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Optimization of production strategies for African indigenous trees: a case study of tree growers and sellers of Dovyalis *caffra* (Kei apple) from Eastern Cape of South Africa

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Dovyalis caffra commonly known as Kei apple, is an indigenous tree from the Salicaceae family, naturally found in the Eastern Cape region of South Africa, with a significant potential to address food insecurity and climate resilience challenges in rural areas. This review aims to evaluate the production potential, uses, and socio-economic contributions of *D. caffra*, focusing on optimizing its cultivation and market integration through indigenous knowledge and agroforestry system. The research was conducted in the Eastern Cape province of South Africa. Research was conducted using online databases such as ResearchGate, PubMed, and Google Scholar, focusing on keywords like "food security," "*Dovyalis caffra*," and "indigenous trees." Secondary data was gathered from previous studies, and conclusions were drawn from related research. Additionally, a case study involved interviews with five tree growers/sellers in the Eastern Cape, assessing the challenges and benefits of cultivating and marketing *D. caffra*. Findings revealed that some growers are motivated to promote Indigenous species, recognizing the economic and ecological benefits of cultivating Kei apple. The tree's resilience to climate change, soil degradation, water scarcity, and pest infestations makes it a promising alternative to traditional crops. Additionally, its cultivation can diversify food sources and enhance community resilience. Promoting indigenous trees like *D. caffra* through agro processing can maximize their economic value while supporting local communities and sustainable forestry practices.

KEYWORDS

climate change, food security, indigenous trees, in-depth interviewing, market information, Kei-apple

1 Introduction

Climate change is widely acknowledged as a major factor contributing to diminished productivity in agriculture and shortages of food in Southern Africa as well as developing countries (Mdoda et al., 2025). The Food and Agriculture Organization (FAO, 1996) defines food security as a situation whereby all people have economic, social, and physical access to enough, nutritious, and secure food that fits their food preferences and dietary requirements

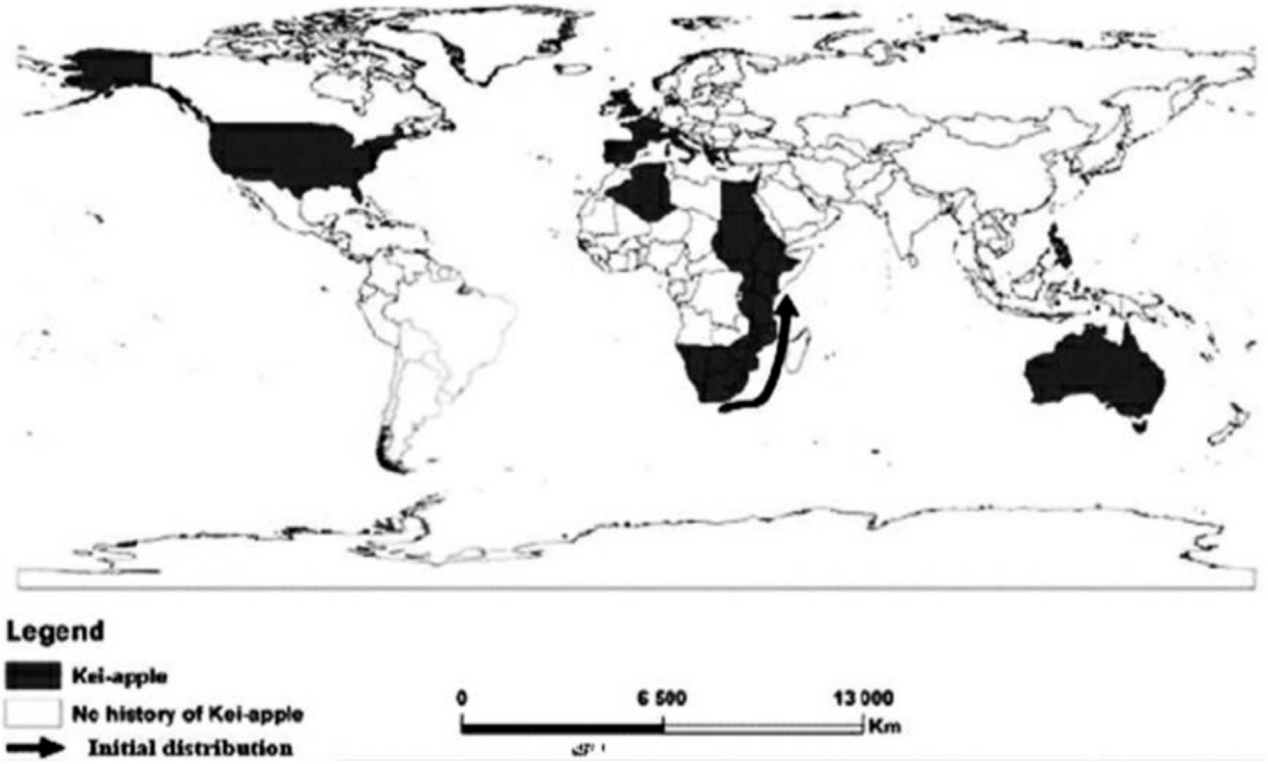

FIGURE 1
Distribution and global occurrence of *Dovyalis caffra* (Waweru et al., 2022).

for a life of wellness and activity (Mutengwa et al., 2023). However, in Southern Africa achieving food security is a daunting task given the region's multiple stressor environment (Raza et al., 2025). Climate change manifests itself in extreme weather events that negatively affect Southern African agriculture, including heat stress, floods, droughts, rising temperatures and pest invasions (Mutengwa et al., 2023).

Rural food systems have been influenced by climate change, endangering the security of food and nutrition in developing countries (Myers et al., 2017). Numerous studies have emphasized the possible role that underutilized plants could play in such circumstances (Ogwu et al., 2024). Although there is growing interest in these underutilized plants, there are still significant research gaps. Indigenous plants, such as *Dovyalis caffra* from the Salicaceae family, can provide valuable resources during times of food scarcity and require minimal water (Omotayo et al., 2018). Climate change and food shortages make indigenous plants, such as *D. caffra*, a valuable resource for the growing global population.

This review explores the present condition of the lesser-known indigenous plant, the Kei-apple tree, emphasizing its advantages, applications, and potential to aid national development objectives. It focuses on how this plant could support rural communities in adapting to climate change, enhance food security, and create job opportunities. Through a case study carried out in South Africa's Eastern Cape province, the review provides insights into the growing, promotion, and sale of indigenous trees like *D. caffra*. These plants, such as *D. caffra*, are drought tolerant, nutrient-rich, and culturally significant, providing a sustainable source of food and income for rural people.

1.1 Origin and distribution of *Dovyalis caffra*

1.1.1 Geographical distribution

Dovyalis caffra, commonly known as the Kei apple, is indigenous to the Kei River region in southwest Africa and is widely distributed in the surrounding areas of Eastern Cape and the KwaZulu Natal (Aremu et al., 2017). It is also cultivated in the north-western region of South Africa (previously called, Transvaal). This plant was first introduced to England in 1838, and from there, it spread to regions including the Philippines, northwestern Australia, Egypt, Algeria, southern France, Italy, Jamaica, southern California, and Florida (Tadesse, 2023). The plants create an impenetrable hedge barrier when they are planted closely together.

