

Review

Exploring the biochemical constituents, medicinal properties and potential commercialization of *Ximenia caffra* Sond. for enhancing human health: a comprehensive review

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Received: 1 August 2023 / Accepted: 21 November 2023

Published online: 20 January 2024

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Abstract

In the realm of sustainable development, universal access to safe and nutritious food and medicine is paramount, particularly championed by the “Zero Hunger” initiative. This article comprehensively reviews the status of research on *Ximenia caffra* Sond, commonly known as Wild sour plum, an underutilized plant offering versatile applications in both food and medicine. The study delves into *X. caffra*'s phytochemistry, drawing from peer-reviewed articles sourced from Scopus, Web of Science, Google Scholar, and ScienceDirect. The findings illuminate the plant's richness in diverse bioactive compounds such as polyphenols, flavonoids, tannins, and terpenoids, underpinning its multifaceted medicinal and nutritional properties. The nutritional and phytochemical abundance of *X. caffra* underscores a compelling case for advancing from sporadic tribal consumption to full-scale commercialization, necessitating further research to optimize cultivation techniques and extraction methods for commercial products.

Article Highlights

Bioactive Wealth: *Ximenia caffra*, a source of polyphenols, flavonoids, and terpenoids, holds robust medicinal and nutritional promise.

Market Shift: Findings highlight the need for commercialisation of *X. caffra* use through cultivation and extraction for product output.

Zero Hunger Ally: *X. caffra* emerges as vital for safe, nutritious food, supporting SDG goals, the “Zero Hunger” initiative.

Keywords Bioactive compounds · Commercialisation · Medicinal properties · *Ximenia caffra* · Zero Hunger initiative

1 Introduction

People have different reasons for the consumption of specific groups of fruit; however, the main traditional aim for consumption is the potential supply of energy and nutrients [1]. Production of highly nutritional-dense crops is required to meet the world's growing nutritional demand in the twenty-first century. Producers of conventional crops such as grains, vegetable and fruits face intense pressure to grow crops in the best conditions due to the ongoing demand for high-quality food from both developed and developing nations. An ongoing quest for “new” crops that may be added to

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the food supply and/or are commercially viable is essential to addressing the world's food and medicinal shortages [2–4]. This highlights the need to introduce alternative crops that perform well under adverse conditions in order to meet the nutritional and medical demand, globally. In recent years, studies on climate change adaptation have focused notably on the production and use of underutilized food crops, including wild edible fruit species [5]. As a result, the sustainable development goals (SDG) have garnered more study interest towards eradication of hunger under slogan (Zero hunger). Wild edible fruit crops, according to [1, 6] are those that grow naturally without regular access to agricultural inputs like irrigation and fertilizer. The Olacaceae family of flowering plants in Sub-Saharan Africa has *Ximenia caffra* (*X. caffra*) commonly known as Wild sour plum, which is one of the several examples of underutilized wild fruit trees that can be consumed and, it grows naturally throughout Sub-Saharan Africa [7–10]. The tree can sometimes be found in grasslands and woodlands, as well as on rocky outcrops. In South Africa, the tree is commonly found in Kwazulu Natal and Limpopo Province [11, 12]. In terms of utilisation, different authors reported that ripe fruit is abundant in potassium, protein, and vitamin C [13]. The oil content of the seed is range between 50 and 65% [14, 15]. Fruits are finest consumed when slightly overripe, but they can also be used to make value-added products such as jam, desserts, jellies and it can be included in porridge. Regarding medicinal use, to calm red, irritated eyes, a decoction of the leaves is used as a wash. Infusions of the roots and leaves are taken for abdominal pain, bilharziasis, and dysentery [16, 17]. The roots are also used as a treatment for diarrhoea and dysentery [13]. Roots that have been grounded up are used in soup, as an aphrodisiac in beer, and as a treatment for sores to hasten healing [13]. Dried leaf powders are given orally for fever and sterility, while leaf extracts are gargled for tonsillitis and used as a vermifuge [18]. In order to treat morning sickness during pregnancy, the roots are decocted and used to make porridge. Moreover, the root decoction is also used to treat infertility [15]. The plant can be propagated from fresh seed on substrates with good drainage, aeration and a moderate water retention capacity [19]. Under favourable conditions, the seeds begin to sprout after 14–30 days. When planted in the ground where it can come into contact with the roots of other plants, the plant thrives [10]. It can endure light cold and drought, and it grows at a moderate rate height of up to 0.5 m per year. However, it requires full sun [20]. This review investigated the biochemical components of *X. caffra* and its significance in human health and nutrition, for prospective commercialization.

