Journal of Functional Foods 75 (2020) 104220

Contents lists available at ScienceDirect

Journal of Functional Foods

journal homepage: www.elsevier.com/locate/jff

Southern African indigenous fruits and their byproducts: Prospects as food antioxidants

Trust M. Pfukwa[a], Obert C. Chikwanha[b], Chenaimoyo L.F. Katiyatiya[b], Olaniyi A. Fawole[c], Marena Manley[a], Cletos Mapiye[b,*]

[a] Department of Food Science, Faculty of AgriSciences, Stellenbosch University, Private Bag X1, Matieland, Stellenbosch 7602, South Africa
[b] Department of Animal Sciences, Faculty of AgriSciences, Stellenbosch University, Private Bag X1, Matieland, Stellenbosch 7602, South Africa
[c] Postharvest Research Laboratory, Department of Botany and Plant Biotechnology, Faculty of Science, University of Johannesburg, Private Bag 524, Auckland Park 2006, South Africa

ARTICLE INFO

Keywords:
Antioxidants
Bioprospecting
Indigenous fruit
Bioeconomy

ABSTRACT

The discourse regarding plant-based preservatives for food application has generally revolved around extracts from commercial fruits, vegetables, herbs and spices with indigenous fruits (IFs) on the periphery, with little investment into their valorisation. While being important food sources at community level, IFs and their byproducts are also incorporated into medicinal remedies, combating various diseases. Their ethnomedicinal usage indicates potent bioactive profile that alleviate effects of oxidative stress, which accompany disease *in vivo*. This is supported by *in vitro* antioxidant activity of the IFs and their byproducts. As such, the current review explores the potential of bioprospecting extracts from nine IFs and their byproducts as food antioxidants. Evidence presented shows that IFs have high content of bioactive compounds further translating to high antioxidant activity. Research gaps in information concerning *in vitro* bioactivity warrant further research to provide impetus for valorisation and food application of IFs.

1. Introduction

In sub-Saharan Africa, indigenous fruits (IFs) play a pivotal role in society (Stadlmayr, Charrondière, Eisenwagen, Jamnadass, & Kehlenbeck, 2013; Van Wyk, 2011). In the Global South, IFs native to a country have remained on the societal and economic fringes and are still relatively unknown in the commercial market (Mabhaudhi et al., 2019). They contribute to a small share of global food systems with limitations being attributed to lack of seed production systems, breeding and agronomic improvement technologies (Kasolo, Chemining'wa, & Temu, 2018). Additionally, there is an observed lack of access to market information, low level of acceptability and access, strong deficiencies in processing technologies and skills, and inherently weak value chains to propel the IFs to wider commercial markets (Kasolo et al., 2018; Omotayo & Aremu, 2020). Gaps in knowledge concerning IFs should be addressed to promote and expand their use in food applications.

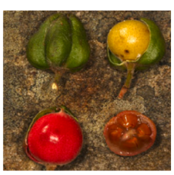
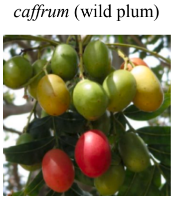
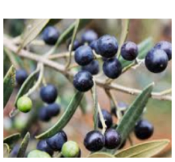
While the central aspect to the importance of IFs and their byproducts has been the provision of food, they have also been used as medicinal remedies for animal and human diseases (Maroyi, 2019; Nguyen et al., 2016; Van Vuuren & Frank, 2020). In terms of IFs, 'byproducts' refer to the parts of the fruit which are left after consumption or juice extraction such as the skin/peel, pulp, seed or stones. Indigenous fruits and their phytochemical extracts have been used as remedies for several diseases, such as sinusitis, fever, asthma, diarrhea, indigestion and skin diseases (Castañeda-Loaiza et al., 2020; Khoo, Azlan, Kong, & Ismail, 2016; Van Vuuren & Frank, 2020). This association is important since these remedies offer the antioxidant and/or antimicrobial effects required to counter the oxidative stress and microbial infections that accompany these ailments (Moyo, Finnie, & Van Staden, 2011; Van Der Watt & Pretorius, 2001; Van Vuuren & Frank, 2020). In addition, many plants have been used as sources of economically important constituents for incorporation into fragrances, pharmaceuticals, pesticides, food flavours and preservatives (Maroyi, 2019; Mokoka, Mcgaw, Eloff, Mcgaw, & Programme, 2010; Stevenson, Isman, & Belmain, 2017).

Overall, IFs and their byproducts remain undervalued and underutilised resources and there is little documentation on their phytochemical composition and bioactivity (Kasolo et al., 2018). In many parts of Southern Africa, most IFs are still collected from wild trees and

* Corresponding author.
E-mail addresses: tmpfukwa@gmail.com (T.M. Pfukwa), occhikwanha@yahoo.com (O.C. Chikwanha), 17223504@sun.ac.za (C.L.F. Katiyatiya), olaniyif@uj.ac.za (O.A. Fawole), mman@sun.ac.za (M. Manley), cmapiye@sun.ac.za (C. Mapiye).

https://doi.org/10.1016/j.jff.2020.104220
Received 27 July 2020; Received in revised form 18 September 2020; Accepted 23 September 2020
1756-4646/

Table 1
Current uses of indigenous fruits and their byproducts.

Fruit	Food uses of indigenous fruit and byproducts	Medicinal uses of indigenous fruit	Medicinal properties of other plant parts of indigenous fruit trees	Citation
Carissa macrocarpa (Amathungulu) 	• Eaten fresh • Preparation of fruit salad, jam, pies, sauces, desserts, yoghurt, jellies and ice cream • Used as topping for cakes and puddings	• Oleanolic acid and B-amyrin from the fruit can be used as a natural alternative to aspirin	• Leaves are used against diarrhoea in livestock	Moodley et al. (2011), Mphaphuli et al. (2020), Souilem et al. (2019)
Carpobrotus edulis (Hottentot-fig) 	• Eaten fresh • Preparation of jam, pickles or chutney • Consumed as a dehydrated fruit snack or cooked	• Treats tuberculosis, respiratory infections, toothache, earache, facial eczema, wounds, burns, hypertension, and diabetes mellitus	• Leaf juice used: • As a mouthwash for sore throat or gum infections • For the treatment of burn wounds. • To soothe pain from spider and tick bites. • For treatment against fungal and bacterial infections, sinusitis, diarrhoea, infantile eczema, tuberculosis and internal chest conditions	Castañeda-Loaiza et al. (2020), Mudimba and Nguta (2019), Rocha et al. (2017), Van Der Watt and Pretorius (2001)
Osyris compressa (Cape sumach) 	• Eaten fresh • Skin and pulp of ripe fruit consumed fresh and used to make jam	• A paste of fruit is applied to the forehead to relieve headache	• Boiled concoctions of the bark, mixed with other herbs are used to improve blood circulatory, digestive, respiratory and nervous systems • Bark oils and paste used to treat skin diseases such as infectious sores, ulcers, acne and rashes	Shyaula (2012)
Diospyros whyteana (bladder nut) 	• Fruits are eaten as a snack	• No data	• Roots are used for treating dysmenorrhea, irritating rashes and as an antibacterial	Verschaeve et al. (2004)
Dovyalis caffra (Kei apple) 	• Preparation of juices and liqueur • Incorporated into fruit salads and desserts • Made into syrups, shortcake, jam, jelly, drinks and pickles • Added to porridge for nutrient enrichment • Seed roasted seed used as coffee substitute	• Juice from crushed fruit used to treat cough in livestock • Fruit extract promotes gastrointestinal motility and inhibits tightening and shortening of the uterine muscles	• Roots and thorns used to treat amenorrhea and chest pains • Bark is used as a remedy for rheumatism	Ngemakwe et al. (2017), Aremu et al. (2019)
Harpephyllum caffrum (wild plum) 	• Fruit juice mixed with porridge to form a pudding-like product • Whole fruits processed into syrups, jams, jellies, liqueurs and novel flavors	• Fruits uses in the treatment of skin problems (acne, eczema, pimples, rash and skin cuts) and wounds	• Stem bark used for treating acne, eczema, pain and childhood convulsions and epilepsy • Aqueous stem-bark extracts have anticonvulsant, and analgesic and blood detoxification properties	Maroyi (2019), Moodley et al. (2014), Ojewole and Amabeoku (2007), Van Vuuren and Frank (2020)
Olea europaea var. *cuspidata* (wild olive) 	• No data	• Ripe fruits boiled with sugar and used as cough syrup • Fruit infusion used for treating bloody stool and diarrhea in humans	• Leaves extracts have antitumoral, anti-inflammatory, antioxidant, hepatoprotective, cardioprotective and antimicrobial activities	Long, Tilney, and Van Wyk (2010), Msomi and Simelane (2017), Sánchez-Quesada et al. (2013)
Sclerocarya birrea (marula) 	• Fruits processed into juice, jam, jellies, sorbet and alcoholic drinks • Leaves used to make tea	• Fruits used in the treatment of goiter	• Leaves and stem barks concoctions used to treat hypertension, diarrhoea, indigestion, dysentery, ulcers, proctitis, diabetes mellitus, fever, malaria, fungal infections and skin disease	Ojewole et al. (2010), Sarkar et al. (2014), Schulze-Kaysers, Feuereisen, and Schieber (2015)

(*continued on next page*)

Table 1 (*continued*)

Fruit	Food uses of indigenous fruit and byproducts	Medicinal uses of indigenous fruit	Medicinal properties of other plant parts of indigenous fruit trees	Citation
Syzygium guineense (water-pear) 	• Eaten fresh • Fruit pulp used in the preparation of juices, jellies, conserves, beer brewing and distilling spirits	• Treating infertility in women, treating wounds • Fruits also used as a remedy for dysentery	• Leaves are used for treating asthma, dermatosis, malaria, pneumonia, infertility fever, stomachache, ringworm, wounds, herpes zoster and diabetes • Bark is used against chronic diarrhea and chest pain	Nguyen et al. (2016), Verschaeve et al. (2004)

largely underutilised (Kasolo et al., 2018; Nkosi, Mostert, Dzikiti, & Ntuli, 2020). Previous studies showed that IFs and their byproducts are rich in phytochemicals (i.e. phenolic acids, flavonoids, triterpenes, stilbenes and lignans) with antioxidant and antimicrobial properties (Loots, van der Westhuizen, & Jerling, 2006; Ngemakwe, Remize, Thaoge, & Sivakumar, 2017). Bioprospecting these IFs and their byproducts could provide novel sources of bioactive compounds in food application. This supports earlier propositions alluded to by Falowo, Fayemi, and Muchenje (2014) on the use of edible medicinal plants to preserve the functionality of meat and ensure production of meat products with nutraceutical properties. Therefore, the current review explored nine underutilised Southern African IFs for potential application of extracts of their byproducts as food antioxidants.