Kei apple typically thrives in areas with a Mediterranean climate, such as hills and mountains along coastal regions. It can tolerate mild drought and prefers sandy or loamy soil with good drainage. Although it is found in other parts of South Africa, Namibia, and Angola, its cultivation and introduction as an ornamental plant with edible fruits have led to its spread worldwide (Waweru et al., 2022). Today, *D. caffra* can be found in a number of nations, such as Brazil, United States, Australia, Israel, and New Zealand, where it thrives in conditions that are conducive to its growth as shown in Figure 1.

FIGURE 2
Traits of *Dovyalis caffra*: **(A)** *D. caffra* tree with thorns, **(B)** Kei apple tree at flowering stage, and **(C)** Fruits and seeds of Kei apple (Augustyn et al., 2016.ppt).

1.2 Characteristics and botanical description of Kei apple

Dovyalis caffra tree is an evergreen that bears little golden apples-like fruits. The tree is covered in a thick fruit layer with a vibrant scent and a yellow pulp beneath its tough, slender skin (Tadesse, 2023). This subtropical plant is frost and drought-tolerant, making it a shrub or small tree with moderate hardiness (Wilken et al., 2024). Its lush green foliage, which offers year-round screening and shade, reaches heights of 3–8 m. On young branchlets, the bark is smooth; on older branches and stems, it is fissured, flaky, or corky. The tree crown is heavily branched, and while the stem has few thorns, young branches typically have 40–70 mm thorns as shown in Figure 2 (Waweru et al., 2022).

The Kei apple features plain leaves often grouped closely together on its small lateral branches. These leaves are glossy and dark green. There are about 35 noticeable veins that extend from the base on both sides, and they are 20–55 by 5–30 mm in size, with a narrow to broad obovate-elliptic shape. The petiole can grow up to 5 mm long, and the leaf apex is round with an occasional notch. The base tapers to a narrow round with a margin and a slight roll under (Orwa, 2009). In the leaf axils, the female flowers can be seen in clusters of three or more on stalks that are 4–10 mm long, male flowers on the other hand are found in dense clusters of five to ten and are 3 mm long.

1.3 Uses and importance of *Dovyalis caffra*

Dovyalis caffra has multiple uses. It can be planted as a border fence or as an impenetrable hedge to keep humans and animals out of a garden. The leaves are utilized by bees for foraging and as fodder, or bulk feed for cattle (Nouman et al., 2014). The edible fruits which are rich in vitamin C content (17 mg per 100 g), are used to make jams. Fermenting fruits yields an acidic herbicide (Omotayo et al., 2018). However, there is currently no evidence to suggest that this fermented fruit-derived herbicide is available for commercial purposes.

Currently no commercial products based on Kei apple herbicide are available or been documented at agricultural markets and/or scientific literature.

FIGURE 3
Kei apple fencing (Tadesse, 2023).

1.3.1 *Dovyalis caffra* uses in agro forestry

Kei apple is a spiny shrub or moderate-growing tree widely used in agroforestry, particularly as a live fence in African landscapes. When planted at high density it creates a sturdy hedge with trees or shrubs arranged in straight or zigzag rows, 30–90 cm apart (Epenhuijsen, 1976). Its prickly structure and unappealing foliage increase its effectiveness as a barrier by making it extremely resistant to goat and other animal grazing (Omotayo et al., 2018). In addition to serving as ornamental borders for homes, animal sheds, and farms, these prickly hedges also serve as a deterrent to thieves.

Live fences as shown in Figure 3 serve several important functions. They help control the movement of both domestic and wild animals, mark cultivated areas, and act as fire-resistant buffer zones for crops (Dharani, 2019). The use of dense, thorny vegetation, such as Kei apple combined with shrubs and climbing vines, increases the fence's ability to deter animals. For example, denser fences are necessary to deter young goats, while larger animals might require different specifications (Tadesse, 2023).

1.4 *Dovyalis caffra*'s potential health benefits

Dovyalis caffra is an important fruit tree that produces aromatic fruits that resemble apricot-like fruits, which can be consumed both cooked and raw by humans and wildlife, addressing food insecurity and malnutrition with essential nutrients (Maroyi, 2018). The fruit pulp is rich in fatty acids (0.5–1.2 g/100 g, primarily linoleic acid at 0.3–0.7 g/100 g), proteins, carbohydrates, and vitamin C (17 mg/100 g) (Waweru et al., 2022; NRC 2008). Compared to apricots (1.5–2.0 g/100 g fatty acids) and plums (0.7–1.5 g/100 g), Kei apple has lower fatty acid content but higher vitamin C making it a valuable dietary resource (Maroyi, 2018; Waweru et al., 2022; Xu et al., 2025). Due to the high acidity, the fruit is cut in half, peeled, and the seeds are removed. It is then sprinkled with sugar and let rest for a few hours before serving. This dish is usually served as a dessert. Additionally, *D. caffra* fruits are used to make dried fruit, syrups, shortcake, jam, jelly, and fruit salads additions (Qanash et al., 2022).

1.4.1 Medicinal use of *Dovyalis caffra*

Dovyalis caffa has a long history of traditional medicinal uses. According to ethnobotanical evidence, the Kei apple is used in both traditional and modern medicine, especially to help those with gout and pain management (Clement et al., 2023). According to research on ripe Kei apples by Qanash et al. (2022), the fruit has a strong acidic flavour that requires sweetening before eating. High-performance liquid chromatography (HPLC) analysis discovered several compounds in Kei apple extract as shown in Figure 4, such as phenols and flavonoids, etc. Higher dietary flavonoid consumption has also been linked in other studies to a lower risk of cardiovascular disease and some forms of cancer (Sesso et al., 2003). A 2017 meta-analysis indicated a 14% decrease in cardiovascular disease mortality associated with elevated flavonoid consumption (Kim and Youjin, 2017), whereas a 2019 review and a 2025 meta-analysis documented diminished risks of multiple cancers, including a 24% reduction in lung cancer risk (Rodríguez-García et al., 2019; Yang et al., 2025).

Vitamin C has been shown to improve vital physiological functions and prevent diseases like atherosclerosis, cataracts, diabetes, glaucoma, the common cold, stroke, heart diseases, and macular degeneration. Other phenolic compounds found in the extract are chlorogenic acid, catechin, gallic acid, hesperidin, rutin, ellagic acid, kaempferol, apigenin, and quercetin. Chlorogenic acid (Table 1) was found to be the most abundant phenolic ingredient in the extract, followed by gallic acid and catechin. This finding is shown to be the main phenolic compound in Kei apple fruit by Taher et al. (2018), who also noted that it was present in comparable concentrations.

Research conducted *in vitro* demonstrated that *D. caffra* contains strong antimicrobial, antioxidant, antiviral, and anticancer effects (Simelane et al. 2013). The extracts from the seeds have demonstrated significant antibacterial activity against *Staphylococcus aureus*, with a minimum inhibitory concentration of 1 μg/mL (Al-Habib et al., 2010). Plant extracts containing these phytochemicals have been associated with a variety of pharmacological activities (Ogbole et al., 2023).

