommended daily intake (130,000) is 122.700 mg. The body uses carbohydrates as an energy source Fig. 2, which helps with the fermentation process, participates in the metabolism of triglycerides and cholesterol and aids in the metabolism of insulin and blood sugar [16]. According to the values from the published literature, marula pulp (61,700 mg), contributes roughly about 47% of the total amount of carbohydrates in human nutrition, and marula nuts roughly (7300 mg), is approximately 5.6%. Additionally, the study's findings may suggest that consuming 61,700 mg of marula fruit pulp and its value-added products, which contribute about 47% and marula nuts (7300 mg), which is 5.6% contribution, may potentially assist in preventing illnesses or ailments such as constipation, nausea, and persistent fatigue, which are linked to low carbohydrate intake in the human diet [17, 18].

Concerning protein, published literature results reflect the range of 12,500 to 30,100 mg/100 g in all value-added products. Furthermore, the results show that the highest protein content (30,100 mg/100 g) was reported in marula pulp, followed by marula nuts at 28,400 m/100 g. The difference between marula fruit pulp protein content (30,100 mg) and average recommended daily intake (51,000 mg) is 20,900 mg, and the difference between marula nut protein content (28,400 mg) and average recommended daily intake (51,000 mg) is 24,500 mg. Protein forms a very important part of a healthy diet since it is responsible for building and repairing muscles and bones and making hormones and enzymes, Fig. 3 [19–21]. Values from the published literature indicate that marula fruit pulp could contribute about 59% protein, and marula nuts about 55% of the average recommended daily intake of protein in the human diet. The study findings could mean that consumption of 28,100 mg fresh weigh (FW) of marula fruit pulp and its value-added products, which contribute about 59% and marula nuts (28,400 mg dry weight-DW), which accounts to 55% protein, may play a pivotal role in the development and repair of body cells, while preventing conditions such as weak muscles and poor hair and nail growth, which are linked with low protein content in the human diet [20].

For fibre content, published literature results show a range of 2470 to 10,500 mg/100 g in both marula fruit pulp and nuts. Additionally, results demonstrate that marula fruit pulp has a high fibre content (10,500 mg/100 g) compared to that of the marula nut (2470 mg/100 g), whereas the average recommended daily intake is 28,000 mg/100 g. The difference between the highest marula pulp fibre content (10,500 mg) and fibre average recommended daily intake (28,000 mg) is 17,500 mg. The difference between the marula nut fibre content (2470 mg) and the fibre recommended daily intake (28,000 mg) is 25,530 mg. These values imply that marula fruit pulp could contribute about 36% and marula nuts about 9% of the recommended daily intake of fibre in the human diet. Fibre is important for human health and nutrition because it controls the functions of the digestive system and lowers the total blood cholesterol, Fig. 4 [21]. Additionally,

Table 1 Proximate composition of marula fruit and value-added products (mg/100 g)

	Carbohydrates	Protein	Fibre	Lipids	Literature
Alcohol	nr	nr	nr	nr	
Fruit pulp	25,300–61,700	12,500–30,100	4250–10,500	9700–25,300	[13, 14]
Jam	nr	nr	nr	Nr	nr
Nuts	6400–7300	26,500–28,400	0–2470	28,400–53,000	[15, 16]
ARDI	130,000	51,000	28,000	4500	[19, 27]

ARDI Average recommended daily intake, *Nr* not reported

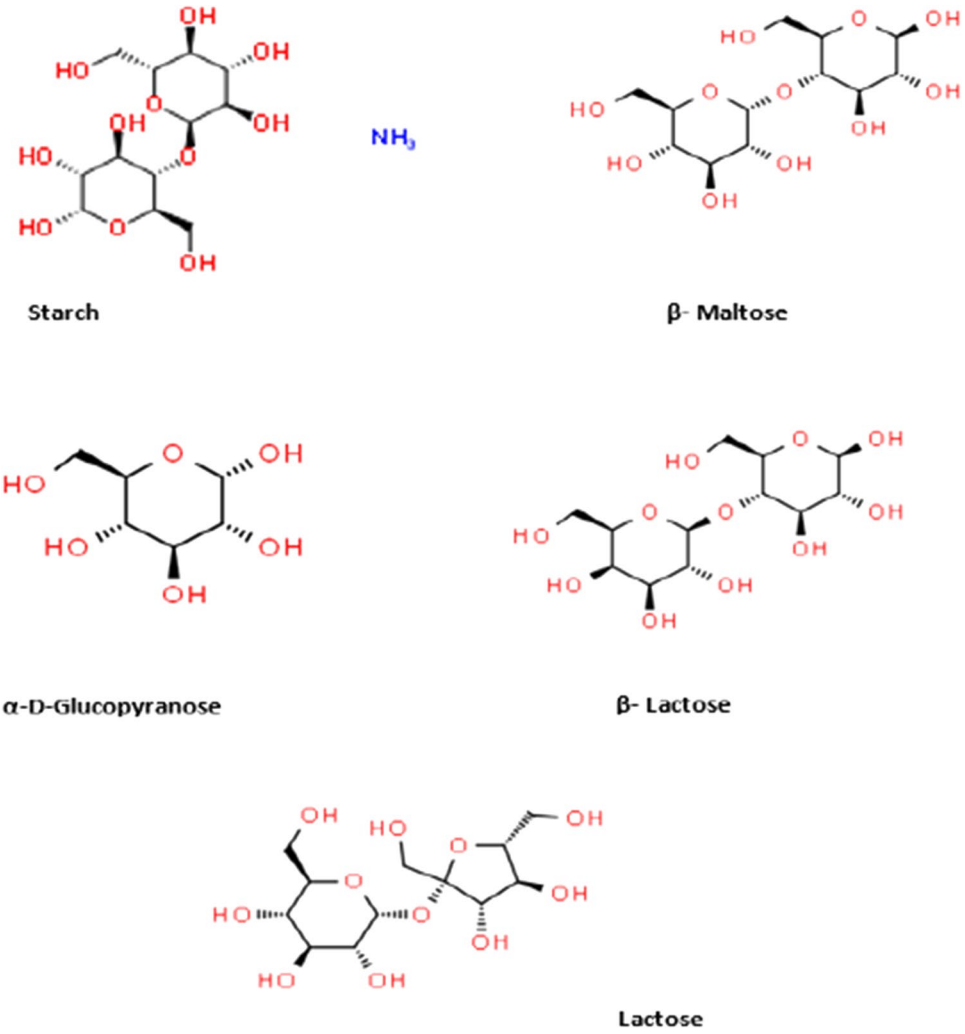

Fig. 2 Various carbohydrates of Marula fruit and its value-added products

dietary fibre helps to solidify the food that has been broken down, which makes it easier for the material to flow through the body and reduces the chance of constipation [22]. Even though values reported from published literature are lower in terms of percentage contribution to recommended daily intake, consumption 10.500 mg FW of marula fruit pulp, which contribute about 36% and marula nuts (2470 mg DW), which contribute about 9% of dietary fibre has the potential to curb or prevent symptom conditions such as constipation, haemorrhoids, obesity, heart-related diseases, diabetes, and bowel cancer, which are associated with low fibre intake, [22–24].