2. Review methodology

The inclusion criteria for the nine Southern African IFs selected for this review was based on perceived commercialisation potential, abundance and ease of propagation with respect to the fruit. Of the nine indigenous fruits selected, four have been commercialised (*Carpobrotus edulis* N.E.Br., *Dovyalis caffra* Warb., *Olea europaea* var. *cuspidata (*Wall. & G.Don*) Cif.* and *Sclerocarya birrea* Hochst. (Global Biodiversity Information Facility Secretariat, 2019b, 2019d, 2019f, 2019h). Three of the fruits [i.e., *Carissa macrocarpa* A.DC., *Harpephyllum caffrum* Bernh. and *Syzygium guineense* DC. (Global Biodiversity Information Facility Secretariat, 2019a, 2019e, 2019i) have demonstrated exceptional potential for new enterprises and have been engaged in trial plantings. *Diospyros whyteana* (Hiern) F.White and *Osyris compressa* A.DC. (Global Biodiversity Information Facility Secretariat, 2019g, 2019c) are currently not considered to be of commercial interest, but present potential for innovative processing.

A comprehensive literature search was conducted on Web of Science, Scopus, Google Scholar, PubMed, GBIF, PlantZAfrica, Tree SA and Useful Tropical Plants databases. Boolean search strings 'Southern African' AND 'indigenous fruits' AND 'neglected and underutilised fruits' AND 'bioprospecting' AND 'indigenous fruit ethnomedicinal use, phytochemistry and biological activities' were used. There was no consistency regarding the existing information on the nine IFs, hence the current review only presents the available data for each fruit.

3. Description, distribution and ecology of selected indigenous fruits in Sourthen Africa

The IFs described in the current review, apart from *Sclerocarya birrea* (marula), are harvested from the wild (Hiwilepo-Van Hal, 2013). Despite being in their natural habitat as well as widely consumed and popular among local communities (Kasolo et al., 2018), little effort has been given to harness them as crops of commercial importance or towards valorisation of their byproducts. More attention should be afforded to them as their natural habitat is increasingly threatened by over-exploitation for firewood and expansion of commercial agriculture fueled by population growth (Augustyn et al., 2018). In an effort to add value IFs, it is important to highlight how they are currently being used, which parts are used and how are they being processed.

The processing of many commercial fruits has seen waste being generated causing environmental concerns (Djilas, Čanadanović-Brunet, & Ćetković, 2009; Sharma, Mahato, Cho, & Lee, 2017). Current efforts, however, attempt to reduce waste and retain value of the fruits in the chain as much as possible and for as long as possible. Having the possible alternative uses for IFs goes a long way to incorporate this reduced-waste approach in their valorisation. As such, nutritional aspects, sensory properties, potential health benefits, food processing, agronomy, opportunities for development of cosmetics, and uses in traditional medicine are reviewed together. This demonstrates their versatility and gives information on how sustainability can be moulded into the valorisation process for IFs. Nevertheless, the main hypothesis of the study is that the link between indigenous fruits and ethnomedicinal application points to IFs as having a potent content of bioactive components which can be harvested and applied as novel natural antioxidants in foods.

3.1. *Carissa macrocarpa*

The primary habitat for *C. macrocarpa* (Amathungulu) shrubs is the coastal bush, forest and sand dunes, stretching from the Cape and Kwazulu-Natal Provinces of South Africa through to Zimbabwe, Mozambique and Zambia to the Democratic Republic of Congo (DRC) and Kenya (Carolus, Porter, & Reynolds, 2004). They exist as evergreen, dense thorny shrubs or small trees up to a height of 4 m. They have characteristic Y-shaped thorns and exude a white, milky, non-toxic gummy sap from all parts of the plant (Patel, 2013). Flowering and fruiting season stretch from November to April. Amathungulu fruits are oval or oblong in shape with a magenta-red to scarlet colour culminating to a final dark crimson colour (Table 1). Propagation of *C. macrocarpa* can be done using seeds with seed germination occurring within two weeks. Vegetative propagation can also be employed, either by air-layering, ground layering or shield budding (Carolus et al., 2004). Shrubs of Amathungulu are widely grown for ornamental purposes as a garden hedge and found alongside roadsides and parking lots in the form of xeriscaping (Carolus et al., 2004; Morton, 1987). This is a form of water-wise landscaping that targets to reduce or eliminate the need for supplemental water from irrigation by incorporating native drought resistant plants.

3.2. *Carpobrotus edulis*

This succulent extremophile plant is recognised as an aggressive invasive species of coastal areas worldwide (Castañeda-Loaiza et al., 2020). *Carpobrotus edulis* (Hottentot-fig) natural habitat is the coastal and inland slopes from the Cape Provinces of South Africa but has also naturalised in parts of Australia, as well as the Mediterranean and southern coastal areas of England (Castañeda-Loaiza et al., 2020). It possesses very efficient reproductive and dispersal abilities. The roots develop easily from cuttings, with succulent leaves and stem-forming dense groundcover (Malan & Notten, 2006). Flowering season is from August to October with Hottentot-fig distinguishable from other species by its yellow flowers. Harvesting of the fruit runs from October through to March. Yellow, fleshy, spin-top-shaped fruits are produced (Table 1), becoming reddish-brown, wrinkled and leathery as they mature with small seeds embedded in a sticky mucilage (Global Invasive Species Database, 2020).

3.3. *Osyris compressa*

This shrub is also commonly known as *Colpoon compressum* (Global Biodiversity Information Facility Secretariat, 2019g) and locally as Cape sumach (Voigt & Notten, 2006). It grows on the coastal dunes and inland slopes of the Cape Peninsula in the west, along the south coast advancing north into tropical Eastern Africa (Manning, 2018). It is hemi-parasitic, meaning it can photosynthesise but also derive its nutritional requirements from roots of a host plant (Voigt & Notten, 2006). The flowers, which are borne in small terminal heads or panicles, and fruits are produced erratically throughout the year, but mainly from April to December. The bisexual flowers occurring in the long flowering season, the hemi-parasitic nature and leaf adaptation to conserve moisture make this shrub adaptable to fynbos, savannah and coastal conditions (Shyaula, 2012). While similar to the inland species, *Osyris lanceolata*, the latter can be distinguished by its alternate leaves and the axillary flowers (Voigt & Notten, 2006). The *O. compressa* shrub bears glossy, pea-sized berries with a prolate spheroid shape and a circular groove from the perianth lobes which crown its tip (Fern, 2014). The fruits have a sweet flavour and turn purple-black when ripe (Table 1) (Voigt & Notten, 2006). *Osyris compressa* grows from seeds which fall on the ground and cannot be propagated from cuttings. It is also not well established in cultivation and is best left to reproduce naturally (Voigt & Notten, 2006).

3.4. *Diospyros whyteana*

Diospyros whyteana (bladder nut) is naturalised in forests, on mountain slopes and in rocky outcrops from South Africa stretching as far north as Ethiopia (Viljoen, 2002). It is in the same genus as edible persimmon (*Diospyros kaki*) native to China. *Diospyros whyteana's* attractiveness as an ornamental tree has seen it being planted in many gardens (Rauf et al., 2017). Its propagation is done from seed, which have to be scarified before planting. Flowering and fruiting season is from August to January. The fruit, which is a fleshy berry turning scarlet to reddish brown when ripe (Table 1), appears on female plants and is enveloped by an accrescent calyx (Becking, 2018).

3.5. *Dovyalis caffra*

The shrubs of *D. caffra* (Kei apple) are adapted to the valley bushveld, dry areas, wooded grassland, and on forest edges (Ndou, 2003). Its distribution stretches from the Kei River in South Africa, from which its common name is derived, north-eastwards through Swaziland, Zimbabwe and Mozambique into Tanzania (Ndou, 2003). It has also been successfully introduced in Australia, Egypt, Italy, France and USA (Omotayo, Ncama, & Aremu, 2018). Based on its traits as a drought and frost resistant plant, it has also been introduced to Israel as a desert fruit (Ndou, 2003). *Dovyalis caffra* can be propagated from the dry seed of mature fruits or from hardwood cuttings pretreated with root stimulating hormone. Other challenges in its propagation were investigated by Hae and Funnah (2011). It grows to a height range of 3–8 m, with long sharp thorns on the stem and branches and dense green foliage (Aremu, Ncama, & Omotayo, 2019). In Southern Africa, flowering and fruiting season start in November and ends in January. The fruits are spherical, with a tough skin, 40–60 mm in diameter, developing to a bright yellowish-orange colour at maturity (Table 1) (Omotayo et al., 2018). The flesh is apricot-like, juicy and highly acidic with 5–15 seeds embeded in the center (Loots et al., 2006).

3.6. *Harpephyllum caffrum*

The tree of *H. caffrum* (wild plum) fruit is evergreen, growing up to 15 m in height (Maroyi, 2019). Its habitat is in frost free areas stretching from Eastern Cape, northwards through Swaziland and southern Mozambique and into Zimbabwe (Dlamini, 2004). Flowers appear in September with fruit ripening through to March. It can be grown easily from seeds which require a day of soaking before planting. Propagation can also be done from cuttings and truncheons. Its attribute as a neat evergreen tree has seen *H. caffrum* being widely cultivated in South Africa as a decorative tree along streets and as an ornamental tree (Maroyi, 2019). It has also been introduced to Egypt based on its attributes as a good xeriscaping plant and for its edible fruits (Maroyi, 2019). The *H. caffrum* fruit has a small oval shape and ripens to a red colour with a sour pulp (Table 1).

3.7. *Olea europaea var. cuspidata*

Prior to 1980, this species of wild olive was known as *Olea africana* subsp. *cuspidate* (Msomi & Simelane, 2017). The closely related species, O. *europaea* subsp. *europaea* (the common olive) has silvery-grey leaves with pointed tips while wild olive has pale-green–brown undersides of the leaves which have hooked tips. This tree is noted as being frost, drought and wind resistant. It is widely distributed across Africa as well as in Mascarene Islands, Arabia, India to Afghanistan and Pakistan (Msomi & Simelane, 2017). Wild olive flowering occurs in October to February with fruiting taking place from March to July. Fruits are small and spherical with a thin flesh that ripens to a purple black colour (Table 1). It is mainly propagated by rooting of semi-hardwood cuttings prepared form one-year old branches treated with rooting hormone. Seed propagation is also possible, though it is a less preferred method as it gives variable seedlings (Joffe, 2002).

3.8. *Sclerocarya birrea*

Sclerocarya birrea (marula) natural habitat is the semi-arid, deciduous and savannah regions of sub-Saharan Africa (Hall, O'brien, & Sinclair, 2002). It has three subspecies which occur in its vast geographic range namely *caffra* in Southern Africa, *birrea* in west Africa and further north, and *multifoliolata,* which occurs in a small region where the two major species overlap (Hall et al., 2002). Flowers appear from September to November and it bears fleshy fruit about 3 cm in diameter. It propagates naturally from seed, coppice, truncheons and gregarious root suckering (Hall et al., 2002). *Sclerocarya birrea* has received significant attention towards its domestication and commercialization (Mutshinyalo & Tshisevhe, 2003). The fruits are plum-sized (3–4 cm in diameter) with a plain tough peel ripening to a pale-yellow colour (Table 1) (Hillman, Mizrahi, & Beit-Yannai, 2008). Its flesh is fibrous mucilaginous in texture, highly aromatic with a juicy, sweet-–sour taste. In the center of the fruit is a hard nut containing 1–4 locules which enclose the soft white oil-rich seed (Hillman et al., 2008),

3.9. *Syzygium guineense*

This evergreen tree, belonging to the family *Myrtaceae,* is distributed throughout sub-Saharan Africa and grows up to a height of 12–15 m (Nguyen et al., 2016). This species is naturally found in the areas of Senegal, stretching to Somalia in the east and extending southward to South Africa. Another species of *Syzygium*, *S. cordatum,* also has similar distribution to the former. Flowers appear from August to December and fruiting is from December to April giving edible fruits that are usually dark purple when mature (Table 1), with a single rounded seed. Their habitat is the lowland forests, in areas close to swamps and sometimes along riverbanks (Zenze, 2013). It usually grows in moist conditions and sometimes even in water. *Syzygium guineense* thrives in moist, well-drained soils with a high-water table, but will also grow in open woodlands (Zenze, 2013). Propagation can be done easily from fresh seed. Since the seeds do not store well, sowing can be done immediately after collection and cleaning of seed (Fern, Fern, & Morris, 2019b).