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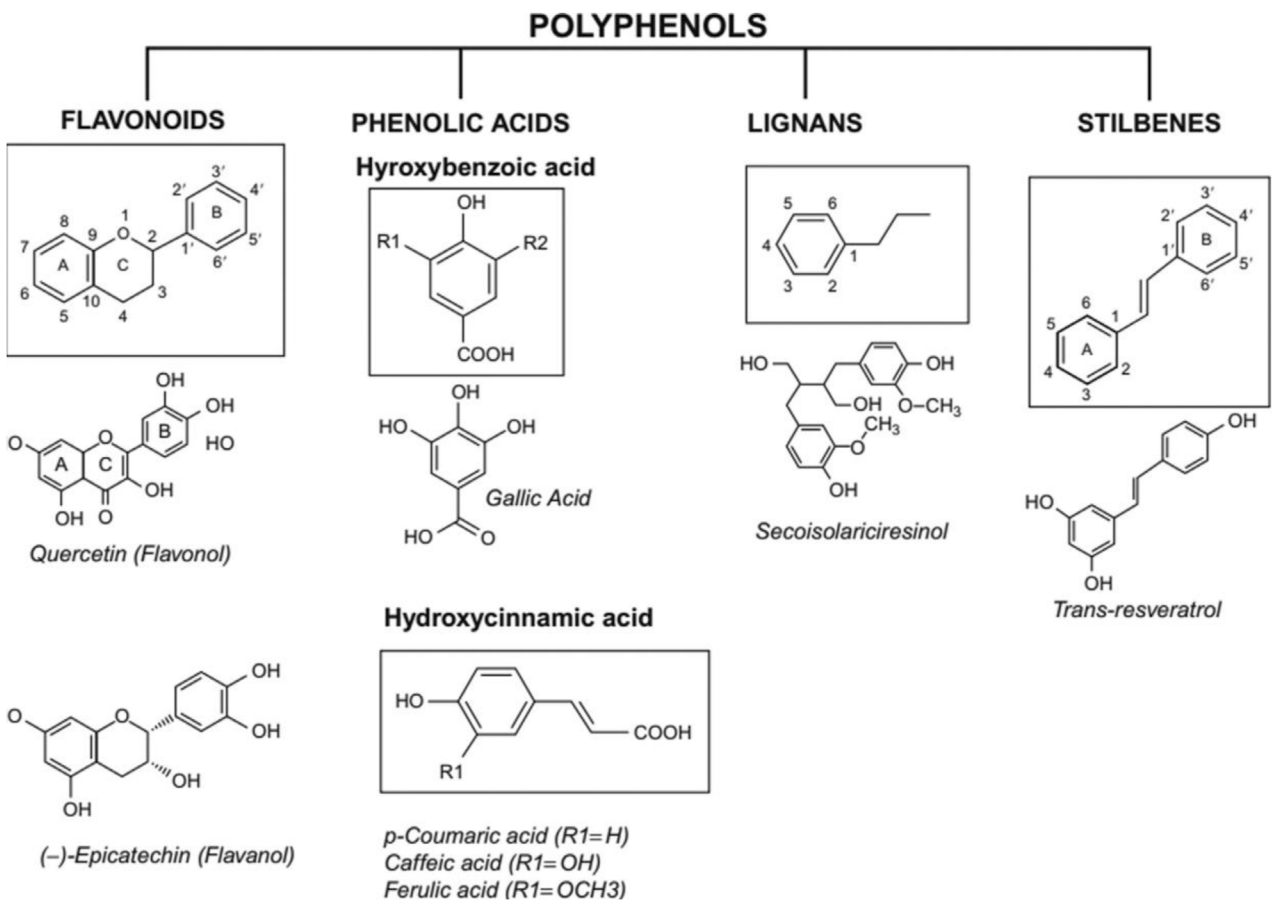

FIGURE 4
Fundamental structure of Polyphenols (Celep et al., 2014).

TABLE 1 Flavonoid and Phenolic contents of *Dovyalis caffra* fruit extract (Qanash et al.,2022).

Compound	Concentration (μg/g)
Catechin	168 ± 0.58
Gallic acid	15.66 ± 0.02
Chlorogenic acid	2107.96 ± 0.07
Hesperidin	2.10 ± 0.2
Rutin	4.45 ± 0.10
Ellagic acid	1.82 ± 0.10
Quercetin	2.13 ± 0.10
kaempferol	2.02 ± 0.02
Apigenin	1.72 ± 0.02

Research by Al-Rajhi et al. (2022) emphasized the potential of *D. caffra* in environmentally friendly production of silver nanoparticles, demonstrating efficacy against clinical pathogenic bacteria and cancer cells (AgNPs). These AgNPs, produced using *D. caffra*, shown effectiveness against clinical pathogenic bacteria and cells, likely attributable to the antibacterial and anticancer capabilities of silver, potentially augmented by the bioactive chemicals in the plant extract.

1.5 Production strategies that can be adopted

Agroforestry represents one of the oldest practices in the world. It has been estimated to exist for over 1300 years (Santoro et al., 2020), with over 1.2 billion practitioners worldwide (Zomer et al., 2023). Agroforestry enables farmers to cultivate multiple goods and services on the same piece of land in a cohesive way, addressing a wider range of demands. By incorporating trees into their agricultural practices, farmers can reap economic, social, and environmental benefits, including enhanced food security (Jones-Garcia and Krishna, 2021). To guarantee a year-round food supply, farmers are expanding production, creating various revenue streams, and cultivating a mix of indigenous and exotic fruit trees (Dawson et al., 2014). Farmers can depend on the Kei apple fruit trees to act as a safety net and provide a consistent food supply or source of income during times of rising food prices or harvest failures (Omotayo et al., 2019). Agroforestry systems contribute to ecosystem services, which further reduce food insecurity (Clark and Nicholas, 2013). Planting trees alongside crops establishes

TABLE 2 Demographic and geographical data of participants of the Eastern Cape who were interviewed for the research study.

Variables		Frequency	Percent (%)
Gender	Male	3	60
	Female	2	40
Age	20–30	1	20.0
	31–40	2	40.0
	41–50	2	40.0
	Older	0.0	0.0
Employment	Self-employed	2	40.0
	Permanent Employed	2	40.0
	Temporary	1	20.0
	Casual Employment	0	0.0
Main Business in trees	Propagation	0	0.0
	Growing	1	20.0
	Sales	3	60.0
	Direct	1	20.0
Mainly Selling Trees	Indigenous	0	0.0
	Exotic	0	0.0
	Both	5	100
	Other	0	0.0
Tree Knowledge	Formal education	2	40.0
	Short Course	1	20.0
	Self-trained	2	40.0
	Still learning	0	0.0
Grow *Dovyalis Caffra*	Seed Propagated	0	0.0
	Cutting Propagated	3	60
	Containerized	0	0.0
	Open ground	2	40
Sell *Dovyalis Caffra*	200 or more/Year	1	20
	100–200 tree/Year	0	0
	50–100 trees/y	1	20.0
	Less than 50 trees/Year	3	60.0

microclimates that shade crops from direct sunlight and rain, protect them from pests, erosion, and floods, improve soil fertility, and promote animal production. Agroforestry also helps to maintain populations of pollinator species like birds and insects, which are critical for many crops. Increased biodiversity caused by incorporating trees into agricultural land improves rural farmers' food and nutrition security (Clark and Nicholas, 2013).