Published literature show that marula fruit contains lipid content ranging from 9700–25,300 mg/100 g, and marula nut lipid content ranges from 28,400–53,000 mg/100 g, with the average recommended daily intake being 4500 mg/100 g. The difference between the highest marula fruit pulp fibre content (25,300 mg) and the recommended daily intake (4,500 mg) is 20,800 mg, and that between marula nut fibre content (53,000 mg) and the average recommended daily intake (4500 mg/100 g) is 48,500 mg. These values mean that the marula fruit pulp and the nuts exceed the average recommended daily intake could contribute by 20,800 mg and 48,300 mg, respectively, of the recommended daily intake of lipids required by humans daily. The role of lipids in humans includes absorption of vitamins A, D and E, Fig. 5 [17, 18]. Moreover, due to their fat-soluble nature, these vitamins can only be absorbed in the presence of lipids [17]. Even though the values obtained from the published literature exceeds the average recommended daily intake, consumption of 100 mg FW of marula fruit pulp and nuts may potentially assist in the prevention of conditions such as alopecia, dermatitis, and intellectual disability, which are associated a low-fat diet in humans. However, optimum amount needs to be determined to avoid health related risk associated with excess lipids in human health and nutrition [17, 18, 25, 28].

Proximate of marula value-added products (fruit pulp, alcohol, jam, and nuts) are shown in Table 2. Published literature show that beta carotene was only reported in fruit pulp, ranging from 0 to 111 mg/100 g, and the difference between beta carotene in marula fruit pulp (111 mg) and the average recommended daily intake (127.5 mg) is 16 mg. These values mean

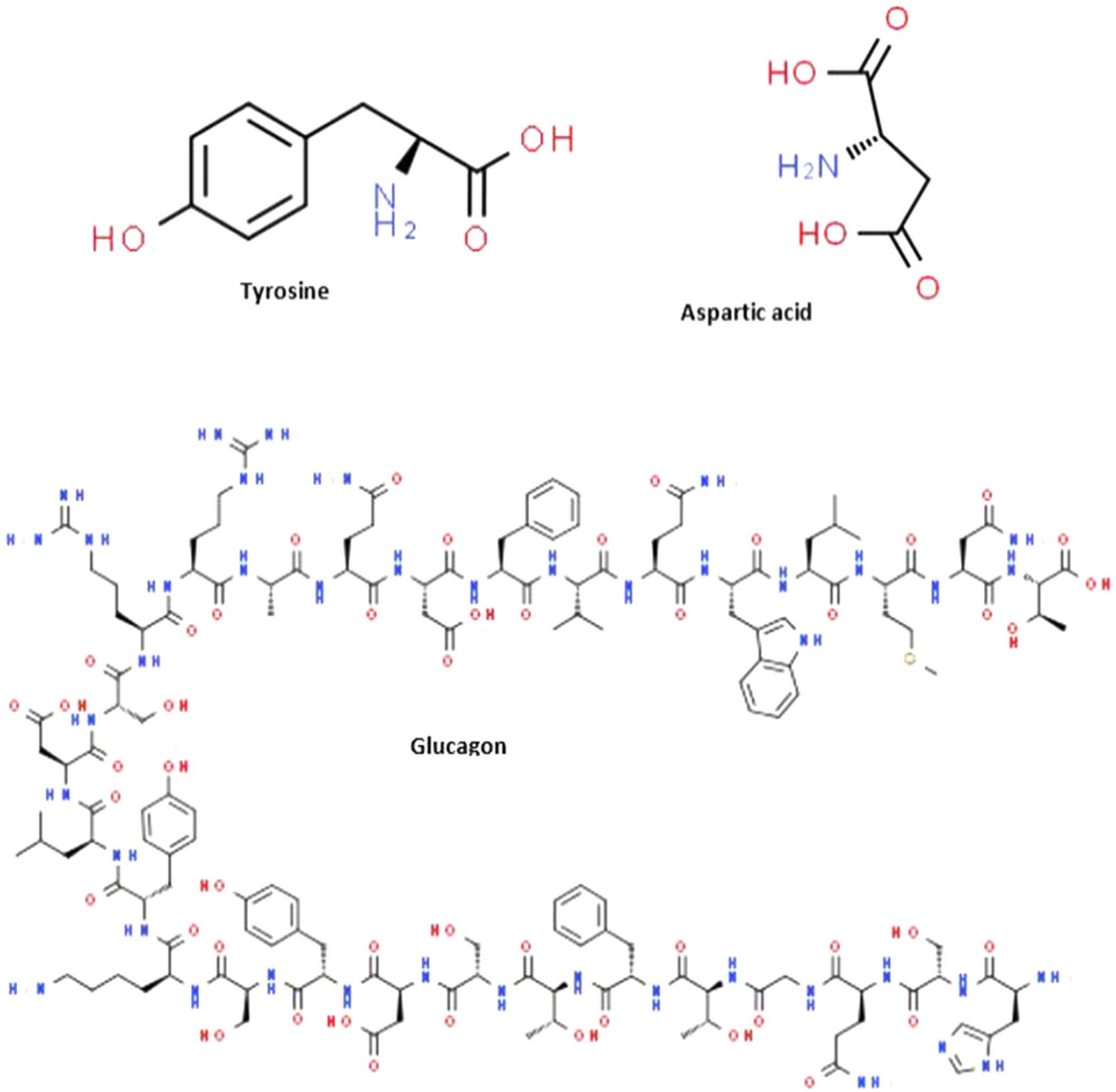

Fig. 3 Various proteins of marula fruit and its value-added products

that marula fruit pulp could contribute about 87% of the beta carotene required by humans daily. Due to its antioxidant properties, beta carotene shields the body from harmful chemicals known as free radicals [13]. Free radicals are known for causing oxidative stress to cells, which can result in a variety of chronic diseases such as cancer [25]. Furthermore, humans transform beta carotene into vitamin A, a strong antioxidant that may be advantageous to the health of the brain, skin, lungs, and eyes [25]. Vitamin A is essential for healthy skin, mucous membranes, a robust immune system, clear vision and eye health [26]. Therefore, findings from the published literature imply that the consumption of marula fruit pulp (111 mg DW), which contribute about 87%, may help prevent conditions such as night blindness, dry skin, and infections, which are related to inadequate beta carotene in the human diet [19, 27–29].

In terms of flavonoid concentration, as shown in Table 2, the fruit pulp ranges from 0 to 56 mg/100 g, and marula alcohol ranges from 0.13 to 2.63 mg/100 g. The recommended daily consumption is 325 mg/100 g. The difference between the flavonoid content of marula fruit pulp (56 mg) and the recommended daily intake (325 mg) is 269 mg. These values