4. Current uses of selected indigenous fruits

Globalization of agricultural markets, particularly in the sub-Saharan region has seen a plummeting appreciation for IFs (Chivandi, Mukonowenzou, Nyakudya, & Erlwanger, 2015). As highlighted by Kasolo et al. (2018), this has narrowed down the prominence of IFs and relegated them to a marginalised status compared to mainstream crops. Through tapping into indigenous knowledge systems, the traditional and modern roles of IFs can be traced to unlock ways to develop their potential current and future uses. In rural communities where they thrive, IFs are an integral part of the diet and used as medicine and are valued for their contribution to the local economy (Baldermann et al., 2016). Table 1 highlights the uses of a selected group of indigenous fruits based on the potential for commercialisation.

4.1. *Carissa macrocarpa*

When fully ripe, the flesh of *C. macrocarpa* is slightly soft and can be eaten whole, with or without peeling and has commendable nutritional composition (Table 2). It can also be incorporated in the preparation of condiments, salads or desserts (Table 1). Mphaphuli et al. (2020) were able to produce mango fruit leathers enriched with Amathungulu fruit paste which in turn improved their phytochemical composition. This product goes a long way in instiling innovation into efforts towards value addition of underutilised IFs. Follow-up studies to determine the sensory quality of the fruit could be important. Extracts from the fruit find ethnomedicinal purpose as pain relief medication (Table 1).

4.2. *Carpobrotus edulis*

Fruits from *C. edulis* are consumed raw, cooked or they can be dried for later use to make pickles or chutney (Fern, Fern, & Morris, 2019a). Valued as a good source of nutrients, its nutritional value (Table 2) was evaluated by Broomhead, Moodley, & Jonnalagadda, (2020). The sensory profile of *C. edulis* gives strong, astringent, salty and sour notes, while the fruits of other species *C. acinaciformis* and *C. delicious* are sweeter (Malan & Notten, 2006). Extracts from the fruit are used for treating skin and respiratory infections, as well as therapy for various diseases, including hypertension and diabetic disorders (Table 1) (Castañeda-Loaiza et al., 2020). In the Western Cape region of South Africa, harvesting of Hottentot-fig has provided sustainable benefits to communities (CapeNature, 2009). An example is the partnership between U'Zenzele Community Development Organization and CapeNature, the South African regulatory body responsible for biodiversity conservation in the Western Cape. Under the agreement, permits were issued out to enable sustainable harvesting of Hottentot-fig (CapeNature, 2009).

4.3. *Dovyalis caffra*

The Kei apple can be consumed fresh in the communities where it is found. Given its nutritional profile (Table 2), the juice from ripe fruits is used to enrich porridges made from pearl millet, maize or sorghum (Aremu et al., 2019). In some Batswana communities, a traditional pudding can be made by mixing *D. caffra* juice with porridge (Aremu et al., 2019). Van Wyk (2011) described Kei apple as having potential in the production of liqueur. The juice from crushed fruit is also administered to livestock as a treatment for coughing (Aremu et al., 2019). Aqueous Kei apple extracts were documented to have stimulatory effects on gastrointestinal movement and inhibitory properties on uterine contractions (Taher, Tadros, & Dawood, 2018). However, the

Table 2
Nutritional composition of selected Southern African indigenous fruits.

Scientific name	Energy	Water (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	Carbohydrate (g/100 g)	Fiber (g/100 g)	Ash (g/100 g)	References
Carissa macrocarpa	100.3 [kcal/100 g Fruit weight (FW)]	78.83	0.74	3.53	16.40	–	0.50	Souilem et al. (2019)
Carpobrotus edulis	1370 kJ/100 g dry weight (DW)	77.6 wet mass (WM)	23.5 (DW)	2 (DW)	64.4 (DW)	–	10.1 (DW)	Broomhead et al. (2020)
	8.53 (kJ/fruit)	80.56	12	–	68	–	–	Vila and D'Antonio (1998)
Dovyalis caffra	–	15.5 DW	4 DW	3 DW	54.05 DW	16.3 DW	7.45 DW	Taher et al. (2018)
Harpephyllum caffrum	–	87.5	0.7	0.2	9.1	1.7	0.8	Maroyi (2019)
Sclerocarya birrea	–	86.3	0.7	0.5	–	–	–	Stadlmayr et al. (2013)
	–	–	1.4	0.9	–	–	3.0	Magaia et al. (2013)
	–	85–87	–	13.5	0.7 – 1.2	2.9	10–20	Hiwilepo-Van Hal (2013)
Syzygium guineense	295 kJ/100 g	81.5	1.6	0.7	13.5	1.8	1.0	Stadlmayr et al. (2013)
	1096 kJ/100 g	–	10.1	4	48.5	30.3	7.1	Saka and Msonthi (1994)

fruit extracts can also prolong stimulation of irregular heart rhythm leading to death through acute heart failure if an acute dose is reached (Taher et al., 2018).

4.4. *Harpephyllum caffrum*

Harpephyllum caffrum fruits can be consumed as is or used for making condiments, deserts and for nutritional enrichment of porridge based on its nutritional profile (Table 2). Their sour taste also make them ideal for the production of rosé wine (Dlamini, 2004). Its sensory profile can be described as having a soft velvety texture and tart acidity that is balanced by creamy notes of mango and passion fruit. This can make it an ideal ingredient in new flavour development as it can blend familiarity with a hint of new and exotic. It is also compatible with other flavors such as orange, banana, lime, coconut, lime, ginger and jalapeño. Extracts from *H. caffrum* fruits are used in the treatment of wounds and skin problems (Maroyi, 2019).

4.5. *Olea europaea var. cuspidata*

Wild olive is rarely consumed as a fruit because of its bitterness but used in various medicinal concoctions (Table 1). Due to its adaptation to semi-arid climates and general hardiness, Wild olive was previously used as graft stock to the commercial olive (*Olea europaea* L.) providing vigor and possible resistance to olive fungal diseases (Hannachi et al., 2009).

4.6. *Sclerocarya birrea*

Trees of marula are valued in Africa for their fruit, commercial, cultural and ethnomedicinal contribution from almost every part of the tree (Ojewole, Mawoza, Chiwororo, & Owira, 2010) and commonly referred to as the ‘Tree of life’, in communities where it grows (Schulze-Kaysers, Feuereisen, & Schieber, 2015). The marula is either eaten raw or fermented to produce condiments, frozen desserts and alcoholic beverages (Table 1). Considering its nutritional composition (Table 2), marula fruit makes valuable contribution to nutrient intake of rural communities especially during dry seasons. Ethnomedicinal reports have indicated that marula nut oil has been used for moisturising and hydrating the skin (Komane, Vermaak, Summers, & Viljoen, 2015). Based on these reports, marula oil has become popular as a natural ingredient in cosmetic formulations. Komane et al. (2015) attributed the dermal hydrating, non-irritant and moisturising properties of marula oil to the presence of oleic and palmitic acids. Despite being traded widely as a cosmetic agent, marula oil was found to have no anti-aging properties (Shoko et al., 2018). However, anti-aging properties were found to be more pronounced in the marula tree stems, a property attributed to epicatechin gallate, epigallocatechin gallate activity of their ethanolic extracts (Shoko et al., 2018).

4.7. *Syzygium guineense*

Fruits from *S. guineense* have a sweet flavor but rather bland taste and are usually consumed as a wayside nibble (Fern et al., 2019b). The water-pear skin and pulp are consumed while the seed is discarded. The fruits are highly perishable and should be consumed soon after harvesting (Fern et al., 2019b). Although this perishable nature could be attributed to the fruits’ thin skin, it is important to investigate the respiration rates and ethylene production in the ripe fruits. This means that the creation of value chains is critical for the promotion of *S. guineense* as there could be a short window between optimally ripe stage and wasting of product. Juice from the fruits can be used to make a beverage or it can be fermented into vinegar (Fern et al., 2019b). Nguyen et al. (2016) highlighted the extensive ethnomedicinal role of water-pear tree parts amongst traditional healers in various districts of Mali, West Africa. The traditional healers surveyed, reported that fruit powder could be applied every morning to a wound for healing. The dried fruit powder, two finger pinches added to coffee, was also reported to treat infertility in women when drank every morning for a long period (Nguyen et al., 2016). Dyes from water-pear fruits have also been adopted for other non-food uses. Extracts from water-pear pulp used as sensitisers in dye-sensitised solar cells were found to have promising photoelectrochemical performance (Tadesse, Abebe, Chebude, Garcia, & Yohannes, 2012). This was attributed to their content of anthocyanin, carotene and chlorophyll (Tadesse et al., 2012).

Overall, ethnobotanical knowledge of IFs reveals extensive use of these resources in traditional medicine, sometimes referred to as traditional, complementary and alternative medicine (Mahomoodally, 2013). Tree parts such as the leaves, bark, fruits and flowers are used for various ailments by chewing raw or boiling in water which is then taken orally (Mudimba & Nguta, 2019). Work by Nguyen et al. (2016) revealed other ways in which the plant parts are prepared (ashing, decoctions, drying and grinding) and administered (steaming, drinking, topical application). Prior to the introduction of allopathic and western forms of medicine, the use of medicinal plants in traditional medicine was the dominant medical system. Research by Oyebode et al. (2016) has, however, found an overall decrease in the use of traditional medicine with usage mostly among marginalised groups who reside in rural areas and are of a lower socio-economic status. Among the countries with the highest use, traditional medicine is incorporated as adjuvant therapy in tandem with modern medicine (Oyebode et al., 2016). Considering the decline in the use of traditional medicine, Oyebode et al. (2016) argues for an understanding of the role that traditional medicine can assume in delivering sustainable human health and wellbeing. Nguyen et al. (2016) merged an in-depth ethnopharmacological study on *Syzygium guineense* with an extensive evaluation of its phytochemistry and antioxidant properties. Indeed, indigenous fruit derivatives such as phenolics, terpenoids, essential oils and alkaloids are cited as next-generation therapeutics together with bacteriophages, antibacterial peptides and metal nanoparticles (Gokoglu, 2019; Kurek, Nadkowska, Pliszka, & Wolska, 2012). Evidence for therapeutics functions stems from their use in medicinal herbs for the control of microbial manifestations in animal and human diseases. Considering the dearth in literature for fruit portion compared to the bark, root and leaves; such an approach is critical in providing information towards the valorisation of the fruit portion.