Implementing organic soil management techniques such as mulching and composting can enhance soil fertility and structure, providing the trees with the necessary nutrients for optimal growth. Suitable irrigation practices, like drip irrigation or swales, can assist in managing water efficiently, ensuring the trees receive adequate moisture without becoming excessively waterlogged, which is vital for their health and fruit yield (Wach, 2020).

The techniques of pruning and thinning are vital for growing Kei apples. Consistently eliminating crowded branches encourages fruit growth and reduces the likelihood of disease by enhancing airflow and allowing more sunlight to reach the plants. In addition, growing trees in permaculture systems where they are arranged in circular beds with crops that rotate can improve nutrient cycling, maximize resource utilization, and produce a microclimate that is advantageous to all plants (Zhang et al., 2018). Moreover, supplying local farmers with the knowledge and abilities necessary to effectively implement these practices can empower

them through community education and training programs focused on improved agricultural methods (Ogwu et al., 2024). By adopting these enhanced cultivation techniques, it is possible to significantly improve food security and foster regional economic growth, while also increasing the yield and quality of Kei apples (Zhang et al., 2018)

2 Research methodology

The research methodology involved utilizing online research engines such as ResearchGate, PubMed, and Google Scholar as data sources. Key topics, including "Food security," "*D. caffra*," "indigenous trees," and "effect of low nutrition on plants," were searched to gather secondary data from prior publications. The findings and conclusions were derived from the analysis of relevant studies and their results. A questionnaire was compiled and used for a case study interviews with five tree growers and sellers in South Africa's Eastern Cape province. Participants were selected based on their experience in growing and selling *D. caffra* or other indigenous trees, ensuring diverse perspectives from individuals involved in propagation, growing on, sales, or direct planting within the region. The case study was designed to collect in-depth knowledge into the problems and benefits of growing and marketing trees such as *D. caffra* from the perspective of the tree growers/sellers. Interviews focused on the type of tree, demand and quality of trees from consumers and landscape contractors. Information was also collected on how product lines were selected and interactions with consumers/buyers in how they manage their tree production program. Semi structured in-depth interviewing involved interviewing a limited number of respondents in-depth one-on-one to learn more about their opinions of the tree businesses and to gather information about how they felt about answering structured questions. Qualitative data, which is descriptive in nature, captures observable qualities and characteristics that provide insights into experiences, perceptions, and behaviors as shown in Table 2.

2.1 Data analysis

Descriptive statistics such as percentages were used for the respondents' information to analyse the data gathered from the study.

3 Ethical consideration

Ethical clearance and approval for the research study were secured from the University of Fort Hare.

4 Results and discussion

This study provided a comprehensive analysis of the tree-growing and selling industry in the Eastern Cape Province of South Africa, focusing on *D. caffra*, a native species with substantial potential for agroforestry, food security, and economic growth. The results from the database search and respondents to the questionnaires provided valuable insights into the current landscape of tree production and sales, identifying opportunities and challenges within the industry as listed in Table 3.

4.1 Number of respondents

The study interviewed five tree growers and sellers, comprising three street vendors (whose main business is growing), one nursery-based grower, and one provider of direct planting services. This purposive sample, selected for their experience with *D. caffra* cultivation and marketing, offers diverse insights into the tree-growing and selling process. Street vendors, typically characterized by their adaptability and demand-driven strategies, highlight a dynamic approach to the business, while the nursery-based grower exemplifies a more organized and methodical cultivation process. The variation in business models, from flexible street selling to structured nursery cultivation, underscores the diverse practices and approaches within the industry. This diverse sample strengthens the findings, providing a holistic view of the opportunities and challenges faced by both vendors and growers.

4.2 Demographic and geographical data

The demographic profile of the respondents reflects a relatively balanced gender representation, with 60% male and 40% female respondents, offering a broad gender perspective. The age distribution shows that 40% of respondents are between the ages of 31 and 40, another 40% are between the ages of 41 and 50, and 20% are between the ages of 20 and 30. This suggests a mature group, but age does not necessarily indicate expertise in growing and selling trees. To better assess their experience, information on how long each respondent has been in the business was looked at, formal education (40%), short courses (20%), or self-training (40%) indicate different ways to learn about trees. The respondents' employment status also reveals that a substantial portion of the participants are self-employed, which indicates an entrepreneurial drive within the tree-growing and selling industry. Furthermore, the fact that most respondents are more focused on selling rather than cultivating trees speaks to the importance of market demand and business acumen in shaping the industry. This focus on sales might imply that the time and resources needed for cultivation are outweighed by the faster financial returns from selling trees, especially *D. caffra*. Indicating varying sales numbers that might be a reflection of market demand, 60% of respondents sell fewer than 50 *D. caffra* trees annually, 20% sell 50–100 trees, and 20% sell 200 or more. However, particular information on profit margins, manufacturing costs, or market analysis would be required to support the assertion that sales are more commercially viable than production. Although thorough economic comparisons are missing, the larger picture of South Africa's tree-growing sector indicates a need for native trees like *D. caffra* for landscape and fruit production.

4.3 Motivations for growing or selling trees

In Table 4, the respondents generally agreed on the numerous benefits of indigenous trees, particularly in terms of their adaptability to poor soils, drought tolerance, pest resistance, and low maintenance requirements. However, while most respondents acknowledged the potential of *D. caffra* as a tree species, it is clear that there is a gap in knowledge, particularly

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TABLE 3 Underutilized indigenous plant species in Eastern Cape.

Scientific name	Common name	Uses	Growth conditions	Market potential	References
Dovyalis caffra	Kei-apple	Edible fruit, fencing, agroforestry, ornamental	Drought tolerant, grows in sandy or loamy soils	High- Potential for food security and agro-processing	Materechera and Swanepol (2011), Materechera and Swanepol (2013)
Dasispermum suffruticosum	Sea\Dune Parsely	Ornamental plants are commonly used in gardens and landscapes. It features huge, spectacular flowers and beautiful leaves. It can also serve as ground cover or in a water garden. It is also used medicinally due to its anti-inflammatory and antibacterial qualities	Grows in its native environment, which has stable moisture levels. This plant prefers consistent humidity and is relatively drought tolerant	Low - Limited commercial exploitation, with potential for specialized herbal markets	Mucina et al. (2006)
Sclerocarya birrea	Marula	Edible fruits, alcoholic beverages, and medicinal oils	Semi-arid areas, well-drained soils	High - Used for alcoholic beverages and cosmetics	Mariod and Abdelwahab (2012)
Vangueria infausta	Wild Medlar	The plant is valued as both food and medicine, and its leaves are used to make an infusion that is said to help with fever, colds, stomach aches, and other diseases. The leaves can also be consumed, as can the fruit, which can be eaten raw, dried, or cooked	Thrives in warm temperatures, usually between 20 °C and 38 °C (68°F–100°F). It is drought resistant and can thrive in both semi-shade and full sun	Medium-limited commercialization	Maroyi (2018)
Berchemia zeyheri	Red ivorywood/ umgoloti	Timber, fruit consumption. Furniture built from this tree is extremely strong and durable, and it accepts paint and varnish well. The wood is suitable for crafting wooden bows, walking sticks, miniature boxes, and curios	It is a tree that is either evergreen or semi-deciduous and is resilient to drought conditions. but not frost resistant	Low – More valued for timber than fruit	Ali et al. (2008)
Harpephyllum caffrum	Wild plum/ Umngwenya	Shade tree, edible fruits, traditional medicinal purposes	Thrives in a range of soil types	Medium – Limited commercial fruit production	Pfukwa et al. (2022)
Ximenia caffra	Sour plum	Infusions of roots are frequently used to treat dysentery and diarrhea, and they are eaten with the leaves to treat bilharziasis and stomach pain. Roots are crushed into powder and used to sores speed up their recovery; they are also used as an aphrodisiac in soup and beer. Oil extraction	Found on rocky areas, in grasslands, forests, and even on termite mounds	Medium – Potential for cosmetic oil market	Nkwanyana (2013)

regarding cultivation techniques and propagation. Despite many respondents recognizing the potential of indigenous trees for agroforestry and commercial purposes, there is still a need for further training and education on propagation methods to ensure the successful scaling of production. This knowledge gap poses a potential barrier to the widespread cultivation and sale of *D. caffra*, indicating a clear opportunity for intervention through targeted agricultural extension programs.