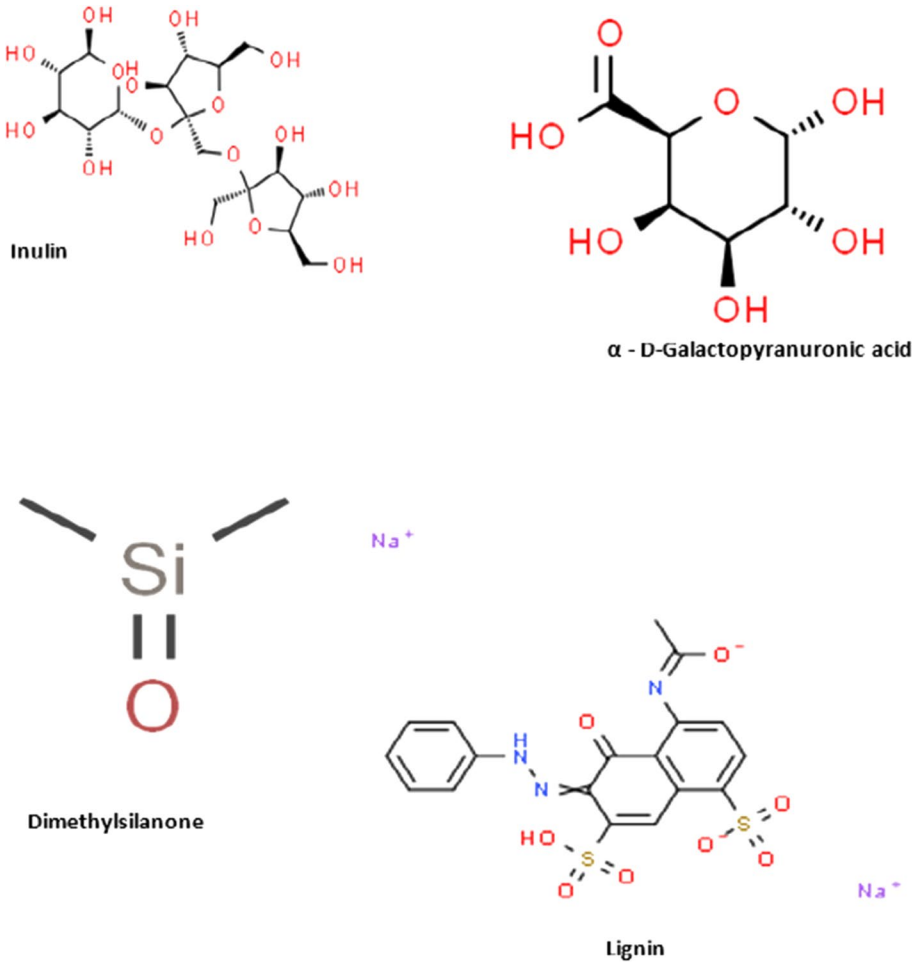

Fig. 4 Various fibers of marula fruit and its value-added products

suggest that marula fruit pulp may contribute approximately 17% of flavonoids required by humans daily. For marula alcoholic beverages, flavonoid content ranges from 0.13 to 2.6 mg/100 g, while the recommended daily intake is 325 mg. The difference between the flavonoid content of marula alcoholic beverage (2.6 mg) and recommended daily intake (325 mg) is 322.4 mg, illustrating that marula alcoholic beverage could potentially contribute about 0.8% of flavonoids required by humans daily. The health benefits of flavonoids are pivotal in humans, because of their anti-cancer capabilities that suppress oxidation, lower inflammation, stop gene mutations and prevent the growth of cancer. Additionally, they support the control of cellular enzyme activities, which involve proteins that activate chemical reactions in cells, Fig. 6 [19, 29]. Additionally, they offer cardio and neuroprotective benefits [27]. Even though study findings from the published literature reveal low values of flavonoid contribution by marula value-added products (pulp and alcoholic beverages), consumption of 2.6 mg FW of marula alcoholic beverage, which contribute about 0.8%, may potentially assist adults in preventing conditions which include diabetes, heart-related disorders, inflammation, excessive bleeding, and nose bleeds, all of which are linked to a low flavonoid diet in humans [17–19, 27].

Regarding phenols (Table 2), published literature results show that phenolic content was reported in marula value-added products (alcoholic beverages and fruit pulp) and that phenolic content of marula alcohol beverage ranges from 1.14 to 963.6 mg/100 g, while the average recommended daily intake is 28.6 mg/100 g. The difference between the highest phenolic content of marula alcoholic beverages (963.6 mg) and recommended daily intake (28.6 mg) is 934.4 mg. This suggests that marula alcoholic beverages may have a phenolic content of roughly 30% more than what is needed daily in the human diet. The study findings could suggest that consumption of 100 mg FW of marula fruit pulp and its value-added products may assist in curbing of conditions such as hypertension, metabolomic challenges and incendiary infections, which are conditions associated with low phenols in human body [19]. However, imbalanced thyroid hormones and kidney damage could be experienced as a result of consuming dietary products with excessive phenol content [28]. In addition, human stroke and early mortality are increased by these situations. Therefore, findings from the published

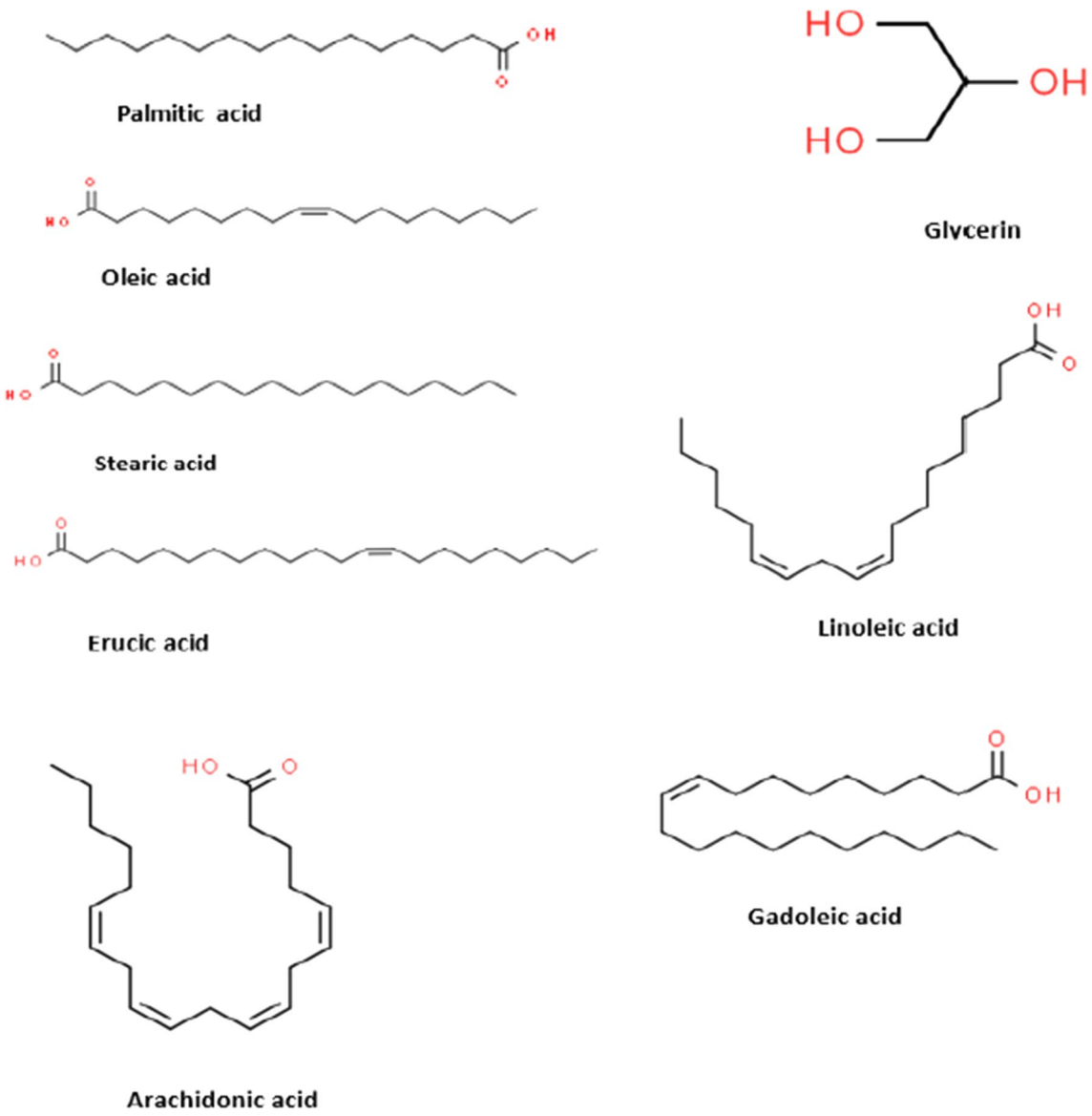

Fig. 5 Various lipids of marula fruit and its value-added products

Table 2 Biochemical constituents of marula fruit and its value-added products (mg/100 g)

	Beta carotene (mg/100 g DW)	Flavonoids (CE/100 g DW)	Phenols (GAE/100 g DW)	Vitamin C (mg/100 g DW)	Literature
Alcohol	nr	0.13–2.63	1.44–963.6	nr	[29]
Fruit pulp	0–111	0–56	226–414	62–179	[13, 30, 31]
Jam	nr	nr	nr	nr	
Nuts	nr	nr	nr	nr	
ARDI	127.5	325	28.6	82.5	[17, 18]

ARDI Average recommended daily intake, *Nr* not reported, *CE* means catechin equivalents, *DW* dry weight, *GAE* garlic means acid equivalents

literature therefore suggest that to avoid the health hazards associated with excessive phenol consumption, it is crucial to precisely determine the level of accepted phenols in marula alcoholic beverages, Fig. 7.