5. Phytochemical content and composition of the selected indigenous fruits

5.1. *Carissa macrocarpa*

Moodley et al. (2011) isolated four pentacyclic oleanane triterpenes (oleanolic acid, β-amyrin, methyl oleanolate and 3β- hydroxyolean-11-en-28,13β-olide) from num num fruits. Oleanolic acid was recovered from methanolic extracts whilst the latter three metabolites were isolated from dochloromethane extracts. The compounds had been separated using column chromatography and identified using Nuclear Magnetic Resonance (NMR). The organic acid contents of num num fruits (3.17 ± 0.010 g/100 g on a fresh weight basis) was also quantified by Souilem et al. (2019). Quinic and citric acids were identified as the main organic acids with oxalic, ascorbic and shikimic acids present in smaller quantities (Table 3). While comprehensive evaluations of *C. macrocarpa* are limited, studies were also done on *Carissa edulis,* which belongs to the same genus. Makumbele et al. (2019) characterised *Carissa edulis* berries and identified several phenolic acids including chlorogenic, cryptochlorogenic, dicaffeoylquinic, neochlorogenic, protocatechuoyl-hexose and quinic acids. Flavonoids present in *Carissa edulis* included procyanidin dimer, procyanidin trimer, catechin, quercetin-3-O-glucosyl-xyloside, quercetin-3-O-robinobioside, quercetin-3-O- rutinoside (rutin), quercetin-3-O-glucoside (isoquercitrin) and quercetin-3-OH-3-methylglutaryl-glucoside (Makumbele et al., 2019).

Table 3
Phytochemical composition of Southern African indigenous fruits and their byproducts.

Fruit	Component	Solvent	Method	Phytochemical compound	Concentration	Reference
Carissa macrocarpa A.DC. (Amathungulu)	Whole fruit	Ethanol/water (80:20 v/v)	UFLC-PDA[a]	Organic acids	3170.0 ± 10.00 mg/100 g fw	Souilem et al. (2019)
				Shikimic acid	2.1 ± 0.10 mg/100 g fw	
				Ascorbic	10.0 ± 0.10 mg/100 g fw	
				Oxalic	20.0 ± 2.00 mg/100 g fw	
				Citric	1540.0 ± 30.00 mg/100 g fw	
				Quinic	1600.0 ± 20.00 mg/100 g fw	
Carpobrotus edulis N.E.Br. (Hottentot-fig)	Peel	Ethanol	HPLC-ESI-MS/MS[b]	TPC	272.82 ± 5.59 mg GAE/g DW	Castañeda-Loaiza et al. (2020)
				TFC	1.58 ± 0.10 mg QE/g DW	
				TTC	20.3 ± 0.98 mg QE/g DW	
	Flesh			TPC	8.72 ± 0.29 mg GAE/g DW	
				TFC	0.07 ± 0.002 mg QE/g DW	
				TTC	0.39 ± 0.02 mg QE/g DW	
Dovyalis caffra Warb. (Kei apple)	Whole fruit	Water/methanol mixture [4:1 v/v]	HPLC[c]	TPC	2.90 g GAE/100 g DW	Taher et al. (2018)
				[Flesh TPC]	1.85g GAE/100 g DW	
				TFC	1.37 g QE/100 g DW	
				[Flesh TFC]	1.14 g QE/100 g DW	
				Flavonoids:	µg/g	
				Pyrogallol	1140	
				Catechin	196	
				Epicatechin	101	
				Hesperidin	79	
				Rutin	26	
				Luteolin	22	
				Resveratrol	6	
				Quercitrin	4	
				Coumarin	2.8	
				Phenolic acids	µg/g	
				Chlorogenic	2270	
				Protocatechuic	210	
				p- coumaric	72	
				Ferulic	61	
				p-OH benzoic	61	
				Ellagic	41	
				Vanillic	39	
				Caffeic	32	
				Isoferulic	30	
				Gallic	28	
				Rosmarinic	6	
				3,4,5-Trimethoxycinnamic	6	
				Cinnamic	1	
				Organic acids	g/100 g	
				Malic	10.15	
				Ascorbic	1.62	
				Propionic	0.64	
				Citric	0.57	
				Oxalic	0.42	
				Succinic	0.35	
				Lactic	0.34	
	Juice	–	GC-MS[d]	TPC	1013 ± 3.0 mg GAE/L	Loots et al. (2006)
				[*Reference fruits*:		
				Grape	269 ± 1.4 mg GAE/L	
				Strawberry	567 ± 10.1 mg GAE/L	
				Orange]	264 ± 0.9 mg GAE/L	
				Flavonoids:		

(*continued on next page*)

Table 3 (*continued*)

Fruit	Component	Solvent	Method	Phytochemical compound	Concentration	Reference
				Catechin	2.71 ± 0.02 mg/L	
				Phenolic acids	mg/L	
				Salicylic	0.35 ± 0.02	
				m-hydroxybenzoic	4.27 ± 0.12	
				vanillic	3.64 ± 0.35	
				gallic	2.36 ± 0.11	
				a-resorcylic	0.57 ± 0.02	
				protocatechuic	9.57 ± 0.13	
				syringic	0.66 ± 0.03	
				m-coumaric	1.67 ± 0.02	
				p-coumaric	15.7 ± 0.30	
				ferulic	0.81 ± 0.02	
				caffeic	128.7 ± 1.03	
				hydro-p-coumaric	0.35 ± 0.04	
				p-hydroxyphenylacetic	10.62 ± 0.62	
				3-methoxy-4-hydroxyphenylacetic	6.24 ± 0.11	
				Organic acids	mg/L	
				Ascorbic acid	669 ± 15.7	
				[*Reference fruits*:		
				Grape	14 ± 1.4	
				Strawberry	693 ± 17.7	
				Orange]	536 ± 12.83	
	De-seeded fruit	Methanol	HPLC	TPC	217–492 mg GAE/100 g	Mpai et al. (2018)
				[Apple;	130	
				Blue berry;	293	
				Peaches]	22	
				Phenolic acids	mg/kg	
				Protocatechuic	32.83–227	
				[Apple;	36	
				Peaches]	6	
				Pyrogallol	917–2602	
				[Apple]	277	
				Ellagic	3.9–42	
				[Apple;	3	
				Blue berry;	6	
				Peaches]	5	
				3-Methoxy-4-hydroxyphenylacetic	0.32–10	
				[Blue berry;	1	
				Peaches]	0.63	
				p-Coumaric	1.34–11	
				[Apple;	11	
				Blue berry;	12	
				Peaches]	3.34	
				Syringic	34–111	
				[Peaches]	14	
				Vanillic	6.0–15.0	
				[Apple;	9	
				Blue berry]	32	
				Ferulic	4.0–12.0	
				[Apple;	227	
				Blue berry	4	
				Peaches]	2	
				p-Hydroxyphenylacetic	4.0–17.0	
				[Peaches]	0.075	

(*continued on next page*)

Table 3 (*continued*)

Fruit	Component	Solvent	Method	Phytochemical compound	Concentration	Reference
Harpephyllum caffrum Bernh.	Whole fruit	Methanol	GC-MS	Flavonoids(+)-catechin	216.5 mg/100 g extract	Moodley et al. (2014)
		Dichloromethane		Triterpenoids	mg/100 g extract	
				B-sitosterol	40.7	
				Lupeol	30.7	
Sclerocarya birrea Hochst. (marula)	Pulp	50% Methanol	HPLC	TPC	2262 µg GAE/g	Ndhlala, Kasiyamhuru, et al. (2006)
				TFC	202 µg catechin/g	
				Condensed tannins	6% DM	

[a] Ultra-fast liquid chromatography coupled to photodiode array detector.
[b] High-performance liquid chromatography coupled with electrospray ionisation mass spectrometry.
[c] High-performance liquid chromatography.
[d] Gas chromatography-mass spectrometry.

5.2. *Carpobrotus edulis*

Phenolic content of Hottentot-fig peel and flesh are shown in Table 3. Studies by Castañeda-Loaiza et al. (2020) showed ethanolic peel extracts to have the greater total phenolics (TPC), flavonoids (TFC) and condensed tannins (TTC) than fresh extracts. Acetone was the least efficient solvent for the extraction of TPC, TFC and TTC from Hottentot-fig (Castañeda-Loaiza et al., 2020). Castañeda-Loaiza et al. (2020) also conducted a comprehensive evaluation of the biochemical composition of Hottentot-fig peel and flesh. The ethanolic peel extracts had the highest number of compounds identified (52) with 50 and 27 compounds identified in the water and acetone peel extracts, respectively. As such the compounds identified in ethanolic extracts of both peel and flesh included syringic acid-O-hexoside, feruloylhexose isomers 1, 2 and 3, ferulic acid, quercetin-di-O-hexoside, isoferulic acid, kaempferol-O-(rhamnosyl) hexoside isomer 1, hyperoside, isoquercitrin, rutin, azelaic acid, astragalin, isorhamnetin-O-hexoside isomer 1, quercetin, kaempferol, isorhamnetin, methoxy-trihydroxyflavone, flavokawain C and emodin (Castañeda-Loaiza et al., 2020). On the other hand, for the ethanolic extracts, catechin, epicatechin, oleanolic acid and uvaol were only identified in the peel (Castañeda-Loaiza et al., 2020). Metabolites such as azelaic acid and emodin have been shown to have important pharmacological properties including antioxidant, antibacterial, immunosuppressive and anti-cancer effects (Castañeda-Loaiza et al., 2020). Research by Castañeda-Loaiza et al. (2020) can be expanded by evaluating the quantities of the compounds in Hottentot-fig extracts, which can help in estimating the value that can be generated from harvesting of the biomolecules.

5.3. *Osyris compressa*

While limited research has been conducted on *O. compressa*, work on other members of the genus *Osyris* gives speculative insight on its composition. Fruits of *Osyris alba* were found to contain the three flavonol glycosides, quercetin 3-*O*-rutinoside, quercetin 3-*O*-glucoside and kaempferol 3-*O*-rutinoside (Iwashina, López-Sáez, & Kitajima, 2008). Rached et al. (2016) also found quercetin 3-*O*-rutinoside as the most abundant flavonol glycoside in the crude aqueous extract from *Osyris quadripartita* leaves. Further research to determine the phytochemical composition of *O. compressa* to promote and expand its sustainable utilisation is recommended.