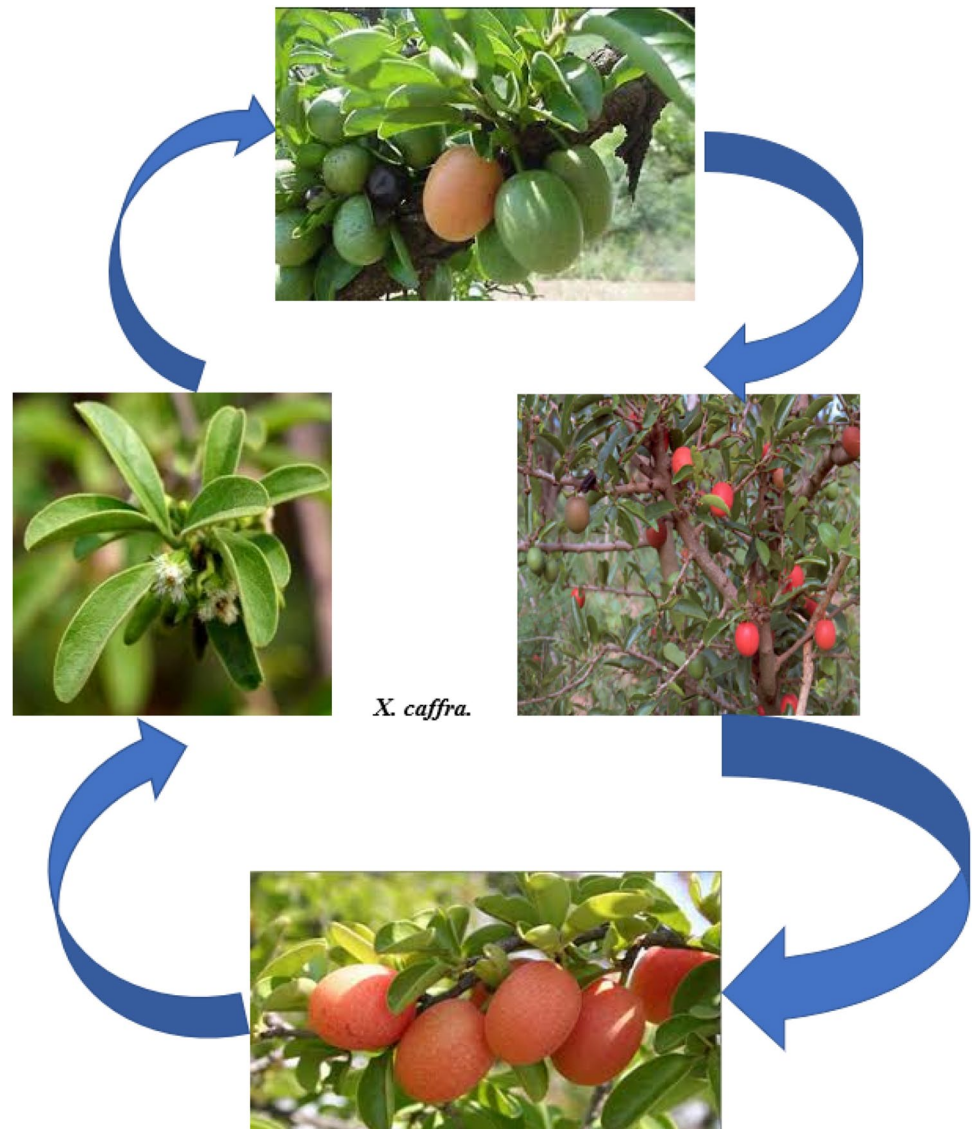
2 Materials and methods

Between January and May 2023, the following databases were used to search online literature: Scopus, Web of Science, Google Scholar, and ScienceDirect. Key phrases utilized included: *Ximenia caffra*, biochemical components, the importance of fruits to human health and nutrition, and African native fruits that are underutilized yet have commercial potential. Authors selected literature between 1990 and 2023, to include in this review. Only 59 of the 150 articles that were found through the search engines were used in this review. Selection criteria included how well each item related to the review paper, and the document arrangement was determined by its usefulness of sections taken into consideration from the literature. The following research questions were developed to aid authors in writing the review article; (i) What is known about the biochemical composition of *X. caffra* in the literature? (ii) How is *X. caffra* used in food and medicine? and (iii) What are the nutritional advantages of *X. caffra* plant material and their role in human health and nutrition?

2.1 Botanical, physical attributes and habitat of *X. caffra*

Ximenia caffra is found in many provinces of South Africa, including Limpopo, Kwazulu Natal, Northwest, and Mpumalanga, in forests and grasslands areas with rocky dominating soils [10]. It is a tiny tree or shrub that produces colourful fruit and has several traditional applications. *Ximenia caffra* is a deciduous tree with an untidy open crown (Fig. 1), with its height ranging from 5 to 6 m tall and is a member of the coffee family [12]. On younger branches, the bark is pale green or brown [11]. The tips of branchlets have spines, with reddish-brown wood and has passive root system [12]. The short, spur branchlets have the leathery, dark green leaves in clusters [13]. In the South African climates, from August to October, tiny, creamy-green, sweet-scented flowers are produced in single-stem clusters, in the axils of the spines or on the dwarf branchlets as shown in Fig. 1 [10]. They are followed by thinly fleshed, round, and appealing drupe fruit that are 25 mm long, shiny, deep crimson, and speckled with white stripes [13]. Birds, other animals, and people enjoy the tart-tasting, but edible fruits and it is believed that its seeds contain oil that can be utilised for various purposes [13].