4.4 Market potential

The responses from the participants revealed a positive outlook on the market potential of *D. caffra* (Table 5). Respondents strongly agree on its ornamental potential, suitability for agroforestry, and its usefulness as both a food source and for farming purposes such as fodder. Furthermore, the high nutritional value of *D. caffra* fruit was acknowledged, with most respondents agreeing that it holds significant potential in the health-conscious consumer market. The potential for added-value products, such as jams, juices, and other processed goods, was also recognized, indicating that diversification in product offerings could significantly increase the marketability and profitability of *D. caffra*. There is a clear consensus on the fruit's potential to integrate into local diets and be marketed in commercial retail chains, which would enhance its visibility and accessibility to a larger customer base. This finding suggests that with proper marketing strategies, *D. caffra*

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TABLE 4 Knowledge of indigenous trees of participants of the Eastern Cape interviewed for the study.

Variables	Strongly agree	Agree	Disagree	Strongly disagree
Adapted to poor soils	40%	60%	0.0%	0.0%
Drought tolerant	20%	80%	0.0%	0.0%
High pest and disease-resistant	40%	60%	0.0	0.0%
Low maintenance plant	20%	40%	40%	0.0%
Invasive potential	40%	60%	0.0%	0.0%
Easy to propagate cuttings, seed	60%	20%	20%	0.0%
Cultivation techniques available	20%	60%	20%	0.0%
Potential for orchard cultivation	40%	60%	0.0%	0.0%
Would benefit from irrigation management	60%	40%	0.0%	0.0%
Suitable for hydroponic growing	40%	20%	40%	0.0%

TABLE 5 The market potential for *Dovyalis caffra* revealed by participants in the Eastern Cape study.

Variables	Strongly agree	Agree	Disagree	Strongly disagree
Ornamental potential	40%	60%	0.0%	0.0%
Agroforestry potential	60%	40%	0.0%	0.0%
Farming potential, hedging, fodder	60%	40%	0.0%	0.0%
Food potential for consumers	20%	80%	0.0%	0.0%
Highly nutritional fruit	60%	40%	0.0%	0.0%
Fruit should be integrated in local diets	0.0%	60%	40%	0.0%
Would benefit from added value products	0.0%	80%	20%	0.0%
Fruit should be marketed in commercial chain stores	40%	60%	0.0	0.0
Tailoring cultivation techniques, processing methods and tastes is important	40%	60%	0.0	0.0
Does the species hold future potential for food security	40%	60%	0.0%	0.0%

could become a mainstream product in both local and international markets.

4.5 Species production and management

The production and management of *D. caffra* vary significantly among the respondents. Some growers rely on seed propagation, while others use cutting propagation. The latter method is preferred due to its greater consistency in fruit quality and tree growth, but it is more labor-intensive and requires technical knowledge. The study found that while *D. caffra* is generally low-maintenance and drought-resistant, it still requires specific growing conditions, including well-drained soils and periodic irrigation. Respondents also noted the occasional pest and disease challenges, although these were not seen as major threats. The scarcity of high-quality cultivars and limited access to expert guidance were identified as key challenges hindering the industry's growth. The lack of standardized cultivation techniques and propagation methods further complicates large-scale production, limiting the tree's potential as a sustainable resource for agroforestry and commercial markets (Venter and Witkowski 2013).

To address these challenges several mitigation strategies are recommended:

Farmers training and education- Growers can receive training that can give them the knowledge and skills required for efficient irrigation, pest control, and propagation. With the help of agricultural extension services, training sessions can give growers the technical know-how required for efficient soil, pest, and propagation management. Nurseries and horticulturists can boost propagation effectiveness and enhance tree and fruit quality by also taking lessons about grafting and budding (Reeves and Hibberd, 2023).

Cultivar development- Research on better cultivars is essential to filling in the gaps in fruit quality and pest resistance. Creating cultivars with less sour fruit, more resistance to pests and diseases, and greater suitability for large-scale production can improve

TABLE 6 A summary of comparisons of *Dovyalis* species and their characteristics.

Scientific name	Common name	Fruit characteristics	Growth conditions	Nutritional content, uses	Tree habit	References
Dovyalis hebecarpa	Ceylon gooseberry	The fruit is a dark purple berry that is furry and juicy	Thrives in humid, constantly moist environments, preferring equally moist soil and having moderate drought tolerance; South Asia (Sri Lanka, India)	It contains a lot of vitamin C minerals and is highly acidic, works well to make jam and jellies	Shrub tree	Venter (2012), Bochi et al. (2015)
Dovyalis rhamnoides	Rhamnus African Apricot	Small, yellow fruit, sweet-sour taste	Found in woodlands, shrublands, and dry forests; East Africa	Utilized as a medicinal plant, a decorative plant, and for its edible fruit	Shrub-like	Azuma et al. (2000)
Dovyalis zeyheri	Zeyher's Kei Apple	The oval kei-apple yields tiny, unnoticeable blossoms and yellowish, edible fruits that draw a variety of wildlife and aid in the spread of its seeds	Found in savanna or forest areas and is well-suited to arid climates, Southern Africa	Edible fruit, hedge plant	Medium-sized tree, thorny	Stanstrup et al. (2010), Waweru et al. (2022)
Dovyalis longispina	Natal apricot	Dark yellow fruit, and very sour	Found along the coast, in coastal bush on sand dunes, and low-lying places near mangroves; Southern Africa (Natal)	Edible fruit, fencing	Low-growing shrub, very thorny	Grainger et al. (2011), Moll (1980)
Dovyalis caffra	Kei apple/ umqokolo	Yellow-orange fruit, tart taste, high vitamin C	Thrives in subtropical-like areas with moderate rainfall, requiring a balance of moisture and well-drained conditions; Southern Africa	Edible fruit, fencing, ornamental, agroforestry	Shrubby tree, thorny, drought-resistant	Tadesse (2023)
Dovyalis abyssinica	Abyssinian gooseberry	Orange- red, sour edible	Thrives in highlands, well drained; East Africa (Ethiopia, Uganda)	Edible fruit, medicinal	Small tree shrub	Baylie et al. (2024)
Dovyalis macro-calyx		Orange- yellow	Dry woodlands, savannas; East Africa	Edible fruit, medicinal	Shrub/small tree	Kigen et al. (2017)

economic viability. Such initiatives may involve collaboration with agricultural research institutions to develop cultivars suited to the area conditions.