5.4. *Diospyros whyteana*

Phytochemical composition of *D. whyteana* fruits, to the best of the authors' knowledge, has not been investigated. However, other commercially important fruits from other *Diospyros* species include *D. kaki* (Oriental Persimmon), *D. virginiana* (North American persimmon), *D. digyna* (black sapote), *D. lotus* (date-plum) and *D. rhombifolia* (princess persimmon) (Rauf et al., 2017). Compounds identified in these commercially grown species include plumbagin (2-Methyljuglone), droserone, 7-methyljuglone, 3-bromoplumbagin, 3-chloroplumbagin, elliptinone, 3-methylnaphthalene-1,8-diol and diospyrol (Rauf et al., 2017). It is recognised that phytochemical composition varies as a function of genetic and environmental factors (Biesiada & Tomczak, 2012; Szakiel, Paczkowski, & Henry, 2011). Environmental factors (e.g., temperature and soil composition) trigger the expression and activity of enzymes involved in synthesis and accumulation of polyphenols (Carbone et al., 2009; Treutter, 2006; Zoratti et al., 2014). Further research could, therefore, enhance the chemotaxonomic data on these species.

5.5. *Dovyalis caffra*

Whole fruit extracts of *D. caffra* were found to have a TPC and TFC of 2901 mg gallic acid/100 g and 1371 mg quercetin/100 g, respectively (Taher et al., 2018). Evaluation of flesh extracts showed less contents of TPC and TFC (1850 mg gallic acid/100 g and 1144 mg quercetin/100 g, respectively) compared to whole fruit. Taher et al. (2018) stated that TPC in Kei apple tissue is greatest in the seed, followed by the skin and then flesh (Table 3). Investigation of Kei apple dry fruits identified 23 phenolic compounds with chlorogenic acid and pyrogallol as the main phenolic compounds while L-malic acid was the main organic acid (Taher et al., 2018). In terms of the whole fruit extract, pyrogallol had been identified as the main phenolic compound with chlorogenic as the second most abundant (Table 3). Other compounds identified include protocatchuic acid, catechin, epicatechin and hesperidin. Mpai et al. (2018) also identified pyrogallol as the main phenolic compound in Kei apple fruit with concentration ranging between 917 and 2602 mg kg^{-1}. Protocatechuic acid, ellargic acid, ferulic acid, syringic acid, p-coumaric acid, vanillic acid and 3-methoxy-4-hydroxyphenyl propionic acid were also reported by Mpai et al. (2018). Caffeic acid, chlorogenic acid, epicatechin, catechol and hesperidin reported by Taher et al. (2018) were not identified by Mpai et al. (2018). The differences in the composition could be attributed to the environmental factors where fruits were harvested (South Africa vs. Egypt) and solvents used in the extraction process [100% methanol vs. water/methanol solution (4:1 v/v)].

Mpai et al. (2018) compared *D. caffra* phenolic composition to three referral fruits [apples (cv. Top red), peaches (cv. Excellence), and blueberries (var. Oz Julieta)]. Overall, *D. caffra* was shown to have significantly greater TPC than the referral fruits (Table 3). While the referral fruits generally had lower quantities of the measured phenolic compounds than *D. caffra* accessions, blueberries had significantly greater quantities of p-coumaric acid and vanillic acid (Mpai et al., 2018). Research by Loots et al. (2006) found *D. caffra* juice had significantly greater TPC compared to grape, strawberry and orange juice (Table 3). Further analysis of the juice using gas chromatography-mass spectrometry (GC–MS) analysis identified hydroxybenzoic acids, and hydroxycinnamic acids (Table 3). Catechin was the only flavonoid reported by Loots et al. (2006) compared to Taher et al. (2018) who identified seven flavonoids, as well as a stilbenoid and a coumarin (Table 3). Despite offering superior chromatographic resolving power and retention time consistency for separation of epimeric or isomeric compounds, GC–MS is restricted to volatile organic compounds and requires chemical derivatisation to increase volatility (Kite, Veitch, Grayer, & Simmonds, 2003). This could have limited the range of compounds that could be detected in *D. caffra* juice by Loots et al. (2006). Use of HPLC or Ultra Performance Liquid Chromatography (UPLC) is suggested to obtain a more comprehensive phenolic profile.

5.6. *Harpephyllum caffrum*

Methanolic extracts of *H. caffrum* fruit were found to contain (+)-catechin, while the triterpenoids β-sitosterol and lupeol were obtained using dichloromethane as a solvent (Moodley, Koorbanally, Shahidul Islam, & Jonnalagadda, 2014). The quantities of chemical constituents (three) were very low. Further research is recommended to fully characterise the extracts in *H. caffrum* using sensitive methods such as UPLC (Chawla & Ranjan, 2016).

5.7. *Olea europaea var. cuspidata*

While most of the interest around wild olive has been on the leaf parts (Long, Tilney, & Van Wyk, 2010; Masoko & Makgapeetja, 2015; Msomi & Simelane, 2017), there has been limited research on the characterisation of its fruits. Wild olive fruits were observed to have a TPC of 1 437 ± 0.59 mg of GAE/100 g fruit weight (FW) which was greater than that of cranberry (282 ± 4.69 mg GAE/100 g FW) but less than that of blueberry (6 080 ± 2.35 mg GAE/100 g FW) (Kucich & Wicht, 2016). Results from TPC measurements using the Folin-Ciocalteu method do not give the full qualification or quantification detail of the plant matrices, which can be offered by chromatographic methods (Dekdouk et al., 2015). As such, more research with advanced methods is warranted.

Research has been conducted on another species of the *Oleaceae* family, the commercial olive, *Olea europaea* L. subsp. *europaea*. The fruit paste extracts of *O. europaea* L. were analysed using HPLC with diode array detector (DAD) by Silva et al. (2006). Compounds detected included hydroxytyrosol, rutin, luteolin-7-glucoside, luteolin- 4′-glucoside and ligstroside (Silva et al., 2006). Dekdouk et al. (2015) further identified phenolic acids (*p*- hydroxybenzoic acid, vanillic acid, caffeic acid, gallic acid, syringic acid, *p*-coumaric acid, ferulic acid, and sinapic acid), flavonoids (luteolin and chrysoeriol), phenolic alcohols (hydroxytyrosol and tyrosol), and secoiridoids (oleuropein and verbascoside). Hydroxytyrosol, oleuropein, verbascoside and luteolin were the most prominent compounds. The commercial cultivar *O. europaea* L. evaluated by Dekdouk et al. (2015) had less TPC (147.13 ± 6.94–290.21 ± 13.21 mg GAE/g) compared to wild olive (1 437 ± 0.59 mg GAE/100 g fruit weight) evaluated by Kucich and Wicht (2016). Therefore, it could be of interest to compare the detailed profile between these two species.

5.8. *Sclerocarya birrea*

Despite being of commercial significance, there has been little research on the detailed composition of *S. birrea* Fruit extracts evaluated by Ndhlala, Kasiyamhuru, et al. (2006), Ndhlala, Mupure, Benhura, Muchuweti (2006) had TPC and TFC of 2262 μg GAE/g, 202 μg catechin/g, respectively. There was no significant difference of TPC between the pulp and peels of the marula (Ndhlala, Kasiyamhuru, et al., 2006; Ndhlala, Mupure, et al., 2006). Further HPLC analysis of the pulp and peel extracts identified caffeic acid, vanillic acid, *p*-hydroxybenzaldehyde, ferulic acid, *p*-hydroxybenzoic acid and *p*-coumaric acid in the *S. birrea* peel. Caffeic acid, ferulic acid and *p*-coumaric acid were identified in the pulp. The TPC and vitamin C content of marula juice evaluated by Borochov-Neori et al. (2008) was found to be 267 mg dL^{-1} and 56 mg of pyrogallol equivalent dL^{-1}, respectively. The HPLC analysis of marula juice detected derivatives of hydrolysable tannins, catechins and hydroxycinnamic acids (Borochov-Neori et al., 2008). Acosta-Estrada, Gutiérrez-Uribe, and Serna-Saldívar (2014) estimated that food matrices contain an average 24% bound phenolics. The lower TPC recorded by Borochov-Neori et al. (2008) may be accounted for by the portion of phenolic compounds that remained bound to the fruit matrix after mechanical squeezing. Ndhlala, Kasiyamhuru, et al. (2006), Ndhlala, Mupure, et al. (2006) found the phenolic compounds in *S. birrea* peel and pulp to have a degree of polymerisation (DP) of 6.8 and 15.4, respectively.

5.9. *Syzygium guineense*

There is not enough literature on the phytochemical composition of IFs from indigenous *Syzygium* species. However, research done on exotic species of the genus *Syzygium,* such as *Syzygium cumini* (L.) Skeels, identified anthocyanins, gallotannins, flavonols, ellagitannins and ellagic acid (Benherlal & Arumughan, 2007). Gallic acid as well as the anthocyanins delphinidin-3-gentiobioside, malvidin-3-laminaribioside, petunidin-3-gentiobioside, petunidin, cyanidin diglycoside and malvidin have also been isolated from *S. cumini* (Ayyanar & Subash-Babu, 2012). In studies by Lestario et al. (2017), fully ripe *S. cumini* had anthocyanin content of 1318.4 mg/100 g DW, while the contents of gallotannins, ellagitannins, flavanonols and flavonols were 93.7 ± 1.09, 2.9 ± 0.28, 7.7 ± 0.47 and 9.7 ± 0.96 mg/100 g DW, respectively. Lestario et al. (2017) identified six anthocyanins in *S. cumini*, including delphinidin-3,5-O-diglucoside; cyanidin-3,5-O-diglucoside; petunidin- 3,5-O-diglucoside; peonidin-3,5-O-diglucoside, delphinidin-3-O-glucoside and malvidin- 3,5-O-diglucoside. The glucone portion of these anthocyanins had a different structure and binding to

Table 4
Antioxidant activity of selected Southern African indigenous fruits and their byproducts.