Fig. 1 Morphological diagram of *X. caffra*



2.2 Common uses of *X. caffra* fruit

It has been reported that ripe fruit of *X. caffra* includes a variety of biochemical components, including vitamins, potassium, and protein [2]. The seeds contain a significant amount of oil according to [13]. Fruits can be used to make jam, dessert, and jelly, in addition to being best consumed when slightly overripe [12]. According [12], nuts are also consumed, and the oil from the seed is used to soften human skins.

2.3 Utilisation of *X. caffra* plant material

Ximenia caffra is a multipurpose plant species that has been utilized for various purposes in Southern Africa. Its plant material, including roots, stem bark, and leaves, has shown promising potential in several applications [12].

***Ximenia caffra* roots:** The roots of *X. caffra* have been traditionally used in Africa for their medicinal properties. Studies have revealed the presence of bioactive compounds in the roots, such as triterpenoids and flavonoids, which possess anti-inflammatory and antimicrobial activities are the main reasons why the crop is believed to be a reliable medicine [17–22]. These bioactive compounds make the roots of *X. caffra* a valuable resource for the development of natural medicines and pharmaceuticals.

***Ximения caffra* stem bark:** The stem bark of *X. caffra* has been investigated for its potential use in the production of natural dyes. Research has shown that the stem bark contains various pigments, including anthocyanins, which can be extracted and used as natural colorants for textiles and other products [23–25]. The utilization of *X. caffra* stem bark for natural dye production offers an environmentally friendly alternative to synthetic dyes, with a potential to reduce the ecological impact of the textile industry.

***Ximения caffra* leaves:** The leaves of *X. caffra* have been utilized for various purposes due to their beneficial properties (Fig. 2). The leaves are known to possess medicinal properties such as anti-inflammatory, antimicrobial, and antioxidant activities [26–28]. They have been used in traditional medicine to alleviate conditions such as pain, skin infections, gastrointestinal disorders, and respiratory ailments [12, 29, 30]. Additionally, *X. caffra* leaves have shown potential in the development of natural skincare products due to their reported moisturizing and anti-aging properties. Research studies have also investigated the phytochemical composition of *X. caffra* leaves, revealing the presence of bioactive compounds including flavonoids, phenolics, and tannins, which contribute to their therapeutic potential [22].

2.4 Calcium

Calcium is a mineral that is most frequently linked to strong bones and teeth, but it also plays a critical role in blood clotting, assisting with muscular contraction, and regulating regular heartbeats and nerve activity [31, 32]. The development of bones and teeth depends on calcium [33]. The need for calcium is therefore greater during adolescence [15, 20, 34]. Because low consumption of calcium may raise the risk of osteoporosis, a disorder in which decreasing bone mass, subsequently weakening bones [33]. Calcium is also crucial during later adulthood and of major relevance from a public health standpoint [2]. The calcium content variation between *X. caffra* (23.2 mg) as reported by [2] in (Table 1), as compared to recommended daily intake (1000 mg) was (977 mg). This could mean *X. caffra* has the potential contribute

Fig. 2 Some of the bioactive compounds isolated from various parts of *X. caffra*, [35]