Strengthening the value chain- Improving market access is key to making *D. caffra* a commercially viable crop. This could involve reinforcing connections among producers, processors, and markets, including local and regional food networks or export markets for distinctive fruits. Farmers could form partnerships or commercial entities that can enhance value chains to make sure small farmers, nurseries, and street vendors benefit from increased demand.

4.6 Data base search

4.6.1 Underutilized indigenous species in the Eastern Cape

This study also highlighted other underutilized indigenous plant species in the Eastern Cape that hold comparable ecological and economic significance. While many of these species, such as *Sclerocarya birrea* (Marula) and *Vangueria infausta* (Wild Medlar), are already commercially recognized, *D. caffra* stands out due to its hardiness and versatility. The identification of these species underscores the untapped potential of the region's biodiversity and presents opportunities for expanding the scope of indigenous plant cultivation. Further research and market exploration of these species could foster the development of a more diverse and sustainable agroforestry industry in the Eastern Cape, benefiting local communities economically and ecologically.

4.6.2 *Dovyalis* species and their characteristics

The comparison of various *Dovyalis* species revealed their distinct growth patterns, fruit characteristics, and uses. While *D. caffra* (Kei apple) is the most widely recognized for its hardiness and multiple uses (fencing, food, and agroforestry), other species like *Dovyalis hebecarpa* (Ceylon gooseberry) and *Dovyalis rhamnoides* (Rhamnus African Apricot) as illustrated in Table 6 show promise for different purposes, such as jam production and medicinal uses. These species contribute to the diversity of *Dovyalis* cultivation and indicate the potential for diversification in agroforestry systems. The varying characteristics and uses of these species highlight the need for targeted research to optimize their cultivation and commercialization.

4.6.3 Economic viability and market potential

The study underscores the economic viability of cultivating indigenous trees like *D. caffra* in the Eastern Cape. It is characterized by diverse ecosystems, including forests, coastal regions, and grasslands. Indigenous trees are essential to the preservation of cultural heritage, local economic growth, and biodiversity in the Eastern Cape (Cocks and Dold, 2006; Singh,

2024). Indigenous trees play a vital role in maintaining the ecological balance of the Eastern Cape by providing habitat for a wide range of fauna and flora, thereby promoting biodiversity (Singh, 2024). Examples of these species include the Yellowwood (*Podocarpus spp*) and the Knob Thorn (*Acacia nigrescens*), which are essential to local ecosystems and support wildlife by providing food and shelter, as well as contributing to soil health through their root systems that prevent erosion (Moll, 2012). Additionally, compared to non-native species, indigenous trees are better adapted to the local climate because their deep-rooted roots allow them to access groundwater during dry spells, making them more resilient to droughts which is a crucial factor considering the region's unpredictable climate.

For communities in the Eastern Cape, the cultivation of indigenous trees has a major economic impact. Local businesses can be supported by producing wood from these trees, and sustainable methods that do not deplete resources are ensured. Locally grown fruit-bearing trees, such as the Marula (*S. birrea*) yield food items that can be harvested responsibly and sold domestically and abroad (Emanuel et al., 2005). A recent study by Chauke et al. (2025) reports that the fruit and other goods made from marula have done well in the commercial market. Furthermore, when integrated with agricultural crops in agroforestry systems, native trees have a function. This method increases soil fertility, gives crops shade, and generates extra cash from the sale of tree products like nuts and fruits.

Planting native trees improves soil fertility by adding organic matter, repairing degraded areas, and boosting carbon sequestration capacity. All these benefits translate into improved environmental health (Sang et al., 2013). These ecological benefits are vital for reducing the negative impacts of climate change on rural communities. Consumers are increasingly supporting businesses that use sustainable practices. This shift makes a customer base willing to pay a premium for indigenous trees that benefit local ecosystems (Sang et al., 2013). Many businesses recognize their role in promoting sustainability through corporate social responsibility (CSR) initiatives such as tree planting programs or collaborations with local nurseries specializing in indigenous species (Heslin and Ochoa, 2008). By cultivating an environment where tree farming is economically beneficial, socially enriching, and environmentally sustainable, stakeholders can collaborate to create greener habitats that benefit both people and nature.

5 Conclusion

This study offers a thorough examination of the opportunities and challenges surrounding the cultivation and commercialization of *D. caffra* (Kei Apple) in the Eastern Cape. The findings suggest that while the tree holds significant economic potential, considerable gaps remain in knowledge related to propagation techniques, cultivation practices, and market awareness. Addressing these gaps through focused research, farmer education, and market expansion will be crucial in unlocking the full potential of *D. caffra* and other indigenous species in the region. Promoting the cultivation of indigenous species can enhance food security, foster sustainable agricultural practices, and contribute to local economic development in the Eastern Cape. The improvement of production methods for *D. caffra* has significant potential to enhance food security, boost economic growth, and promote environmental sustainability. As an underutilized indigenous species, *D. caffra* is highly adaptable to challenging climatic conditions, making it an excellent candidate for agroforestry, commercial farming, and as a nutritional supplement.

Despite its many advantages, challenges such as limited propagation techniques, a lack of standardized cultivation methods, and low market awareness continue to hinder its widespread adoption. However, by refining production methods, investing in research, and offering education to farmers, *D. caffra* can be developed into a more sustainable resource. Future research should focus on improving propagation techniques, boosting fruit yield through better irrigation and pruning practices, and exploring value-added products to increase market appeal. With the growing demand for resilient, nutrient-dense crops, *D. caffra* presents a promising opportunity for agro-processing industries, rural employment, and environmental conservation. By cultivating collaborations among local farmers, researchers, and policymakers, the full potential of this indigenous tree can be realized, ensuring its critical role in sustainable agriculture and food security for future generations.

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References

Al-Habib, A., Al-Saleh, E., Safer, A. M., and Afzal, M. (2010). Bactericidal effect of grape seed extract on methicillin-resistant *Staphylococcus aureus* (MRSA). *J. Toxicol. Sci.* 35 (3), 357–364. doi:10.2131/jts.35.357

Al-Rajhi, A. M., Salem, S. S., Alharbi, A. A., and Abdelghany, T. M. (2022). Ecofriendly synthesis of silver nanoparticles using Kei-apple (Dovyalis caffra) fruit and their efficacy against cancer cells and clinical pathogenic microorganisms. *Arabian J. Chem.* 15 (7), 103927. doi:10.1016/j.arabjc.2022.103927

Ali, A. C., Uetimane, E., Lhate, I. A., and Terziev, N. (2008). Anatomical characteristics, properties and use of traditionally used and lesser-known wood species from Mozambique: a literature review. *Wood Sci. Technol.* 42, 453–472. doi:10.1007/s00226-008-0186-5

Amuri, B., Maseho, M., Simbi, L., Okusa, P., Duez, P., and Byanga, K. (2017). Hypoglycemic and antihyperglycemic activities of nine medicinal herbs used as antidiabetic in the region of Lubumbashi (DR Congo). *Phytotherapy Res.* 31 (7), 1029–1033. doi:10.1002/ptr.5814

Augustyn, W. A., Regnier, T., De Jager, K., Hajari, E., Du Preez, R., and Nonyane, D. (2016). A preliminary study on the chemical characteristics of Kei apple (Dovyalis caffra), an undervalued South African fruit. *South Afr. J. Bot.* 117, 268–275. doi:10.1016/j.sajb.2018.05.032