Fruit	Component	Solvent	Assay	Values	Reference
Carissa macrocarpa A.DC. (Amathungulu)	Whole fruit	Ethanol/water (80:20 v/v)	DPPH[a]: (EC_{50})	9.9 mg/ml	Souilem et al. (2019)
			[Trolox EC_{50}]	41 ± 1 μg/ml	
			FRAP[b] (EC_{50})	1.59 mg/ml	
			[Trolox EC_{50}]	18 ± 1 μg/ml	
			TBARS[c]inhibition (EC_{50})	1.23 mg/ml	
			[Trolox EC_{50}]	23 ± 1 μg/ml	
			B-carotene bleaching:(EC_{50})	0.88 mg/ml	
			[Trolox EC_{50}]	41.7 ± 0.3 μg/ml	
	Whole fruit	–	TEAC[d]	7.6 μmol TE/g FW[*]	Kucich & Wicht (2016)
			TAC[e]	49.95 μmol TE/g FW	
Carpobrotus edulis N.E.Br. (Hottentot-fig)	Fruit peel	Ethanol	DPPH: IC_{50}	0.59 ± 0.03 mg/ml	Castañeda-Loaiza et al. (2020)
			ABTSf: IC_{50}	0.85 ± 0.02 mg/ml	
			FRAP: IC_{50}	0.09 ± 0.003 mg/ml	
	Fruit flesh	Ethanol	DPPH: IC_{50}	5.51 ± 0.16 mg/ml	
			ABTS: IC_{50}	6.40 ± 0.12 mg/ml	
			FRAP: IC_{50}	0.63 ± 0.01 mg/ml	
	Whole fruit	NR	TEAC	0.6 μmol TE/g FW	Kucich & Wicht (2016)
			TAC	63.47 μmol TE/g FW	
Osyris compressa A.DC. (Cape sumach)	Whole fruit	NR	TEAC	8.5 μmol TE/g FW	Kucich & Wicht (2016)
			TAC	378.99 μmol TE/g FW	
Dovyalis caffra Warb. (Kei-apple)	De-seeded fruits	Methanol	DPPH: IC_{50}	0.23–0.62 μg/ml	Mpai et al. (2018)
			Reference fruits:		
			Apple	0.28 mg/ml	
			Blueberry	0.77 mg/ml	
			Peaches	0.14 mg/ml	
			FRAP: IC_{50}	17–49 μmol TE/g FW	
			Reference fruits:		
			Apple	24 μmol TE/g FW	
			Blueberry	52 μmol TE/g FW	
			Peaches	5 μmol TE/g FW	
	Whole fruit	Water/methanol mixture [4:1 v/v]	DPPH: IC_{50}	95.09 μg/ml	Taher et al. (2018)
			Positive control		
			BHT[g]	32.25 mg/ml	
	Flesh		DPPH: IC_{50}	187.12 μg/ml	
	Juice	–	FRAP:	6.1 mM AAE/L	Loots et al. (2006)
			Reference fruits:		
			Grape	1.51 mM AAE/L	
			Strawberry	3.52 mM AAE/L	
			Orange	2.25 mM AAE/L	
			ORAC[h]	43.9 mM TE/L	
			Reference fruits:		
			Grape	15.7 mM TE/L	
			Strawberry	33 mM TE/L	
			Orange	21.6 mM TE/L	
Harpephyllum caffrum Bernh.	Whole fruit	NR	TEAC	55.6 μmol TE/g FW	Kucich & Wicht (2016)
			TAC	153 μmol TE/g FW	
	Whole fruit	NR	TEAC	34.2 μmol TE/g FW	

(*continued on next page*)

Table 4 (*continued*)

Fruit	Component	Solvent	Assay	Values	Reference
Olea europaea var. *cuspidata* (Wall. & G.Don) Cif. (wild olive)			TAC	336.52 μmol TE/g FW	Kucich & Wicht (2016)
Sclerocarya birrea Hochst. (marula)	Juice	–	FRAP	22 mM AAE/ml	Borochov-Neori et al. (2008)
			TBARS inhibition: (IC_{50})	0.050 μl/mL	
			Lipid peroxides (IC_{50})	0.055 μl/mL	

[f] 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid (ABTS).
[a] 2,2-diphenyl-2-picrylhy-drazyl (DPPH).
[b] Ferric Reducing Antioxidant Power (FRAP).
[c] Thiobarbituric Acid Reactive Substances (TBARS).
[d] Trolox Equivalent Antioxidant Capacity (TEAC).
[e] Total Antioxidant Capacity (TAC).
[g] Butylated hydroxytoluene (BHT).
[h] Oxygen Radical Absorbance Capacity (ORAC).
* Values reported per gram fresh weight of fruit; NR- Not Reported.

the anthocyanin aglycone to those identified by Ayyanar and Subash-Babu (2012). These qualitative differences can be attributed to the genetic background of the species as well as the environmental effects (Pervaiz, Songtao, Faghihi, Haider, & Fang, 2017).

Lestario et al. (2017) noted that levels of gallotannins, flavonols, ellagitannins and ellagic acid were greater at early stages of maturation (green-yellow and green-pink) and decreased as the fruit ripened. Zhang and Lin (2009) identified hydrolysable (ellagitannins) and condensed tannins (epiafzelechin oligomers) in *S. cumini*. The ellagitannins isolated consisted of a glucose core surrounded by gallic acid and ellagic acid units while the condensed tannins were identified as B-type oligomers of the flavan-3-ol epiafzelechin (propelargonidin) with a degree of polymerisation up to eleven. It will be of research interest and chemotaxonomic significance to compare the phytochemical profiles of *S. guineense* to that of *S. cumini*, given the differences highlighted within the *S. cumini* species.

6. In vitro antioxidant activity of the selected indigenous fruits

According to Granato et al. (2018) antioxidants mechanism of action involves single electron transfer (SET), hydrogen atom transfer (HAT) and transition metal chelating. Using these channels, antioxidants are able to scavenge for species that initiate peroxidation, chelate pro-oxidant metal ions, trap reactive oxygen species (ROS), prevent the propagation of auto oxidative chain reactions and stimulate endogenous production of antioxidant compounds (Granato et al., 2018; Oroian & Escriche, 2015). Various *in vitro* screening methods have been employed to anticipate the antioxidant activity of test compounds which can be categorised as either SET or HAT-based assays. In HAT-based assays, thermal decomposition of azo compounds generates peroxyl radicals which are scavenged on a competitive reaction scheme between antioxidant and substrate (Huang, Ou, & Prior, 2005). The effective antioxidant will, therefore, seek to react faster with the radical than the substrate molecule (Apak, 2019). These assays include oxygen radical absorbance capacity (ORAC), inhibition of induced low-density lipoprotein autoxidation, crocin bleaching assays and total radical trapping antioxidant parameter (TRAP). In SET-based assays, the reaction occurs between an antioxidant and an oxidant, with the latter changing colour/fluorescence/chemiluminescence when reduced (Apak, 2019; Huang et al., 2005). Assays based on SET include Folin-Ciocalteau, Trolox equivalence antioxidant capacity (TEAC/ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), cupric reducing antioxidant capacity (CUPRAC), ferric ion reducing antioxidant power (FRAP), ferricyanide, and cerium (IV) reduction assays (Apak, 2019; Huang et al., 2005).

Conceptual and technical limitations have led to debate on validity of results obtained from these assays and their use in screening functionality of polyphenols (De Camargo et al., 2019). It has been proposed that the antioxidant activity displayed *in vitro* does not probably occur *in vivo* due to poor absorption or rapid conjugation (Huang et al., 2005; Schaich, Tian, & Xie, 2015). Furthermore, it has also been stated that in most *in vitro* assays, the chemistry (unclear reaction mechanisms and kinetic information) and molecular substrates are not biologically relevant (Schaich et al., 2015). Considering this, Granato et al. (2018) encourage *in vitro* screening data to be supported by *in vitro* biological test, simulated digestion or *in vivo* assessment. De Camargo et al. (2019) was able to highlight this by demonstrating that grape juice containing higher TPC, ORAC and FRAP activity translated to a greater reduction in the activation of NF-κB thus showing the importance of the screening methods. Likewise, marula juice with high *in vitro* radical scavenging capacity, high ferric reducing ability and efficiency in inhibiting low density lipoprotein oxidation also promoted the attenuation of serum oxidative stress thus reducing the risk of atherosclerosis in healthy individuals (Borochov-Neori et al., 2008). Evaluation of the data from *in vitro* chemical assays is therefore critical for this review to speculate on the performance of their extracts and since almost all the IFs have only been screened using colorimetric methods. Moreover, there exists a dearth of information on the application of extracts from IFs in the food matrix and this warrants research.

6.1. *Carissa macrocarpa*

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, reducing power, β-carotene bleaching inhibition and thiobarbituric acid reactive substance (TBARS) inhibition of hydroethanolic extracts of Amathungulu were investigated by Souilem et al. (2019). Encouraging results for the Amathungulu extracts were given by the β-carotene bleaching inhibition and TBARS inhibition assays with results comparable to a Trolox positive control (Table 4). Extrapolations can also be made from studies done on the antioxidant activity of *Carissa edulis,* which is in the same genus as *C. macrocarpa.* In work by Makumbele et al. (2019), antioxidant activity of *C. edulis* at 3 ripening stages (3rd stage being most ripe), was compared to that of commercial blueberries. Crude methanolic extracts of *C. edulis* methanolic extracts had DPPH radical scavenging activity values in the range 18.36 ± 0.12–20.24 ± 0.27 mmol TE/g (Makumbele et al., 2019). The radical scavenging activity was noted to decrease from the first to the third ripening stage, with no significant difference between the commercial blueberries and *Carissa edulis* extracts from the first ripening stage (Makumbele et al., 2019).

6.2. *Carpobrotus edulis*

Castañeda-Loaiza et al. (2020) evaluated the antioxidant activity of *Carpobrotus edulis* (L.) N.E. Br fruit. Water, ethanol and acetone extracts of either the peel or flesh of Hottentot-fig were investigated. Gallic acid and butylated hydroxytoluene (BHT) were used as controls in the evaluation of antiradical activity while ethylenediaminetetraacetic acid (EDTA) was the control for metal chelation activities. Ethanolic extracts of fruit peel had greater antiradical activity towards DPPH and 2,2′-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) than flesh and peel water extracts or flesh acetone extracts. The radical scavenging capacity of ethanolic fruits peel extract was, however, less than that of gallic acid and BHT in the DPPH and ABTS assays (Table 4). Despite having low capacity to chelate iron and copper ions, the ethanolic extracts of the peel showed significant iron reducing capacity (Table 3). Transition metal ions of iron and copper in meat are potent pro-oxidants catalysing H_2O_2 decomposition through Fenton reactions to form hydroxyl radical (OH•) (Papuc, Goran, Predescu, & Nicorescu, 2017). Chelation, therefore, reduces the participation of the pro-oxidants in deleterious reactions. The reducing capacity shown could help maintain myoglobin in the ferrous form resulting in improved colour stability and wholesomeness at the point of sale (Suman, Hunt, Nair, & Rentfrow, 2014).

6.3. *Osyris compressa*

The reducing power, β-Carotene bleaching inhibition and TBARS inhibition antioxidant activity of *O. quadripartita* aqueous extracts were found to be greater than gallic acid (Table 4). Investigation of *O. compressa* antioxidant activity will, therefore, have chemotaxanomic significance for the *Osyris* genus.

6.4. *Diospyros whyteana*

There is a scarcity of literature on the bioactivity of *D. whyteana* fruits and its byproducts. Research is warranted to gather scientific data critical in the valorisation process.

6.5. *Dovyalis caffra*

Radical scavenging capacity and reducing the power of *D. caffra* was evaluated by Loots et al. (2006) and more recently by Taher et al. (2018). Loots et al. (2006) determined the ORAC and FRAP of juice from Kei apple, grape, strawberry and orange. Compared to the commercial fruits, Kei apple had significantly higher ORAC and FRAP values (Table 4). The phenolic acid fraction was shown to have the most contribution to the radical scavenging and reducing power followed by the procyanidin, catechin, anthocyanin fraction, flavonol, and the anthocyanin polymers (Loots et al., 2006). In contrast, Mpai et al. (2018) reported blueberries to have greater reducing potential than *D. caffra* based on FRAP method (Table 4). Electron donation potential based on DPPH assay was also greater in peach and apple extracts compared to the extracts from *D. caffra* accessions (Mpai et al., 2018). This was indicated by the lower IC_{50} value for peach and apple as opposed to greater IC_{50} values for *D. caffra* accessions (Table 4). Taher et al. (2018) assayed the electron-donating ability of *D. caffra* whole fruit extracts and fresh extracts using DPPH with BHT as a standard. The highest electron-donating capacity was recorded for BHT, followed by whole fruit extracts, and lastly for fresh extracts (Table 4).