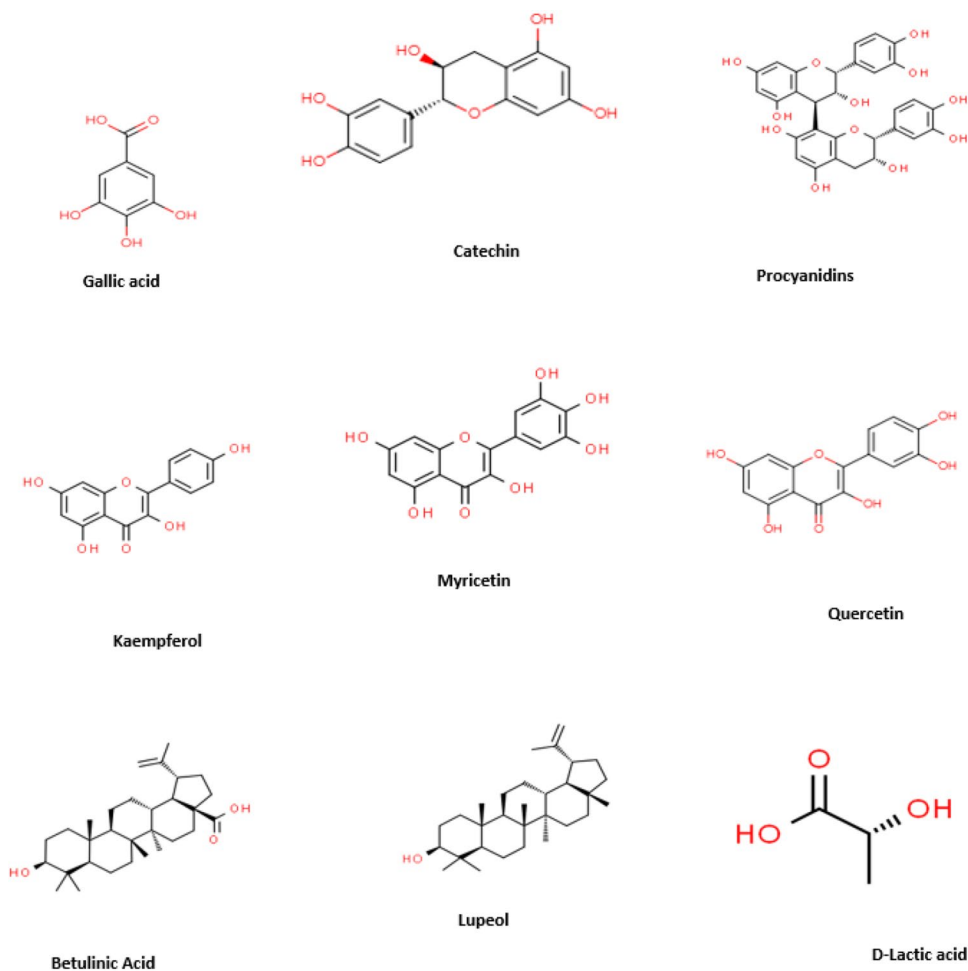


Table 1 Macro-mineral content of *X. caffra* fruit

Macro-mineral element	Average concentration range (mg 100 g)	RDI (mg)	Literature
Calcium	20–23.2	1000	[16, 36]
Phosphorus	11.7–128	3000	[16, 36]
Magnesium	15.5–19	370	[35, 36]
Sodium	0.82–40	2300	[35, 36]
Pottassium	576–677	1800	[16, 36]

Source: Authors listed on the table

about (2.3%) of calcium recommended per day by humans. Even though the *X. caffra* calcium content is lower when compared to the recommended daily intake (RDI), the value reported shows that *X. caffra* has a potential to curb various diseases such as poor bone development and dental problems, which are inked to calcium deficiency in human diet.

2.5 Phosphorus

All human tissues and cells require phosphorus for growth, maintenance, and repair, as well as for the creation of the genetic building blocks, DNA and RNA [33]. Vitamin D and various minerals such as iodine, magnesium, and zinc, require phosphorus in order to be balanced and used [33]. The variation between *X. caffra* phosphorus content (128 mg) as quantified by [2] in (Table 1) and recommended daily intake (3000) was (2872 mg), which is (4.3%) of recommended daily intake. The phosphorus value reported by [2] could mean that *X. caffra* has a potential role in prevention of health-related challenges such as loss of appetite, bone pain and stiff joint, which are symptoms linked with phosphorus deficiency in human diet.

2.6 Magnesium

The mineral is crucial for helping more than 300 enzymes carry out numerous chemical processes in the body, including those that produce proteins, and nerve function [1]. In addition, magnesium is necessary for a variety of bodily functions, including controlling blood pressure, blood sugar levels, and muscle and neuron function [1]. Authors such as [15] reported the role of magnesium as being a crucial role player in maintaining healthy body temperature, releasing stored energy from muscles, and synthesising proteins [15]. The variation between the magnesium content of *X. caffra* (17.5 mg) as reported by [15] in (Table 1), compared to recommended daily intake (370 mg) is (353 mg), which is about (4.7%) of recommended daily intake. Even though the magnesium content of *X. caffra* is lower, values reported could mean that consumption of *X. caffra* has potential to prevent diseases such as irregular heartbeat, nausea and diarrhoea, which are linked to magnesium deficiency in human in human diet.

2.7 Sodium

According to [1], the human body need sodium in order to conduct nerve impulses, muscle relaxation and maintaining the right ratio of water and minerals. For these essential processes, it is estimated that human body require at least 500 mg of sodium every day [15]. The variation between sodium content (3.4 mg) of *X. caffra* as reported by [35], in (Table 1), compared to recommended daily intake (2300 mg) was (2297 mg), which is approximately (0.02%) of recommended daily intake (RDI). Even the sodium content is lower, when compared to the recommended daily intake, *X. caffra* has a potential role in curbing alignments such as muscle crumps and nausea, which are symptoms conditions linked sodium deficiency in human diet.

2.8 Potassium

[36] reported that a diet rich in potassium lowers blood pressure and mitigates the negative effects of salt. For a very long time, high blood pressure has been linked to inadequate potassium intake [1]. In addition to regulating heartbeat and helping muscles contract, potassium is required for the transmission of nerve impulses as well as the release of energy from fat, carbohydrates, and protein [1]. The variation between potassium content of *X. caffra* (671.7 mg) as reported

by [37] in (Table 1), when compared to recommended daily intake (1800 mg) was (1224 mg), which was about (55%) of recommended daily intake. This could mean that the *X. caffra* has potential to decrease human health risks such as cardiovascular disease, which are symptom diseases linked with potassium deficiency in human diet.