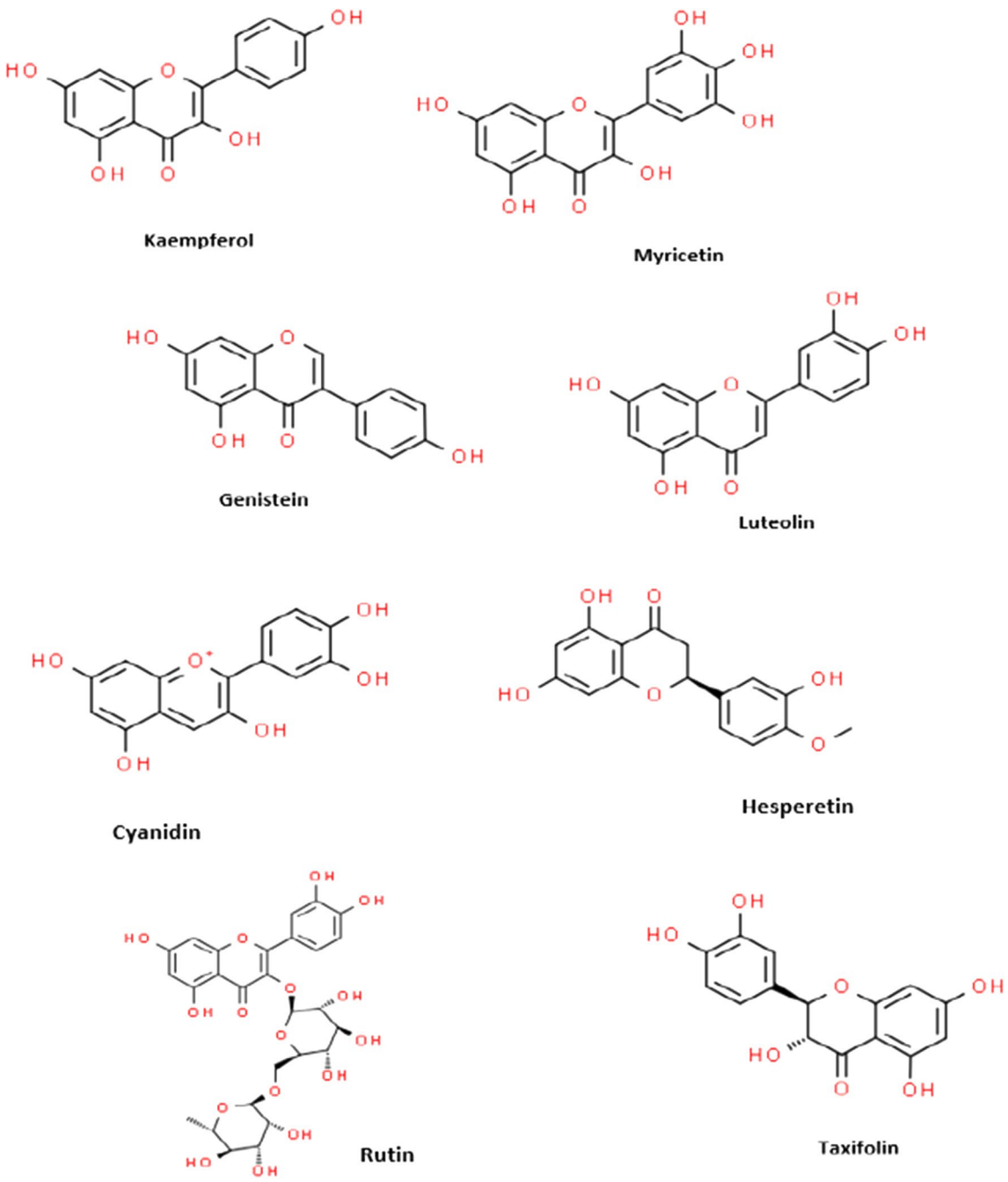

Fig. 6 Various flavonoids of marula fruit and its value-added products

Regarding vitamin C, only one value-added product (marula fruit pulp) was reported to contain the vitamin in the literature, (Table 2). Vitamin C content ranges from 62 to 179 mg/100 g, while the average recommended daily intake is 82.5 mg/100 g. The difference between the highest vitamin C content of marula fruit pulp (179 mg) and average recommended daily intake (82.5 mg) is 96.5 mg. These values indicate that marula fruit pulp as a value-added product contributes about 96.5 mg of vitamin C more than the average recommended daily intake. All tissues in the human body require vitamin C to develop and repair, assisting in the formation of the crucial protein known as collagen, which is necessary for the formation of the human body's blood vessels, tendons, ligaments, and skin [32]. Additionally, it is an antioxidant that shields the body from harm caused by free radicals [33]. Therefore, consumption of 100 mg FW of marula fruit pulp and its value-added products could assist in strengthening immunity, reducing the intensity of allergic reactions and aid in preventing infections. Furthermore, consumption of marula fruit pulp products may also assist in curbing symptoms