Azuma, T., Kajita, T., Yokoyama, J., and Ohashi, H. (2000). Phylogenetic relationships of Salix (Salicaceae) based on rbcL sequence data. *Am. J. Bot.* 87 (1), 67–75. doi:10.2307/2656686

Baylie, T., Tsega, W., Getinet, M., Abebaw, D., Azanaw, G., Adugna, A., et al. (2024). Evaluation of antioxidant and antihyperglycemic effects Dovyalis Abyssinica (A. Rich). *Metab. Open* 22, 100286. doi:10.1016/j.metop.2024.100286

Bochi, V. C., Barcia, M. T., Rodrigues, D., and Godoy, H. T. (2015). Biochemical characterization of Dovyalis hebecarpa fruits: a source of anthocyanins with high antioxidant capacity. *J. Food Sci.* 80 (10), C2127–C2133. doi:10.1111/1750-3841.12978

Celep, G. S., Rastmanesh, R., and Marotta, F. (2014). "Microbial metabolism of polyphenols and health," in *Polyphenols in human health and disease* (Academic Press), 577–589.

Chauke, H., Silue, Y., Aremu, A. O., and Fawole, O. A. (2025). Nutritional values, phytochemical composition and bioactivities of Sclerocarya birrea (Marula) seeds and its potential applications: current research and future directions. *South Afr. J. Bot.* 179, 188–197. doi:10.1016/j.sajb.2025.02.008

Clark, K. H., and Nicholas, K. A. (2013). Introducing urban food forestry: a multifunctional approach to increase food security and provide ecosystem services. *Landsc. Ecol.* 28, 1649–1669. doi:10.1007/s10980-013-9903-z

Clement, R. P., Runyogote, J., Raymond, J., and Chacha, M. N. (2023). Ethnobiological survey to determine the link between health benefits and qualities of Maasai traditional food system in Monduli, Arusha, Tanzania. *Agroecol. Sustain. Food Syst.* 47 (8), 1077–1124. doi:10.1080/21683565.2023.2229786

Cocks, M. L., and Dold, A. P. (2006). Cultural significance of biodiversity: the role of medicinal plants in urban African cultural practices in the Eastern Cape, South Africa. *J. Ethnobiol.* 26 (1), 60–81. doi:10.2993/0278-0771(2006)26[60:csobtr]2.0.co;2

Dawson, I. K., Leakey, R., Clement, C. R., Weber, J. C., Cornelius, J. P., Roshetko, J. M., et al. (2014). The management of tree genetic resources and the livelihoods of rural communities in the tropics: non-timber forest products, smallholder agroforestry practices and tree commodity crops. *For. Ecol. Manag.* 333, 9–21. doi:10.1016/j.foreco.2014.01.021

Dharani, N. (2019). *Field guide to common trees and shrubs of East Africa*. South Africa: Penguin Random House.

Emanuel, P. L., Shackleton, C. M., and Baxter, J. S. (2005). Modelling the sustainable harvest of Sclerocarya birrea subsp. caffra fruits in the South African lowveld. *For. Ecol. Manag.* 214 (1-3), 91–103. doi:10.1016/j.foreco.2005.03.066

Epenhuijsen, C. V. (1976). Deciduous fruits in Tanzania.

FAO (1996). *Declaration on world food security and world food summit plan of action, 1996*. Rome, Italy: FAO, 13–17.

Grainger, M. J., van Aarde, R. J., and Wassenaar, T. D. (2011). Landscape composition influences the restoration of subtropical coastal dune forest. *Restor. Ecol.* 19 (101), 111–120. doi:10.1111/j.1526-100x.2009.00630.x

Heslin, P. A., and Ochoa, J. D. (2008). Understanding and developing strategic corporate social responsibility. *Organ. Dyn.* 37, 125–144. doi:10.1016/j.orgdyn.2008.02.002

Jones-Garcia, E., and Krishna, V. V. (2021). Farmer adoption of sustainable intensification technologies in the maize systems of the Global South. A review. *Agron. Sustain. Dev.* 41 (1), 8.

Kigen, G., Kipkore, W., Wanjohi, B., Haruki, B., and Kemboi, J. (2017). Medicinal plants used by traditional healers in sangurur, elgeyo marakwet county, Kenya. *Pharmacogn. Res.* 9 (4), 333–347. doi:10.4103/pr.pr_42_17

Kim, Y., and Youjin, Je (2017). Flavonoid intake and mortality from cardiovascular disease and all causes: a meta-analysis of prospective cohort studies. *Clin. Nutr. ESPEN* 20, 68–77. doi:10.1016/j.clnesp.2017.03.004

Mariod, A. A., and Abdelwahab, S. I. (2012). Sclerocarya birrea (Marula), an African tree of nutritional and medicinal uses: a review. *Food Rev. Int.* 28 (4), 375–388. doi:10.1080/87559129.2012.660716

Maroyi, A. (2018). Nutraceutical and ethnopharmacological properties of Vangueria infausta subsp. infausta. *Molecules* 23 (5), 1089. doi:10.3390/molecules23051089

Materechera, S. A., and Swanepol, H. R. (2011). Integrating the indigenous Kei apple (Dovyalis Caffra) into a local permaculture vegetable home eco-gardening system among resource-poor households in a semi-arid environment of South Africa. *II Int. Symposium Underutilized Plant Species Crops Future-Beyond Food Secur.* 979, 225–232.

Materechera, S. A., and Swanepol, H. R. (2013). Integrating the indigenous Kei apple (Dovyalis Caffra) into a local permaculture vegetable home eco-gardening system among resource-poor households in a semi-arid environment of South Africa. *Acta Hortic.* 979, 225–232. doi:10.17660/actahortic.2013.979.22

Mdoda, L., Loki, O., and Sikwela, M. M. (2025). Evaluating the economic effect of sustainable agricultural practices on small-scale farmers in the Eastern Cape Province: a propensity score matching analysis. *Int. J. Agric. Sustain.* 24 (1), 2478733.

Moll, E. J. (1980). A quantitative ecological study of the Hlogwene Forest, Natal. *South Afr. For. J.* 114 (1), 19–24. doi:10.1080/00382167.1980.9629829

Moll, E. (2012). *What's that Tree?* South Africa: Penguin Random House.

Mucina, L., Adams, J. B., Knevel, I. C., Rutherford, M. C., Powrie, L. W., Bolton, J. J., et al. (2006). Coastal vegetation of South Africa. *Veg. S. Afr. Lesotho Swazil. Strelitzia* 19, 658–583.

Mutengwa, C. S., Mnkeni, P., and Kondwakwenda, A. (2023). Climate-smart agriculture and food security in Southern Africa: a review of the vulnerability of smallholder agriculture and food security to climate change. *Sustainability* 15 (4), 2882. doi:10.3390/su15042882

Myers, S. S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., et al. (2017). Climate change and global food systems: potential impacts on food security and undernutrition. *Annu. Rev. public health* 38, 259–277. doi:10.1146/annurev-publhealth-031816-044356

Nkwanyana, M. N. (2013). *An ethnobotanical and antidiarrhoeal Investigation of plants used traditionally in the Maputaland area homesteads*. Doctoral dissertation, University of Zululand.