2.9 Copper

The mineral copper is present in every part of the body [1]. It keeps nerve cells and immune system healthy, therefore aids in the production of red blood cells in human body [38]. Collagen, a crucial component of bones and connective tissue, is also formed with the aid of this substance [36]. The idea that minor deficiencies of this crucial mineral may play a role in the onset and progression of several disease such as diabetes and cardiovascular disease, has gained more attention in the twenty-first century [34]. This micro mineral can be deficient during pregnancy, which can cause severe morphological defects in the foetus, long-lasting neurological and immune problems [33]. The variation between *X. caffra* copper content (0.23 mg), as reported by [35] in (Table 2) and recommended daily intake (2), was (1.77 mg). Even though the values reported was lower, compared to the recommended daily intake, consumption of *X. caffra* could assist in curbing human ailments such as anaemia, low body temperature, osteoporosis, bone fractures, low white blood cell count, irregular heartbeat, loss of skin colour, and thyroid issues, which are all associated with potential copper deficiency in human diet.

2.10 Iron

The body need iron for growth and development [15]. In addition, authors such as [36] also highlighted that the body requires iron to create the proteins myoglobin, which oxygenates muscles. It is found in red blood cells and transports oxygen from the lungs to all areas of the body [33]. The *X. caffra* iron content (20.4 mg) reported by [2, 35] in (Table 2) and recommended daily intake (8.7 mg) was (11.4 mg). Values obtained could mean that consumption of *X. caffra* has a great potential to prevent health related complications such as fatigue, which is associated with lower red blood cells, which carry oxygen throughout the whole body [33].

2.11 Manganese

Manganese aids in the formation of bones, vital hormones, blood clotting and connective tissue [39]. Additionally, it affects blood sugar control, calcium absorption, metabolism of fats and carbohydrates [33]. Manganese has a crucial role in maintaining healthy neuron and brain function [15]. Authors such as [40] also reported manganese as a crucial component of enzyme systems, particularly those that handle oxygen. Manganese also helps to stimulates brain growth, reproduction, regulate blood sugar levels and supports bone structure [33]. The variation between *X. caffra* manganese content (1.7 mg) as reported by [35] in (Table 2) and recommended daily intake (2.3 mg) was (0.6 m). Values reported could mean that consumption of *X. caffra* will assist in curbing diseases such as skin rash, hair depigmentation, premenstrual pain in women and poor growth in children, which are associated with manganese deficiency in human diet.

2.12 Zinc

Zinc plays a crucial role in the production of DNA, cell proliferation, the synthesis of proteins, the repair of damaged tissue, and the maintenance of a strong immune system in human body [33]. A sufficient amount of zinc is needed during periods of rapid growth, such as childhood, adolescence, and pregnancy, as it aids in cell growth and

Table 2 Micro-mineral content of *X. caffra* fruit

Micro-mineral element	Average concentration range (mg/100 g)	Average RDI (mg)	Literature
Copper	0.1–0.23	2	[36]
Iron	0.69–20.4	8.7	[16, 36]
Manganese	0.4–1.7	2.3	[36]
Zinc	0.02–1	8	[16, 36]

Source: Authors listed on the table

multiplication [15]. More than 200 enzymes, including carboxypeptidase, liver alcohol dehydrogenase, and carbonic anhydrase, which are essential in digestion, metabolism, reproduction, and wound healing require zinc for optimal functioning [1]. Zinc is a widespread microelement that plays a catalytic or structural role in these enzymes [1]. The variation between *X. caffra* zinc content (1 mg), reported by [16, 36], in (Table 2) and recommended daily intake (8 mg) was (7 mg). Although, the *X. caffra* zinc content was lower, compared to recommended daily intake, consumption of *X. caffra* has a potential to prevent human health complications such as loss of taste and smell, memory issues and poor wounds healing, which are symptoms associated with zinc deficiency in human diet.

2.13 Fat

According to [1], fat aids in the body's absorption of vitamins A, D, and E. These vitamins are only absorbed with the aid of lipids because they are fat-soluble [1]. Body fat is created from any fat that is not utilized by human body's cells or transformed into energy [24]. The variation between the *X. caffra* fat content (0.4 mg) as reported by [24] in (Table 3) and recommended daily intake (11 mg), Sibiyi et al. (2021), was (10.6 mg). This means that *X. caffra* contributes about (3.6%) of recommended daily intake of fats. Although the fat content of *X. caffra* is significantly lower, when compared to the recommended daily intake, consumption of *X. caffra* fruit can help people stay healthy and reduce ailments such as dry rashes and hair loss, while also boosting their immune systems, which are symptoms linked to fat deficiency in human diet.