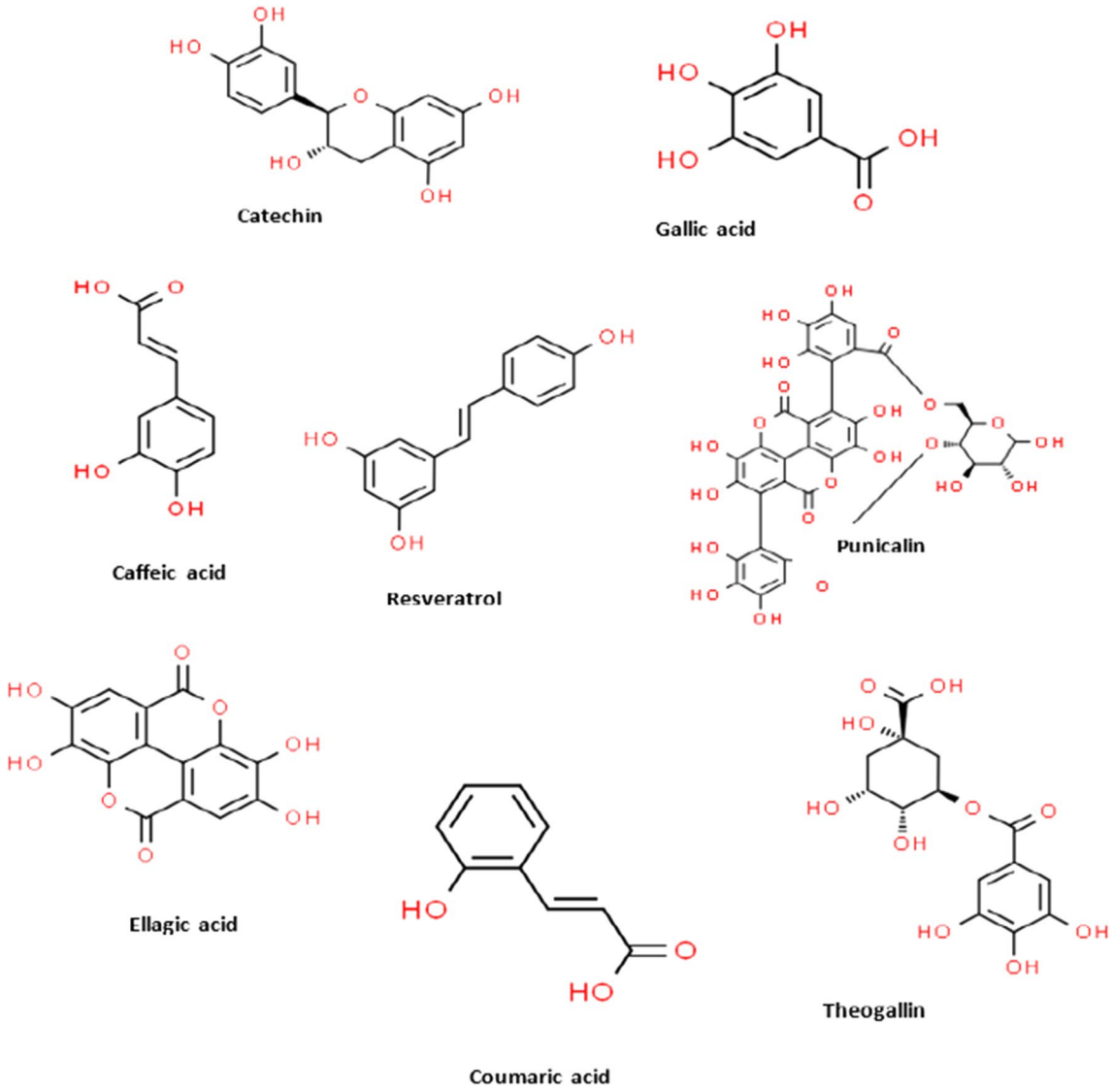

Fig. 7 Various phenols of marula fruit and its value-added products

such as dry hair and skin, excessive bruising, and bleeding, which are indicators of a vitamin C deficiency in the human diet [17–19, 27, 28].

3.2 Macro-minerals of marula fruit, its value-added products and their significant role in human health and nutrition

The macro-minerals of marula fruit pulp and its value-added products (nuts) are shown in Table 3. Published literature indicate that marula fruit pulp and nuts contain macronutrients such as calcium, magnesium, potassium, and sodium. For fruit pulp, the results show that calcium content ranges from 6.2 to 51.7 mg/100 g, while the average recommended daily intake is 1150 mg/100 g. The difference between the highest calcium content of marula fruit pulp (51.7 mg) and the average recommended daily intake (1150 mg) is 1098.3 mg. These values suggest that marula fruit pulp contributes about 4.5% of the calcium required by humans daily. Results show that calcium concentration in marula nuts ranges from 106 to 165 mg/100 g, while the average recommended daily intake is 1150 mg/100 g. The difference between the maximum calcium content of marula nuts (156 mg) and the daily recommended consumption is (1150 mg) is 994 mg. According to the published literature, marula nuts may provide roughly 13.6% of the daily calcium intake advised for people.

Table 3 Macro-minerals content of marula fruit and its value-added products (mg/100 g)

	Calcium	Magnesium	Potassium	Sodium	Literature
Alcohol	nr	nr	nr	nr	
Fruit pulp	6.2–51.7	10.5–167.1	44.5–133.4	2.6–14.9	[15, 13]
Jam	nr	nr	nr	nr	
Nuts	106–156	193–467	0–677	nr	[15]
ARDI	1150	330	2450	2300	[17, 18]

ARDI Average recommended daily intake, *Nr* not reported

Calcium is necessary for the human body's muscles to contract and nerves to transmit signals from the brain to every area of the body [27]. In addition, calcium aids in the release of hormones that have an impact on numerous bodily activities and helps blood arteries carry blood throughout the body [17]. Although values obtained from the published literature are low in terms of the percentage contribution to the nutritional daily recommendation for humans, consumption of marula fruit pulp (51.37 mg FW), which contribute about 4.5%, and its value-added products such as nuts (156 mg DW), which contribute about 13.6%, could potentially help prevent conditions such as fatigue and muscle aches, which are linked to low calcium intake in the human diet.

Regarding the magnesium content of marula fruit and its value-added products, published literature results in Table 3 show that only fruit pulp and nuts are reported in the literature. Study results illustrate that the magnesium content of marula fruit pulp ranges from 10.5 to 167.1 mg/100 g, while the magnesium average recommended daily intake is 330 mg/100 g. The difference between the highest magnesium content (167 mg) of marula fruit pulp and average recommended daily intake (330 mg) is 163 mg. These values imply that marula fruit pulp and its value-added products could contribute about 50.6% of magnesium required by humans daily.

The published literature findings presented in Table 3 indicate that the magnesium concentration of marula nuts varies from 193 to 467 mg/100 g, while 330 mg/100 g is the average recommended daily intake. There is a discrepancy of 137 mg between the maximum magnesium content of marula nuts (467 mg) and the recommended daily consumption (330 mg). The published literature suggests that marula fruit nuts may provide an additional 137 mg than what is normally advised for humans to consume daily. In human health and nutrition, magnesium is needed to sustain healthy immune systems, maintain normal nerve, and muscle function, stabilise the heartbeat and maintain strong bones [34, 35]. Additionally, it assists in controlling blood sugar levels [27]. The values obtained from the published literature for marula fruit pulp and nuts demonstrate that consumption of marula fruit pulp (167.1 mg FW) and nuts (100 mg DW), could assist in curbing various conditions, for example poor appetite, nausea, constant fatigue, muscle cramps and unusual heartbeat, which are symptoms linked to a diet low in magnesium. However, optimum magnesium amounts needed to be consumed from marula nuts should be determined to avoid health risks associated with excessive magnesium, since it could cause conditions, such as vomiting, diarrhoea and abdominal stomach cramps [17–19, 27].

Regarding potassium content, Table 3 shows that potassium content only for marula fruit pulp and nuts has been reported in the literature. For marula fruit pulp, study results show a range of 44.5 to 133.4 mg/100 g, while the average recommended daily intake is 2 450 mg/100 g. The difference between the highest potassium content (133.4 mg) of marula fruit pulp and average recommended daily intake (2450 mg) is 2317 mg. These values could mean that marula fruit pulp and its value-added products could contribute about (5.4%) of potassium required by humans daily. For marula nuts, study results show a range of 0–667 mg/100 g, while the average recommended daily intake is 2450 mg/100 g. The difference between the highest potassium content (677 mg) of marula nuts and average recommended daily intake (2450) is 1 773 mg. These values suggest that marula nuts as a value-added product could contribute about 27.6% of the potassium required by humans daily.

Potassium is necessary for the human body to maintain normal fluid levels inside cells [16]. In addition, it also helps maintain a normal heartbeat and supports nerve and muscle function [19, 36]. Furthermore, food rich in potassium could help to mitigate some of the adverse consequences of high blood pressure caused by salt [17, 18, 27]. Even though the values obtained from the published literature are low, the consumption of marula fruit pulp (133.1 mg FW), which contribute about (5.4%) and nuts (2450 DW), which contribute (27.6%), could potentially prevent several symptom conditions such as weak muscles, paralysis, and abnormal heartbeat, which are symptoms related to low potassium intake in the human diet.