6.6. *Harpephyllum caffrum*

Moodley et al. (2014) evaluated the antioxidant activity of bioactive compounds isolated from *H. caffrum* fruit based on FRAP and DPPH assays. The reducing power of (+)-catechin, was found to be greater than ascorbic acid. At the same time, triterpenoids β-sitosterol and lupeol did not show any significant radical scavenging or reducing capacity. The antioxidant activity of β-sitosterol was investigated by Ayaz et al. (2017) using the DPPH, ABTS and H_2O_2 assays with ascorbic acid as a positive control. In contrast to Moodley et al. (2014), Ayaz et al. (2017) demonstrated the antioxidant activity of β-sitosterol with IC_{50} values of 140, 120, and 280 μg/ml for the DPPH, ABTS and H_2O_2 assays respectively. Ascorbic acid had significantly least IC_{50} values in all assays, thus showing greater radical scavenging capacity than β-sitosterol. In terms of application, radical scavenging and reducing ability is an important antioxidant attribute for food application such as maintaining the integrity of meat color. Color stability in meat is rendered through the reduction of ferric myoglobin to ferrous myoglobin (Faustman, 2014). When applied as natural preservatives, such compounds could play a key role in maintaining the redox stability of processed meat, thereby extending its shelf life.

6.7. *Olea europaea var. cuspidata*

The Trolox Equivalent Antioxidant Capacity (TEAC) and Total Antioxidant Capacity (TAC) of wild olive are reported in Table 4. Wild olive TEAC and TAC values were the second and third greatest, respectively, from 12 fruits assayed including two referral fruits cranberry and blueberry (Kucich & Wicht, 2016). In formulating their ranking index [Antioxidant Potency Composite Index (APCI)], Kucich and Wicht (2016) incorporated the values from the TPC. According to Granato et al. (2018), the Folin-Ciocalteu assay cannot be used for evaluation of *in vitro* antioxidant capacity since there is currently no accepted standard mechanism to measure the antioxidant activity. It would, therefore, be of significant scientific value to evaluate the antioxidant properties of these fruits and their extracts.

6.8. *Sclerocarya birrea*

Dietary supplementation of marula juice to healthy individuals was found to attenuate serum oxidative stress (Borochov-Neori et al., 2008). Marula juice at 1 μl/ml and 2 μl/ml demonstrated radical scavenging capacity by causing a 32% and 62% reduction, respectively, in optical density (OD) of DPPH solution (Borochov-Neori et al., 2008). The formation of TBARS and lipid peroxides in copper-ion-induced low density lipoproteins (LDL) oxidation was reduced by marula juice with IC_{50} values of 0.050 and 0.055 μl/ml, respectively (Table 4). In the study, a reduction in AAPH-induced oxidation was observed in the serum derived from individuals who had consumed marula juice for 3 weeks. Other observed beneficial effects of administering marula juice included the reduction in serum low density lipoproteins (LDL), the increment in serum high density lipoprotein (HDL). While the juice has demonstrated high antioxidant activity, evaluating the bioactivity of extracts from *S. birrea* byproducts such as the fruit peels can expand the value chain of this versatile product. Ndhlala, Kasiyamhuru, et al. (2006), Ndhlala, Mupure, et al. (2006) observed greater reducing power in marula peel compared to its pulp extracts. This could have been attributed to differences in the DP of phenolic extracts of *S. birrea* pulp and peel extracts. According to Zhou et al. (2014), antioxidant activity is positively correlated with DP when mean DP is less than 10. As such, this could contribute to the peel extracts from *S. birrea* having greater antioxidant capacity than pulp extracts.

6.9. *Syzygium guineense*

As highlighted earlier, the literature on the bioactivity of water-pear fruit, is scarce. However, a related species, *S. cumini*, has been evaluated. The DPPH radical scavenging activity and FRAP reducing ability of *S. cumini* fruit peel and stone were assayed by Zhang and Lin (2009). Butylated hydroxyanisole (BHA), ascorbic acid and (+)-catechin were the assay reference compounds. *Syzygium cumini* fruit stone had the greatest radical scavenging capacity (IC_{50} of 82.21 ± 0.77 μg/ml of extract), which was not significantly different from that of ascorbic acid but significantly greater than (+)-catechin (106.4 ± 4.28 μg/ml) and BHA (113.0 ± 4.28 μg/ml). Fruit skin showed the least radical scavenging activity of the compounds assayed with an IC_{50} of 165.05 ± 3.90 μg/ml. The FRAP reducing ability value observed for fruit stone (6.21 ± 0.19 mmol AAE/g) was significantly less than that of BHA (7.4 ± 0.14 mmol AAE/g) but significantly higher than that of (+)-catechin (4.3 ± 0.07 mmol AAE/g) and fruit skin (3.02 ± 0.06 mmol AAE/g). The high radical scavenging capacity of *S. cumini* fruit stone could be attributed to the hydrolysable and condensed tannins found in the fruit.

Overall, limited research on IFs has created gaps in information on their bioactivity. Most research work has been observed to cover the root, the stems, bark (roots and stems) and the leaves. Filling the knowledge gap for IFs could help in their marketability while increasing their contribution to sustainable, healthy food systems as well as agrobiodiversity.

7. Toxicological effects

The research focus on the root, leaf and bark component of indigenous trees at the expense of the fruits portion has meant a scarcity of toxicological data on the fruits. However, in studies by Souilem et al. (2019), Amathungulu fruit extracts were shown to be cytotoxic toward cancer cell lines MCF-7 (breast adenocarcinoma), NCI- H460 (non-small cell lung carcinoma), HeLa (cervical carcinoma). In contrast, no cytotoxic activity was detected for the extracts against non-tumor cells from freshly harvested porcine liver (Souilem et al., 2019). Such toxicological data for plant extracts is important since the growing consumer discontent with synthetic preservatives is centered on increasing food healthfulness and safety in processed products (Aziz & Karboune, 2016; Hung, de Kok, & Verbeke, 2016).

Work by Taher et al. (2018) incorporated acute and sub-chronic toxicity studies in an animal model. There was no detectable toxicity or mortality upon oral administration of *D. caffra* extracts in the acute toxicity experiment. It was also observed by Taher et al. (2018) that oral administration of *D. caffra* extract at levels up to 1000 mg/kg body weight/day in the sub-chronic study did not cause any adverse effects in male and female rats. These results are an important step in providing scientific evidence of the safety of natural extracts with potential for pharmaceutical or food application.

8. Potential and hurdles in the application of indigenous fruits as food antioxidants

Bioprospecting IFs offers the opportunity for access to novel products which can be channelled towards food processing, preservation and/or seasoning. The value chain for marula provides a template which can be adapted for other fruits. While the flesh of the marula fruit is channeled towards the production of liquor, the seed oil is fed into the skincare industry for the production of a range of products. In South Africa, there have been efforts to set up the 'Marula Industrial Hub" with the aim of valorising the marula fruit beyond the alcohol industry (Naidoo, 2019). The project aims to capitalise on the potential of marula for the production of juice, jam and cosmetics (Naidoo, 2019). Other fruits, stated earlier, including C. *macrocarpa, Carpobrotus edulis, D. caffra* and *S. guineense* also have potential for valorisation. Cernansky (2015) emphasizes the importance of engaging farmers to cultivate IFs not only to reap the nutritional and ecological benefits but also save them from extinction. The approach feeds into the broader concept of the importance of developing a circular bioeconomy. Considering that most of the IFs are adapted to growing in marginal and harsh conditions with limited nutrients and water resources, their adoption could offer the agricultural sector conservative approaches to nutrient and water utilisation. The future impact of this is a potentially more climate-smart food system. Despite the noted potential, the ability of many rural communities to derive economic benefit from available indigenous fruits is impeded by lack of appropriate technology and understanding of markets (Goyvaerts, 2015).

Despite promising research conducted towards utilisation of plant derived antioxidants, their application is hindered by a variety of reasons. The most common of these is the high economic cost of producing natural antioxidants (Statistics Market Research Consulting Pvt Ltd, 2017). Most extraction methods have prohibitive costs, which hinder their commercialisation as potential preservatives. It would, therefore, be prudent to integrate a feasible scale-up plan into the studies geared towards finding plant-based preservatives with potential for commercialisation. It can also be noted that while some antioxidant work has been done on particular fruits and their byproducts, several of these studies offer only a limited number of assays and often poorly validated. The frequent lack of specificity in the techniques applied in measurement makes the information more obsolete. These limitations may incorrectly influence the results. Hermans et al. (2007) highlighted that when evaluating potential bioactive compounds, it is critical to account for *in vivo* problems of digestion, absorption, distribution, metabolism and excretion. While being attractive in terms of low-cost and high-throughput, *in vitro* chemical assays only yield an index value that allows comparing and ordering different products (López-Alarcón & Denicola, 2013). Therefore, to improve the applicability of the *in vitro* chemical antioxidant assays, *in vivo* or at least cellular-based *in vitro* studies are warranted.

9. Conclusion

The attention accorded to IFs and their byproducts is slowly increasing with the aim of them contributing to circular bioeconomy and more climate-smart food systems. Detailed phytochemistry of the selected IFs can, therefore, enhance the utilitarian value of these underutilised bioresources. Tracing the link between IFs and their ethnomedicinal uses has provided information valuable for their valorisation as sources of natural antioxidants. However, not much scientific data on application of extracts is available for most IFs of interest in Southern Africa, while more work has been done on other non-fruit parts of the indigenous fruit trees. This means that research to promote the value addition and commercialisation of underutilised IFs is of utmost importance. Overall, the evidence from *in vitro* antioxidant activity and their use for ethnomedicinal purposes points to their potential as a source of bioactive compounds with great potential for food preservation. Essentially, this present opportunities for harnessing IFs and their byproducts into innovative food value chains.

Ethical statement

Our research did not include any human subjects and animal experiments.

Funding

The current research is supported by the South African Research Chairs Initiative (SARChI) in Meat Science: Genomics to Nutrinomics partly funded by the South African Department of Science and Technology (UID: 84633), as administered by the NRF of South Africa. TMP, OCC and CLFK are grateful for the SARChI bursary support.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Dr. Donovan Kirkwood from Stellenbosch Gardens for his botanical expertise. Kirstenbosch Gardens for generously sharing their knowledge and resources.

References

Acosta-Estrada, B. A., Gutiérrez-Uribe, J. A., & Serna-Saldívar, S. O. (2014). Bound phenolics in foods, a review. *Food Chemistry, 152*, 46–55. https://doi.org/10.1016/j.foodchem.2013.11.093.

Apak, R. (2019). Current issues in antioxidant measurement. *Journal of Agricultural and Food Chemistry, 67*, 9187–9202. https://doi.org/10.1021/acs.jafc.9b03657.

Aremu, A. O., Ncama, K., & Omotayo, A. O. (2019). Ethnobotanical uses, biological activities and chemical properties of Kei-apple [Dovyalis caffra (Hook.f. & Harv.) Sim]: An indigenous fruit tree of southern Africa. *Journal of Ethnopharmacology, 241*, Article 111963. https://doi.org/10.1016/j.jep.2019.111963.