2.14 Fibre

Recent research [1], reported the role of dietary fiber with softening, increases the weight and volume of human faeces [1]. The likelihood of developing constipation is reduced by a large stool's ease of passage [40]. Because fiber absorbs water and gives the stool volume, it may assist to firm loose, watery stools in the digestive system, thus enhances bowel health [33]. The variation between *X. caffra* content (1.3 mg) as reported by [35] in (Table 3) and recommended daily intake (11 mg) is (9.7 mg). Value reported means that *X. caffra* contributes about (11.8%) of fibre required by human daily. Even though the average dietary fibre content of *X. caffra* was lower, compared to recommended daily intake, consumption of the fruit may promote the growth of beneficial bacteria in human stomach, while reducing the health risks such as inflammation, heart diseases, diabetes and constipation, which are linked with poor fiber concentration in human diet.

2.15 Total phenols

Phenolic compounds are widely distributed throughout the human body organs, such as the liver and kidneys [1]. They are also known to have a variety of biochemical and pharmacological properties, including antioxidant, anti-viral, anticancer, and anti-inflammatory activities [1]. The variation between *X. caffra* phenolic content (1030 GAE mg), as reported by [35] in (Table 3), when compared to recommended daily intake (6 GAE mg) was (1,024 GAE mg). This could mean that *X. caffra* fruit is extremely rich in total phenols. High phenolic content of *X. caffra* could mean that the fruit may play a pivotal role in curbing complications such as diarrhoea, gastrointestinal and mental health problems, which are linked with phenols deficiency in human diet.

Table 3 Biochemical constituents of *X. caffra* fruit

Biochemical constituents	Concentration range	Average RDI (mg)	Literature
Fat (g/100 g)	0.1–0.4	11	[22]
Fibre (g/100 g)	1–3	11	[22]
Total phenols (GAE/100 g)	1030–1917	6	[16]
Total flavonoids (mg 100 ml ⁻¹ CE)	178.5–583	6	[16, 35]
Vitamin C (mg/100 g)	49.2–358.2	17	[16, 25]

Source: Authors listed on the table

2.16 Total flavonoids

Flavonoids have a variety of health advantages, such as antiviral, anticancer, antioxidant, anti-inflammatory effect, cardio-protective and neuroprotective properties [33]. The variation between *X. caffra* flavonoids content (852 CE mg), as reported by [40] in (Table 3), when compared to recommended daily intake (6 CE mg) was (846 CE mg). High flavonoids content of *X. caffra* could mean that the fruit may play a pivotal role in curbing complications such excessive bruising, nose bleeds and haemorrhoids, which are symptoms linked to flavonoids deficiency in human diet.

2.17 Vitamin C

One of the best and safest nutrients is vitamin C, according to authors such as [15] and [33]. Vitamin C offer protection against immune system inadequacies, cardiovascular illness, fatal health issues, eye disease, and even skin aging [1]. The variation between Vitamin C content of *X. caffra* (358 mg), as reported [2] in (Table 3), when compared to recommended daily intake (83 mg) is (275 mg). High Vitamin C content of *X. caffra* could mean that the fruit may play a pivotal role in curbing health complications such as anaemia, bruising gums, dry skin and poor hair growth, which are associated with Vitamin C deficiency in human diet.

2.18 Medicinal values and bioactive compounds of *X. caffra*

Ximenia caffra stands as a botanical treasure with significant medicinal value. This indigenous plant, native to southern Africa, has been revered for generations for its diverse array of therapeutic properties. Its various parts, including the bark, leaves, roots, fruit, and oil from the seeds, offer a broad spectrum of medicinal applications (Table 4). The bark of *X. caffra* has been used as a remedy for syphilis, hookworm and chest pain [41]. The reported active ingredient in the bark includes tannins (Fig. 2), which possess astringent properties and are often used to alleviate diarrhoea. Additionally, the bark's antimicrobial properties make it a valuable natural remedy for wound healing and skin conditions.

The leaves of *X. caffra* also have their place in traditional medicine, known for their potential to treat tonsillitis and soothe inflamed eyes [27, 42, 43]. Moreover, the fruit of *X. caffra* is highly prized for its medicinal and nutritional value. The ripe fruit is a good source of vitamins and minerals, including vitamin C, which is crucial for immune function and wound healing. The fruit's high dietary fiber content aids in digestion and helps manage conditions such as constipation [30]. Traditionally, the fruit has been used to treat various gastrointestinal complaints. Its diverse bioactive compounds (Fig. 2), including polyphenols, flavonoids, and terpenoids, contribute to its antioxidant and antimicrobial properties, which have been employed to combat infections and enhance general health [35].

The roots of this plant are valued for their potential in alleviating gastrointestinal issues. Root infusions or decoctions have been used to treat stomach discomfort and also prevention of sterility in women [41]. The seeds of *X. caffra* are another valuable resource, as they contain an oil rich in essential fatty acids, including oleic and linoleic acids. This oil has been traditionally extracted and used for various medicinal purposes. It serves as a potent emollient and moisturizer for the skin and has been employed to soothe skin ailments such as dryness and irritation [41]. The oil's rich content of antioxidants and anti-inflammatory compounds also makes it beneficial for promoting skin health. Furthermore, the oil extracted from *X. caffra* seeds has been traditionally used for massage and pain relief, especially in cases of sore muscles and joint discomfort [30].