Table 3 shows that only fruit pulp was reported to contain sodium content in the literature. Marula fruit pulp sodium content ranges from 2.6 to 14.9 mg/100 g, while the average recommended daily intake is 2300 mg. The difference

between the highest sodium content (14.9 mg) of marula fruit pulp and average recommended daily intake (2300 mg) is 2 250.1 mg. These values suggest that marula fruit pulp could contribute about 0.64% of the sodium required by humans daily. To conduct nerve impulses, contract and relax muscles and maintain the ideal balance of water and minerals, the human body needs a small amount of sodium [17]. Even though the values obtained from this published literature were lower than the average recommended daily intake, consumption of marula fruit pulp (2.6 mg FW) and its value-added products, which contribute about (0.64%), could assist in curbing symptom diseases such as loss of energy, low appetite, fatigue, muscle cramps and headaches, which are linked with low sodium intake in the human diet [17–19].

3.3 Micro-minerals of marula fruit and its value-added products and their role in human nutrition

Table 4 presents the micro-minerals of marula fruit pulp and its value-added products. Published literature results show that the micro-minerals content only of marula fruit pulp and nuts was reported in the literature. The results show that marula pulp copper content ranges from 0.04 to 1.1 mg/100 g, while the average recommended daily intake is 1.3 mg/100 g. The difference between maximum copper content of marula pulp (1.1 mg) and average recommended daily intake (1.3 mg) is 0.2 mg. These values could mean that marula fruit pulp contributes about 84.6% of the copper required by humans. Copper is necessary for brain cell development in humans [18]. Moreover, the human body uses copper for several essential functions, including the creation of energy, connective tissues, and blood vessels [19, 36]. The values obtained from the published literature indicate that the consumption of marula fruit pulp (1.1 mg FW), which contribute about (84%), and its value-added products could assist in curbing symptoms such as anaemia, neutropenia, irregular heartbeat, skin-related challenges, and thyroid problems, which are conditions associated with low copper intake by humans. Regarding copper, data from published literature show that marula nuts ranges from 0 to 2 mg/100 g, while the average recommended daily intake is 1.3 mg/100 g. The difference between the maximum copper content of marula nuts (2 mg) and the average recommended daily intake (1.3 mg) is 0.7 mg. These values indicate that the value-added products of marula nuts could exceed the average recommended daily intake for humans by 0.7 mg. However, consumption of (1.3 mg DW) of marula nuts, may assist in curbing conditions such as anaemia, bone fractures, irregular heartbeat, and thyroid problems, which are symptoms associated with low copper in human diet [19]. Furthermore, the study found that the nutritional and health benefits of value-added products of marula nuts exceed the average recommended daily intake by 54%, which suggests that the optimal consumption rate should be determined, as excessive consumption of copper can be toxic to humans [27].

Only marula fruit pulp and nuts have been reported in the literature regarding iron content (Table 4). Published literature show that marula fruit pulp iron content ranges from 0.1 to 8.8 mg/100 g, while the average recommended daily intake is 11.5 mg/100 g. The difference between the highest marula fruit pulp iron content (8.8 mg) and the average recommended daily intake (11.5 mg) is 2.7 mg. This means that marula fruit pulp and its value-added products could contribute about 76.5% of the average recommended daily intake of iron required by humans daily. According to Achaglinkame et al. [17], the human body needs iron to grow and thrive, making it a vital mineral for the enhancement of human health. Haemoglobin, a protein found in red blood cells that transports oxygen from the lungs to every area of the body, and myoglobin, a protein found in muscles, depend on iron for optimisation [18]. According to the values obtained from the published literature, consumption of marula fruit pulp (8.8 mg FW), which contribute about (76.5%), and its value-added products could assist in curbing conditions such as constant fatigue, abnormal heartbeat, and respiratory challenges, which are symptoms linked to low iron in the human diet [19].

As per the published literature (Table 4), the iron content of marula nuts ranges from 264 to 677 mg/100 g, while the average recommended daily intake is 11.5 mg/100 g. The difference between the highest marula nut iron content (677 mg) and the average recommended daily intake (11.5 mg) is 665.5 mg. These values indicate that marula nuts exceed

Table 4 Micro-minerals (mg/100 g) of marula fruit and its value-added products

	Copper	Iron	Zinc	Literature
Alcohol	nr	nr	nr	
Fruit pulp	0.04–1.1	0.1–8.8	0.81–3	[15, 13]
Jam	nr	nr	nr	
Nuts	0–2	264–677	2.7–6.2	[15]
ARDI	1.3	11.5	10	[17, 18, 19, 27]

ARDI Average recommended daily intake, *Nr* not reported

the average recommended daily intake by 665 mg in iron content, which might cause a health risk when consumed excessively. Vital organs such as the liver are typically where extra iron is stored in the human body. The accumulated iron in the body can cause significant harm in the future, potentially leading to conditions such as organ failure and chronic illnesses, e.g. diabetes, heart failure and liver disease. Therefore, consumption of 100 mg DW of marula nuts could assist in curbing conditions such as excessive fatigue and poor respiratory system. However, determination of the optimal amount of marula nut consumption might assist in preventing health-related risks associated with excess iron intake [17, 18].

The zinc content for only marula fruit pulp and nuts was reported in the literature, as shown in Table 4. Marula fruit pulp zinc content ranges from 0.81 to 3 mg/100 g, while the average recommended daily intake is 10 mg/100 g. The difference between the highest marula fruit pulp zinc content (3 mg) and the average recommended daily intake (10 mg) is 7 mg. These values could mean that marula fruit pulp contributes about 43% of the zinc required by humans daily. The results show that zinc content of marula nuts ranges from 2.7 to 6.2 mg/100 g, while the average recommended daily intake is 10 mg/100 g. The difference between the maximum marula nut zinc content (6.2 mg) and the average recommended daily intake (10 mg) is 3.8 mg. This could mean that marula nuts contribute about 62% of the average recommended daily intake of zinc required by humans. The human immune system depends on the element zinc to operate at its best [20]. Zinc also has a major impact on wound healing, cell proliferation and division and the breakdown of carbohydrates [18, 27, 37–39]. The values obtained from the published literature could mean that marula fruit pulp (3 mg), contributes about 42% of the zinc required by humans daily, and marula nuts (6.2 mg), could contribute about 62% of the average recommended daily intake of zinc required by humans. This could imply that consuming marula fruit pulp (3 mg FW), its value-added products and nuts (6.2 mg DW), can potentially help prevent conditions such as weak central nervous systems, poor reproductive systems, and gastrointestinal-related issues, all of which are associated with low zinc diets in relation to human health and nutrition [17, 18, 40].

3.4 Future prospect of marula fruit and its value-added products

3.4.1 Postharvest practices of marula fruit

A method for handling, storing, and transporting agricultural products like fruits is known as post-harvest practice [41]. Environmental factors, such as temperature, humidity, preservatives, and atmospheric conditions, have a major impact on fruit post-harvest quality [42]. Understanding effective storage techniques, processing facilities, and preservatives in sufficient detail is necessary to obtain a greater understanding of the processes involved in storing marula fruits and their value-added products, such as juice, jam, nuts, and alcoholic beverages.