Nouman, W., Basra, S., Maqsood, A., Siddiqui, M. T., Yasmeen, A., Gull, T., et al. (2014). Potential of Moringa oleifera L. as livestock fodder crop: a review. *Turkish J. Agric. For.* 38 (1), 1–14. doi:10.3906/tar-1211-66

NRC (2008). *Lost crops of Africa of the national research council*, III. *Fruits*.

Ogbole, O. O., Akin-Ajani, O. D., Ajala, T. O., Ogunniyi, Q. A., Fettke, J., and Odeku, O. A. (2023). Nutritional and pharmacological potentials of orphan legumes: subfamily faboideae. *Heliyon* 9 (4), e15493. doi:10.1016/j.heliyon.2023.e15493

Ogwu, M. C., Izah, S. C., Dessureault-Rompré, J., and Gasparatos, D. (2024). *Sustainable soil systems in global South* (Springer Nature).

Omotayo, A. O., Ncama, K., and Aremu, A. O. (2018). Potentials of the underutilized Kei-apple (Dovyalis *caffra* L.): beyond its nutritional and functional value.

Omotayo, A. O., Ncama, K., and Aremu, A. O. (2019). Exploring the diverse potential of underutilized Kei-apple [Dovyalis caffra (Hook. f. and Harv.) Sim]: a multi-purpose fruit tree. *Hum. Ecol.* 47, 613–618. doi:10.1016/j.jep.2019.1119

Orwa, C. (2009). Agroforestree Database: a tree reference and selection guide. Available online at: http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp.

Pfukwa, T. M., Pheiffer, W., Fawole, O. A., Manley, M., and Mapiye, C. (2022). Cellular antioxidant and viability efficacy of Harpephyllum caffrum peel and Syzygium guineense seed extracts. *Food Bioscience* 49, 101934.

Qanash, H., Yahya, R., Bakri, M. M., Bazaid, A. S., Qanash, S., Shater, A. F., et al. (2022). Anticancer, antioxidant, antiviral and antimicrobial activities of Kei Apple (Dovyalis *caffra*) fruit. *Sci. Rep.* 12 (1), 5914. doi:10.1038/s41598-022-09993-1

Raza, A., Khare, T., Zhang, X., Rahman, M. M., Hussain, M., Gill, S. S., et al. (2025). Novel strategies for designing climate-smart crops to ensure sustainable agriculture and future food security. *J. Sustain. Agric. Environ.* 4 (2), e70048. doi:10.1002/sae2.70048

Reeves, G., and Hibberd, J. (2023). Cambridge Enterprise Ltd, 2023. *Graft-mediated hybridisation of monocotyledonous plants. U.S. Pat.* 11 (602), 107.

Rodríguez-García, C., Sánchez-Quesada, C., and Gaforio, J. J. (2019). Dietary flavonoids as cancer chemopreventive agents: an updated review of human studies. *Antioxidants* 8 (5), 137. doi:10.3390/antiox8050137

Sang, P. M., Lamb, D., Bonner, M., and Schmidt, S. (2013). Carbon sequestration and soil fertility of tropical tree plantations and secondary forest established on degraded land. *Plant Soil* 362, 187–200. doi:10.1007/s11104-012-1281-9

Santoro, A., Venturi, M., Bertani, R., and Agnoletti, M. (2020). A review of the role of forests and agroforestry systems in the FAO Globally Important Agricultural Heritage Systems (GIAHS) programme. *Forests* 11 (8), 860. doi:10.3390/f11080860

Sesso, H. D., Gaziano, J. M., Liu, S., and Buring, J. E. (2003). Flavonoid intake and the risk of cardiovascular disease in women. *The American Journal of Clinical Nutrition* 77 (06), 1400–1408.

Simelane, M. B., Shonhai, A., Shode, F. O., Smith, P., Singh, M., and Opoku, A. R. (2013). Anti-plasmodial activity of some Zulu medicinal plants and of some triterpenes isolated from them. *Molecules* 18 (10), 12313–12323. doi:10.3390/molecules181012313

Singh, H. (2024). *Urban forests, climate change and environmental pollution: Physio-Biochemical and molecular perspectives to enhance urban resilience*. Springer Nature.

Stanstrup, J., Rusch, A. M., Agnolet, S., Rasmussen, H. B., Mølgaard, P., Van Staden, J., et al. (2010). Itoside A and 4-hydroxytremulacin from Dovyalis caffra and Dovyalis zeyheri. *Biochem. Syst. Ecol.* 38 (3), 346–348. doi:10.1016/j.bse.2010.02.006

Tadesse, E. (2023). Attributes, uses, and management of Dovyalis caffra (Kei apple) A Review of literature. *Pesticide Sci. Pest Control* 1 (2), 2833–0943. doi:10.58489/2833-0943/021

Taher, M. A., Tadros, L. K., and Dawood, D. H. (2018). Phytochemical constituents, antioxidant activity and safety evaluation of Kei-apple fruit (Dovyalis caffra). *Food Chem.* 265, 144–151. doi:10.1016/j.foodchem.2018.05.099

Venter, S. M. (2012). *The ecology of baobabs (Adansonia digitata L.) in relation to sustainable utilization in northern Venda, South Africa*. Johannesburg (South Africa): University of the Witwatersrand.

Venter, S. M., and Witkowski, E. T. F. (2013). Where are the young baobabs? Factors affecting regeneration of Adansonia digitata L. in a communally managed region of southern Africa. *J. arid Environ.* 92, 1–13. doi:10.1016/j.jaridenv.2012.12.010

Wach, E. (2020). Growing through climate change: local responses to food security.

Waweru, D. M., Arimi, J. M., Marete, E., Jacquier, J. C., and Harbourne, N. (2022). Current status of utilization and potential of Dovyalis caffra fruit: major focus on Kenya-a review. *Sci. Afr.* 16, e01097. doi:10.1016/j.sciaf.2022.e01097

Wilken, L. E., Kleinert, A., Schmeisser, M., and Dzikiti, S. (2024). Leaf gas exchange, water use, and yield of Marula (Sclerocarya birrea) and Kei Apple (Dovyalis caffra): South African indigenous fruit trees with domestication potential. *South Afr. J. Bot.* 173, 266–278. doi:10.1016/j.sajb.2024.08.031

Xu, M. Q., Ariyo Okaiyeto, S., Niu, X. X., Wang, Q. H., Vidyarthi, S. K., Wang, H., et al. (2025). Bioactive compounds and Health functions of plums: current status and future opportunities. *Food Rev. Int.* 41 (5), 1360–1389. doi:10.1080/87559129.2024.2442666

Yang, K., Song, X., Cheng, C., Shi, Q., Li, X., Long, J., et al. (2025). Association between dietary inflammatory potential and liver cancer risk: a systematic review and dose-response meta-analysis. *Nutr. Cancer* 77 (4-5), 433–443. doi:10.1080/01635581.2025.2471619

Zhang, J., He, C., Chen, L., and Cao, S. (2018). Improving food security in China by taking

Zomer, R. J., Yang, J., Spano, D., and Trabucco, A. (2023). Irrecoverable carbon in mountains and the global mitigation potential of agroforestry and increased tree cover in mountain agricultural systems. *Circ. Agric. Syst.* 3 (1), 0. doi:10.48130/cas-2023-0011