Table 4 Medicinal use of various parts of *X. caffra*

Family	Plant species	Plant part used	Medicinal use	References
Olacaceae	<i>Ximenia caffra</i>	Bark	Remedy for Stomachache, Cough, Bilharzias Malaria, Syphillis and chest pains	[39]
		Roots	Taken orally for fever and infertility	[39]
		Leaves	Soothe inflamed eyes, used as gargle for tonsillitis	[27, 40]
		Fruits	Relieves constipation	[30]
		Oil from seeds	Soothes dry or irritated skin	[39]

Source: Authors listed on the table

The fruit, bark, leaves, roots, and seeds of *X. caffra* collectively demonstrate the plant's diverse potential in traditional medicine, offering remedies for various health issues ranging from gastrointestinal complaints to skincare and pain relief. This multi-faceted use underscores the significance of this plant in indigenous healthcare practices and presents opportunities for further scientific exploration of its medicinal properties.

2.19 Potential value-added products of *X. caffra* fruit

The fruit of *X. caffra* is a valuable resource that offers not only edible fruit but also potential by-products with various applications. To date, no studies have explored the potential utilization of the fruit value-added products, highlighting their economic and environmental significance. The fruit residue obtained after juice extraction can serve as a potential source of dietary fibre which can contribute to improved digestion and overall health. Furthermore, studies confirmed that the fruit residue contain bioactive compounds such as phenolics and flavonoids, which possess antioxidant and antimicrobial properties [2]. These bioactive compounds have potential applications in the food, pharmaceutical, and cosmetic industries.

2.20 Alcohol products

The fruit of *X. caffra* holds potential for the production of alcohol products according to [13]. Fermentation of the fruit pulp can yield alcoholic beverages with unique flavours and aromas. Further research should focus on effectively fermenting *X. caffra* fruit pulp to produce wines and spirits [12]. The development of alcoholic beverages from *X. caffra* will not only offers a novel addition to the beverage industry but also provides opportunities for the utilization of the fruit's abundant resources.

2.21 Oil

The seed inside *X. caffra* fruit is a rich source of oil, which has garnered interest for its potential applications [39]. The oil extracted from *X. caffra* seed is characterized by its high content of fatty acids, primarily oleic acid and linoleic acid [29]. These fatty acids possess various health benefits and contribute to the oil's nutritional value. *X. caffra* oil has demonstrated potential for use in the cosmetic industry due to its moisturizing and emollient properties. Furthermore, studies have investigated its potential as a biodiesel feedstock, highlighting its potential role in the renewable energy sector [44]. The oil derived from *X. caffra* fruit presents a valuable resource with potential applications in both the cosmetic and energy industries.

2.22 Juice

Ximenia caffra fruit is gaining attention as a potential source of juice due to its unique flavour profile and nutritional composition [38]. Studies have revealed that *X. caffra* fruit juice is rich in essential nutrients, including vitamins, minerals, and antioxidants [29]. The juice has a tart and tangy taste, making it suitable for use as a refreshing beverage or as an ingredient in fruit blends and functional drinks. Further exploration and research should focus on optimizing juice extraction methods, determining the best processing techniques, and evaluating the shelf life and sensory attributes of the resulting juice. Incorporating *X. caffra* fruit into the juice industry not only offers a novel addition to the market but also harnesses the potential of this abundant resource in promoting healthy and natural beverage options.

2.23 Jam

The fruit of *X. caffra* has the potential for jam production due to its unique flavour, texture, and high pectin content. Pectin, a natural polysaccharide found in fruits, plays a vital role in the gelling and thickening properties of jams and jellies. *X. caffra* fruit is known to contain a significant amount of pectin, making it suitable for jam production [12, 45]. However, to successfully commercialize *X. caffra* fruit jam, it is essential to formulate and optimize the jam's composition to enhance its quality and extend its shelf life. Further research should focus on developing the ideal recipe and processing methods to ensure a high-quality and long-lasting *X. caffra* fruit jam product.

2.24 Medicine

Ximenia caffra has a long history of use in traditional medicine, and recent scientific studies have provided evidence for its medicinal properties [6, 22, 37]. Various parts of the plant, including the fruit, leaves, and stem bark, have been investigated for their therapeutic potential. *X. caffra* extracts have shown significant antioxidant, anti-inflammatory, antimicrobial, and anticancer activities [26, 29]. These bioactive properties can be attributed to the presence of phenolic compounds, flavonoids, and triterpenoids in the plant. Traditional uses of *X. caffra* include the treatment of ailments such as gastrointestinal disorders, skin infections, and pain management [18, 46]

The scientific validation of *X. caffra* medicinal properties opens up possibilities for its incorporation into modern medicine. Further research is needed to identify and isolate specific bioactive compounds, determine their mechanisms of action, and evaluate their safety and efficacy. *X. caffra* holds a potential hope as a source of natural compounds that could contribute to the development of new therapeutic agents or serve as leads for drug discovery.