3.5 Processing, storage and packaging of marula fruit and its value-added products

Food security is improved by agro processing since it lowers post-harvest losses and increases the supply of processed and preserved foods according to [43]. Extended shelf life of value-added items, like jam, juice, nuts, and alcohol beverages, provide a more consistent food supply in urban, semi-urban, and rural areas [44]. Therefore, to improve the quality of marula value-added products and increase the availability of food and nutrition in both urban and rural communities, a deeper understanding of the efficient processing procedure, types of preservatives, and packaging materials is needed [43].

3.6 Commercialisation of marula fruit and its value-added products

The process of introducing a new value-added products like alcohol beverages, jam, juice, and nuts to the wider market is known as commercialization, and it typically involves several stages, starting with the product introduction, continuing through to its mass production and acceptance [44, 45]. Most marula fruit's value-added products are still underutilised according [45, 46]. This is a significant obstacle that most value-added products from native fruits must overcome, and it stems mostly from a general lack of interest because they cannot afford the capital expenditure necessary for processing, preservation, and packaging [13, 45, 46]. Therefore, timely marketing campaigns, research, and development will stimulate interest in investing in value-added marula products, thereby enhancing the rural economy through economic emancipation—people will begin to produce and sell goods to earn a living and support their families.

4 Conclusion

Marula fruit is one of the underutilised fruits in Southern Africa. It is appreciated by rural communities mainly for its value-added products such as alcoholic beverages, nutritious pulp, nuts, and jam, which are beneficial to human health and nutrition. It contains numerous biochemical components such as calcium, flavonoids, vitamin C, iron, and zinc, which play a vital role in preventing most conditions such as poor immune system, blindness, poor nervous system, and heart-related challenges. There is still an opportunity for the fruit processing industry and rural communities to develop and explore the utilisation of marula fruit for the development of different value-added products such as alcoholic beverages, pulp, nuts, and jam. This could create business opportunities for rural and urban communities through the sale of these products, helping to accelerating SDG 1 (no poverty) and SDG 2 (zero hunger). Consuming marula fruit and its value-added products, which are rich in biochemical compounds, is linked to curbing various chronic diseases such as heart diseases, diabetes, cancer and many more. The health benefits of marula fruit have been established, but there is still limited knowledge on the nutritional benefits of processed marula products such as alcohol, jam, and juice. Therefore, more research in this area is necessary to determine their role in human health and nutrition. Furthermore, it would be important to extract biochemical components of marula fruit and utilise them as potential functional ingredients in different food products. Promoting the commercialisation of marula fruit products will improve both human health and create economic emancipation in rural and semi-urban communities, where food scarcity is still a challenge due to factors such as affordability and accessibility. Lastly, since biochemical constituents such as phenols. Lastly, the study revealed that marula fruit and its value-added products contained excessive amounts of vitamin C, lipids, and iron. Therefore, it is crucial to carry out a toxicological investigation to ascertain the ideal quantity needed to prevent health risks and hazards linked to the consumption of these products.

Author contributions Ms Lerato Isobel Lekhuleni was involved in study design, data gathering, analysis, interpretation and write-up. Dr MK Maluleke was involved in study design, data gathering, analysis, interpretation and write-up. Dr A Shabalala was involved in data analysis, interpretation and write-up.

Funding Open access funding provided by University of South Africa.

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

Declarations

Competing interests The authors declare that they have no conflict of interest.

References

1. Shackleton SE, Shackelton CM, Cunningham AB, Lombard C, Sullivan CA, Netshiluvhi TR. Knowledge on *Sclerocarya birrea* subsp. caffra with emphasis on its importance as a non-timber forest product in South and southern Africa: a summary. Part 1: taxonomy, ecology and role in rural livelihoods. South Afr For J. 2002;194:27–41. https://doi.org/10.1080/20702620.2002.10434589.
2. Phofuetsile K, Jaenicke H, Muok B. Propagation and management. In: Hall JB, O'Brein EM, Sinclair FL, editors. *Sclerocarya birrea*: a monograph. Bangor: University of Wales, School of Agriculture and Forest Sciences; 2002. p. 93–101.
3. Mokgolodi NC, Ding Y, Setshogo MP, Ma C, Liu Y. The importance of an indigenous tree to Southern African communities with specific reference to its domestication and commercialization: a case of the Marula tree. Food Stud J China. 2011;13:36–44. https://doi.org/10.1007/s11632-011-0110-1.
4. Maroyi A. Local knowledge and use of Marula [*Sclerocarya birrea* (a. rich.) hochst.] in South-central Zimbabwe. Indian J Tradit Knowl. 2013;12:1–6.
5. Hamidou A, Iro DG, Boube M, Malik TS, Ali M. Potential germination and initial growth of *Sclerocarya birrea* (A. Rich.) Hoscht., in Niger. J Appl Biosci. 2014;76:6433–43. https://doi.org/10.4314/jab.v76i1.12.

6. Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P, Kwesiga FR. Indigenous fruit trees in the tropics: domestication, utilization and commercialization. Wallingford: CABI Publishing; 2008. p. 1–21.
7. Pfukwa TM, Chikwanha OC, Katiyatiya CL, Fawole OA, Manley M, Mapiye C. Southern African indigenous fruits and their by products: prospects as food antioxidants. J Funct Foods. 2020;75:1–17. https://doi.org/10.1016/j.jff.2020.104220.
8. FAO/UN. Linkages between biodiversity, food and nutrition. Rome: Commission of genetic resources for Food and Agriculture; 2013. p. 1–114.
9. Andualem M. Nutritional and anti-nutritional characteristics of okra (*Abelmoschus esculents* (L.) Moench) accessions grown in Pawe District Northwestern Ethiopia. IJAB. 2023. https://doi.org/10.47278/journal.ijab/2022.040.
10. Chivandi E, Mukonowenzou N, Nyakudya T, Erlwanger KH. Potential of indigenous fruit-bearing trees to curb malnutrition, improve household food security, income and community health in Sub-Saharan Africa: a review. Food Res Int. 2015;76:980–5. https://doi.org/10.1016/j.foodres.2015.06.015.
11. Saeed MZ, Hayat H, Shafiq F, Tareen WUH. Assessing the prospects and challenges of organic agriculture in the pothwar region of Punjab Pakistan. IJAB. 2023. https://doi.org/10.47278/journal.ijab/2022.037.
12. Fortin JS, Royal AB, Kuroki K. Concurrent thoracic mesothelioma and thyroid C-cell adenoma with amyloid deposition in an aged horse. Vet Med. 2018;4(1):63–70. https://doi.org/10.1002/vms3.87.
13. Omotayo AO, Aremu AO. Underutilized African indigenous fruit trees and food–nutrition security: opportunities, challenges, and prospects. Food Energy Secur. 2020;9(3):1–16. https://doi.org/10.1002/fes3.220.
14. Falowo AB, Fayemi PO, Muchenje V. Natural antioxidants against lipid-protein oxidative deterioration in meat and meat products. A review Food Res Int. 2014;64:171–81. https://doi.org/10.1016/j.foodres.2014.06.022.
15. Mashau ME, Kgatla TE, Makhado MV, Mikasi MS, Ramashia SE. Nutritional composition, polyphenolic compounds and biological activities of Marula fruit (*Sclerocarya birrea*) with its potential food applications: a review. Int J Food Prop. 2022;25(1):1549–75. https://doi.org/10.1080/10942912.2022.2064491.
16. Attiogbe FK, Abdul-Razak T. Evaluation of the physicochemical properties of northern Ghana *Sclerocarya birrea* seed oil and proximate analysis of the process waste. Afr J Food Sci. 2016;10(4):48–53. https://doi.org/10.5897/AJFS2016.1425.
17. Hiwilepo-van Hal P, Bille PG, Verkerk R, van Boekel MA, Dekker M. A review of the proximate composition and nutritional value of Marula (*Sclerocarya birrea* subsp. caffra). Phytochem Rev. 2014;13(4):881–92. https://doi.org/10.1007/s11101-014-9352-6.
18. Kamanula M, Munthali CY, Kamanula JF. Nutritional and phytochemical variation of Marula (*Sclerocarya birrea*) (subspecies caffra and birrea) fruit among nine international provenances tested in Malawi. Int J Food Sci. 2022. https://doi.org/10.1155/2022/4686368.
19. Achaglinkame MA, Aderibigbe RO, Hensel O, Sturm B, Korese JK. Nutritional characteristics of four underutilized edible wild fruits of dietary interest in Ghana. Foods. 2019;8(3):1–12. https://doi.org/10.3390/foods803010.
20. Uusiku NP, Oelofse A, Duodu KG, Bester MJ, Faber M. Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: a review. J Food Compost Anal. 2010;2(6):499–509. https://doi.org/10.1016/j.jfca.2010.05.002.
21. Maluleke MK, Moja SJ, Nyathi M, Modise DM. Nutrient concentration of African horned cucumber (*Cucumis metuliferus* L.) fruit under different soil types, environments, and varying irrigation water levels. Horticulturae. 2021;7(4):1–16. https://doi.org/10.3390/horticulturae7040076.
22. Amarteifio JO, Mosase MO. The chemical composition of selected indigenous fruits of Botswana. J Appl SCI Environ. 2006;10(2):43–7. https://doi.org/10.4314/jasem.v10i2.43659.
23. Tian M, Pak S, Ma C, Ma L, Rengasamy KR, Xiao J, Chen F. Chemical features and biological functions of water-insoluble dietary fiber in plant-based foods. Crit Rev Food Sci Nutr. 2022. https://doi.org/10.1080/10408398.2022.2110565.
24. Chiba M, Tsuji T, Nakane K, Komatsu M. High amount of dietary fiber not harmful but favorable for Crohn disease. Perm J. 2015;19(1):1–4.
25. Snauwaert E, Paglialonga F, Vande-Walle J, Wan M, Desloovere A, Polderman N, Shroff R. The benefits of dietary fiber: the gastrointestinal tract and beyond. Pediatr Nephrol. 2023;38(9):2929–38. https://doi.org/10.1007/s00467-022-05837-2.
26. Trautwein EA, McKay S. The role of specific components of a plant-based diet in management of dyslipidemia and the impact on cardiovascular risk. Nutrients. 2020;12(9):1–21. https://doi.org/10.3390/nu12092671.
27. Yang C, Zhao A, Ren Z, Zhang J, Wang P, Zhang Y. Vitamin A nutritional status of urban lactating Chinese women and its associated factors. Nutrients. 2022;14(15):3184. https://doi.org/10.3390/nu14153184.
28. Morales JO, Valdés K, Morales J, Oyarzun-Ampuero F. Lipid nanoparticles for the topical delivery of retinoids and derivatives. Nanomedicine. 2015;10(2):253–69. https://doi.org/10.2217/nnm.14.159.
29. Tuckeldoe RB, Maluleke MK, Adriaanse P. The effect of coconut coir substrate on the yield and nutritional quality of sweet peppers (*Capsicum annuum*) varieties. Sci Rep. 2023;13(1):1–13. https://doi.org/10.1038/s41598-023-29914-0.
30. Borochov-Neori H, Judeinstein S, Greenberg A, Fuhrma B, Attias J, Volkova N, Aviram M. Phenolic antioxidants and antiatherogenic effects of Marula (*Sclerocarrya birrea* Subsp. caffra) fruit juice in healthy humans. J Agric Food Chem. 2008;56(21):9884–91.
31. Tebeila PM. Characterisation and profiling of bioactive constituents, nutrients, and minerals in Marula wine during the fermentation period. Doctoral Thesis, University of Limpopo. 2022. https://doi.org/10.1002/jsfa.6196.
32. Stadlmayr B, Charrondiere UR, Eisenwagen S, Jamnadass R, Kehlenbeck K. Nutrient composition of selected indigenous fruits from sub-Saharan Africa. J Sci Food Agric. 2013;93(11):2627–36. https://doi.org/10.1002/jsfa.6196.
33. Hiwilepo-van Hal P, Bille PG, Verkerk R, Dekker M. The effect of temperature and time on the quality of naturally fermented Marula (*Sclerocarya birrea* subsp. Caffra) juice. LWT. 2013;53(1):70–5. https://doi.org/10.1016/j.lwt.2013.02.021.
34. Raice RT, Chiau E, Sjoholm I, Bergenstahl B. The loss of aroma components of the fruit of *Vangueria infausta* (African medlar) after convective drying. Dry Technol. 2015;33(8):887–95. https://doi.org/10.1080/07373937.2014.995804.
35. Kebonye M, Lekalake RK, Sekwati-Monang B, Selebatso T, Setlalekgomu MR, Sonno K, Haki GD. Proximate composition and determination of the physicochemical characteristics of Mmilo (*Vangueria infausta*) oil from Botswana. Greener J Biol Sci. 2021;11(1):31–6.
36. Zhang YY, Stockmann R, Ng K, Ajlouni S. Opportunities for plant-derived enhancers for iron, zinc, and calcium bioavailability: a review. Compr Rev Food Sci Food Saf. 2021;20(1):652–85. https://doi.org/10.1111/1541-4337.12669.
37. Akbari B, Baghaei-Yazdi N, Bahmaie M, Mahdavi AF. The role of plant-derived natural antioxidants in reduction of oxidative stress. BioFactors. 2022;48(3):611–33. https://doi.org/10.1002/biof.1831.

38. Caswell H. The role of fruit juice in the diet: an overview. Nutr Bull. 2009;34(3):273–88.
39. Bhowmik D, Chiranjib K, Kumar S. A potential medicinal importance of zinc in human health and chronic. Int J Pharmacol. 2010;1(1):05–11.
40. Sangeetha VJ, Dutta S, Moses JA, Anandharamakrishnan C. Zinc nutrition and human health: overview and implications. Foods. 2022. https://doi.org/10.1002/efd2.17.
41. Chen Z, Zhu C. Combined effects of aqueous chlorine dioxide and ultrasonic treatments on postharvest storage quality of plum fruit (*Prunus salicina* L.). Postharvest Biol Technol. 2011;61(2–3):117–23.
42. Mphahlele RR, Fawole OA, Mokwena LM, Opara UL. Effect of extraction method on chemical, volatile composition and antioxidant properties of pomegranate juice. S Afr J Bot. 2016;103:135–44.
43. Taghian DS, van der Goot AJ. Challenges and solutions of extracting value-added ingredients from fruit and vegetable by-products: a review. Crit Rev Food Sci Nutr. 2023;63(25):7749–71. https://doi.org/10.1080/10408398.2022.2049692.
44. Sharma K, Mahato N, Cho MH, Lee YR. Converting citrus wastes into value-added products: economic and environmently friendly approaches. Nutr J. 2017;34:29–46. https://doi.org/10.1016/j.nut.2016.09.006.
45. Devi MP, Bhowmick N, Bhanusree MR, Ghosh SK. Preparation of value-added products through preservation. In: Value addition of horticultural crops: recent trends and future directions. Springer; 2015. p. 13–41.
46. Kore VT, Devi HL, Kabir J. Packaging, storage and value addition of aonla, an underutilized fruit. India Fruits. 2013;68(3):255–66. https://doi.org/10.1051/fruits/2013064.