2.25 Future outlook for *X. caffra* in the biotechnology and food industries

The future outlook for *X. caffra* in the biotechnology and food industries appears promising due to its versatile applications, nutritional value, and bioactive compounds. *X. caffra* fruit and leaves possess a rich nutritional profile, including vitamins, minerals, antioxidants, and bioactive compounds [22, 29, 47–49]. These attributes make sour plum a potential crop for the development of nutraceutical products and functional foods with health-promoting properties. Meeting the growing demand for natural and functional ingredients that support overall well-being, these products can offer consumers new and beneficial options.

Medicinally, the antioxidant, anti-inflammatory, antimicrobial, and anticancer activities [29, 46, 50] of compounds found in *X. caffra* hold promise for developing natural medicines and pharmaceuticals targeting various diseases and disorders. The traditional use of *X. caffra* in African folk medicine provides a valuable starting point for investigating its medicinal potential.

Ximenia caffra metabolite profile, including its oils, pigments, and bioactive compounds, offers opportunities for biotechnological applications. The extraction and utilization of *X. caffra* oil as a potential biodiesel feedstock can contribute to renewable energy sources. Additionally, the pigments present in *X. caffra* stem bark can be explored for natural dye production, providing environmentally friendly alternatives to synthetic dyes.

Cultivation and commercialization of *X. caffra* can play a role in sustainable agriculture and economic development, especially in regions where it is indigenous and prevalent. The plant's ability to thrive in arid and semi-arid environments, along with its versatile applications, makes it a valuable resource for local communities. Promoting the cultivation, processing, and marketing of *X. caffra* products can create income generation opportunities, improve food security, and support sustainable land use practices for both rural, and urban communities.

2.26 Postharvest practice of *X. caffra* fruit

Post-harvest practice, according to [50, 51], is a system for managing, storing, and moving agricultural products like fruits and vegetables following harvest. Fruit post-harvest quality is significantly influenced by environmental conditions, including temperature, humidity, the kind, and quantity of gases in controlled atmospheric storage [52]. Insufficient comprehension of efficient harvesting and storing methods, together with processing facilities, is required to gain a deeper comprehension of procedures for harvesting and storing of fruits of most underutilised crops such as *X. caffra* fruits [8]. Additionally, during the season of excess fruit, improper fruit processing and poor storage practices frequently results in significant fruit waste [52]. As a result, the development of an appropriate scientific postharvest process might extend fruit availability and lead to economic emancipation since communities can preserve fruit and sell them even during out of season, generating revenue to support their livelihoods and enhancing food accessibility [43]. Therefore, future research project on the postharvest treatments and management such as harvest technique, and postharvest storage will ensure that quality *X. caffra* fruits are preserved for longer period, subsequently, improve food availability and accessibility in society, especially those underprivileged community that depend on this fruit as source of food.

2.27 Processing of *X. caffra* value-added products and commercialisation

Value-added products are those products that have been manufactured through the conversion from raw material to another set of characteristics that is considered more desirable in the market [28]. Example of such potential product that could be developed from *X. caffra* includes alcohol, juice, jam, and nuts [43, 44, 53–57]. The advancement of society may be greatly improved by scientific studies that can make it possible to process *X. caffra* into value-added products like juice, jam, nuts, and alcohol. The utilization of *X. caffra* will also improve because of this type of research, which will eventually eradicate malnutrition in underprivileged communities, while creating jobs as people will begin to produce and sell high-quality value-added products from *X. caffra* to support their way of life.

3 Conclusion

The *X. caffra* fruit, which is underutilised is abundant in a number of biochemical components, such as calcium, flavonoids, magnesium, potassium, and phenols. These biochemicals are crucial for preventing most diseases and enhancing human health and nutrition. The fruit processing business still has a lot of room to explore and use the bioactive components of the *X. caffra* fruit. Consuming *X. caffra* fruit, which is rich in several biochemical substances, is linked to both the prevention and treatment of several diseases, including heart disease, wound healing, gum bleeding, and wound healing. The health benefits of *X. caffra* fruit have not been extensively established, little is known about the growth, yield, biochemical and metabolite profiles of this fruit when grown under various agronomic conditions, such as varying irrigation levels, fertilizer types, and soil types. Therefore, more research in this area is still necessary. Furthermore, it is important to extract the biochemical constituents of the *X. caffra* fruit and utilise them as functional ingredients in a variety of culinary items. By promoting the sale of items from *X. caffra*, this will benefit both human health and the struggling rural economy, where food scarcity is still a challenge.

Author contributions MKM was involved in data interpretation, analysis and write-up. LB was involved in data collection, data analysis, data interpretation and write-up. CKMR was involved in data collection, data interpretation, data analysis 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 Authors declare that they have no conflicts of interest.

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