Augustyn, W. A., Regnier, T., De Jager, K., Hajari, E., Du Preez, R., & Nonyane, D. (2018). A preliminary study on the chemical characteristics of Kei apple (*Dovyalis caffra*), an undervalued South African fruit. *South African Journal of Botany, 117*, 268–275. https://doi.org/10.1016/j.sajb.2018.05.032.

Ayaz, M., Junaid, M., Ullah, F., Subhan, F., Sadiq, A., Ali, G., ... Ahmad, S. (2017). Anti-Alzheimer's Studies on β-sitosterol isolated from *Polygonum hydropiper* L. *Frontiers in Pharmacology, 8*, 697. https://doi.org/10.3389/fphar.2017.00697.

Ayyanar, M., & Subash-Babu, P. (2012). *Syzygium cumini* (L.) Skeels: A review of its phytochemical constituents and traditional uses. *Asian Pacific Journal of Tropical Biomedicine, 2*(3), 240–246. https://doi.org/10.1016/S2221-1691(12)60050-1.

Aziz, M., & Karboune, S. (2016). Natural antimicrobial/antioxidant agents in meat and poultry products as well as fruits and vegetables: A review. *Critical Reviews in Food Science and Nutrition, 58*(3), 486–511. https://doi.org/10.1080/10408398.2016.1194256.

Baldermann, S., Blagojević, L., Frede, K., Klopsch, R., Neugart, S., Neumann, A., ... Schreiner, M. (2016). Are neglected plants the food for the future? *Critical Reviews in Plant Sciences, 35*(2), 106–119. https://doi.org/10.1080/07352689.2016.1201399.

Becking, D. (2018). Diospyros whyteana. Retrieved May 6, 2020, from Tree SA website: https://treesa.org/diospyros-whyteana/.

Benherlal, P. S., & Arumughan, C. (2007). Chemical composition and in vitro antioxidant studies on *Syzygium cumini* fruit. *Journal of the Science of Food and Agriculture, 87*, 2560–2569. https://doi.org/10.1002/jsfa.

Biesiada, A., & Tomczak, A. (2012). Biotic and abiotic factors affecting the content of the chosen antioxidant compounds in vegetables. *Vegetable Crops Research Bulletin, 76*, 55–78. https://doi.org/10.2478/v10032-012-0004-3.

Borochov-Neori, H., Judeinstein, S., Greenberg, A., Fuhrman, B., Attias, J., Volkova, N., ... Aviram, M. (2008). Phenolic antioxidants and antiatherogenic effects of marula (*Sclerocarrya birrea* Subsp. *caffra*) fruit juice in healthy humans. *Journal Of Agricultural and Food Chemistry, 56*(21), 9884–9891. https://doi.org/10.1021/jf801467m.

Broomhead, N. K., Moodley, R., & Jonnalagadda, S. B. (2020). Chemical and elemental analysis of the edible fruit of five *Carpobrotus* species from South Africa: Assessment of nutritional value and potential metal toxicity. *International Journal of Environmental Health Research, 30*(4), 357–371. https://doi.org/10.1080/09603123.2019.1595539.

CapeNature (2009). Sour figs: Providing sustainable benefits for communities. Retrieved from https://www.sanbi.org/wp-content/uploads/2018/03/5-communities-harvesting-sour-figs.pdf.

Carbone, F., Preuss, A., H De Vos, R. C., Perrotta, G., Bovy, A. G., Martens, S., & Rosati, C. (2009). Developmental, genetic and environmental factors affect the expression of flavonoid genes, enzymes and metabolites in strawberry fruits. Plant, Cell and Environment, 32, 1117–1131. https://doi.org/10.1111/j.1365-3040.2009.01994.x.

Carolus, B., Porter, H., & Reynolds, Y. (2004). Carissa macrocarpa. Retrieved May 10, 2020, from PlantZAfrica website: http://pza.sanbi.org/carissa-macrocarpa.

Castañeda-Loaiza, V., Placines, C., Rodrigues, M. J., Pereira, C., Zengin, G., Uysal, A., ... Custódio, L. (2020). If you cannot beat them, join them: Exploring the fruits of the invasive species *Carpobrotus edulis* (L.) N.E. Br as a source of bioactive products. *Industrial Crops and Products, 144*, Article 112005. https://doi.org/10.1016/j.indcrop.2019.112005.

Cernansky, R. (2015). Africa's indigenous fruit trees: A blessing in decline. *Environmental Health Perspectives, 123*(12), A291–A296. https://doi.org/10.1289/ehp.123-A291.

Chawla, G., & Ranjan, C. (2016). Principle, instrumentation, and applications of UPLC: A novel technique of liquid chromatography. *Open Chemistry Journal, 3*, 1–16. https://doi.org/10.2174/1874842201603010001.

Chivandi, E., Mukonowenzou, N., Nyakudya, T., & Erlwanger, K. H. (2015). Potential of indigenous fruit-bearing trees to curb malnutrition, improve household food security, income and community health in Sub-Saharan Africa: A review. *Food Research International, 76*, 980–985. https://doi.org/10.1016/j.foodres.2015.06.015.

De Camargo, A. C., Biasoto, A. C. T., Schwember, A. R., Granato, D., Rasera, G. B., Franchin, M., ... Shahidi, F. (2019). Should we ban total phenolics and antioxidant screening methods? The link between antioxidant potential and activation of NF-κB using phenolic compounds from grape by-products. *Food Chemistry, 290*, 229–238. https://doi.org/10.1016/j.foodchem.2019.03.145.

Dekdouk, N., Malafronte, N., Russo, D., Faraone, I., De Tommasi, N., Ameddah, S., ... Milella, L. (2015). Phenolic compounds from *Olea europaea* L. possess antioxidant activity and inhibit carbohydrate metabolizing enzymes in vitro. *Evidence-Based Complementary and Alternative Medicine, 2015*(684925), 1–9. https://doi.org/10.1155/2015/684925.

Djilas, S., Čanadanović-Brunet, J., & Ćetković, G. (2009). By-products of fruits processing as a source of phytochemicals. *Chemical Industry and Chemical Engineering Quarterly, 15*(4), 191–202. https://doi.org/10.2298/CICEQ0904191D.

Dlamini, M. D. (2004). Harpephyllum caffrum. Retrieved May 6, 2020, from PlantZAfrica website: http://pza.sanbi.org/harpephyllum-caffrum.

Falowo, A. B., Fayemi, P. O., & Muchenje, V. (2014). Natural antioxidants against lipid-protein oxidative deterioration in meat and meat products: A review. *Food Research International, 64*, 171–181. https://doi.org/10.1016/j.foodres.2014.06.022.

Faustman, C. (2014). Myoglobin chemistry and modifications that influence (color and) color stability. In 67th Annual Reciprocal Meat Conference (pp. 1–6). Connecticut: American Meat Science Association.

Fern, K. (2014). Osyris compressa - Useful Tropical Plants. Retrieved May 28, 2020, from Tropical Plants Database website: http://tropical.theferns.info/viewtropical.php?id=Osyris+compressa.

Fern, K., Fern, A., & Morris, R. (2019). Carpobrotus edulis - Useful Tropical Plants. Retrieved May 13, 2020, from Tropical Plants Database website: http://tropical.theferns.info/viewtropical.php?id=Carpobrotus+edulis.

Fern, K., Fern, A., & Morris, R. (2019). Syzygium guineense - Useful Tropical Plants. Retrieved May 13, 2020, from Tropical Plants Database website: http://tropical.theferns.info/viewtropical.php?id=Syzygium+guineense.

Global Biodiversity Information Facility Secretariat (2019). Carissa macrocarpa A.DC. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat (2019). Carpobrotus edulis N.E.Br. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat (2019). Diospyros whyteana (Hiern) F.White. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat. (2019). Dovyalis caffra Warb. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat (2019). Harpephyllum caffrum Bernh. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat (2019). Olea europaea subsp. cuspidata (Wall. & G.Don) Cif. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat (2019). Osyris compressa A.DC. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat (2019). Sclerocarya birrea Hochst. https://doi.org/10.15468/39omei.

Global Biodiversity Information Facility Secretariat (2019). Syzygium guineense DC. https://doi.org/10.15468/39omei.

Global Invasive Species Database (2020). Species profile: Carpobrotus edulis. Retrieved May 28, 2020, from GISD website: http://www.iucngisd.org/gisd/species.php?sc=1010.

Gokoglu, N. (2019). Novel natural food preservatives and applications in seafood preservation: A review. *Journal of the Science of Food and Agriculture, 99*(5), 2068–2077. https://doi.org/10.1002/jsfa.9416.

Goyvaerts, E. (2015). Marula nuts are growing SA's rural entrepreneurs in a win-win partnership with scientists and conservationists. Retrieved May 21, 2020, from Science in Africa website: http://www.scienceinafrica.com/biotechnology/food/marula-nuts-are-growing-sa's-rural-entrepreneurs-win-win-partnership-scientists.

Granato, D., Shahidi, F., Wrolstad, R., Kilmartin, P., Melton, L. D., Hidalgo, F. J., ... Finglas, P. (2018). Antioxidant activity, total phenolics and flavonoids contents: Should we ban in vitro screening methods? *Food Chemistry, 264*, 471–475. https://doi.org/10.1016/j.foodchem.2018.04.012.

Hae, M., & Funnah, S. M. (2011). Effects of various pre-sowing treatments on germination of kei apple (*Dovyalis caffra*) seeds harvested at different maturity stages. *Life Science Journal, 8*(SUPPL. 2), 100–105.

Hall, J. B., O'brien, E. M., & Sinclair, F. L. (2002). Sclerocarya birrea: A monograph.

Retrieved from https://agris.fao.org/agris-search/search.do?recordID=GB2012108769.
Hannachi, H., Hilary, A. E., Ae, S., Breton, C., Monji, A. E., Ae, M., ... Bervillé, A. (2009). *Oleaster* (var. *sylvestris*) and subsp. *cuspidata* are suitable genetic resources for improvement of the olive (*Olea europaea* subsp. *europaea* var. *europaea*). *Genetic Resources and Crop Evolution, 56*, 393–403. https://doi.org/10.1007/s10722-008-9374-2.
Hermans, N., Cos, P., Maes, L., De Bruyne, T., Vanden Berghe, D. J., Vlietinck, A., & Pieters, L. (2007). Challenges and pitfalls in antioxidant research. *Current Medicinal Chemistry, 14*(4), 417–430. https://doi.org/10.2174/092986707779941005.
Hillman, Z., Mizrahi, Y., & Beit-Yannai, E. (2008). Evaluation of valuable nutrients in selected genotypes of marula (*Sclerocarya birrea* ssp. *caffra*). *Scientia Horticulturae, 117*, 321–328. https://doi.org/10.1016/j.scienta.2008.05.008.
Hiwilepo-Van Hal, P. (2013). Processing of marula (Sclerocarya birrea subsp. Caffra) fruits: A case study on health-promoting compounds in marula pulp. Wageningen University.
Huang, D., Ou, B., & Prior, R. L. (2005). The chemistry behind antioxidant capacity assays. *Journal of Agricultural and Food Chemistry, 53*(6), 1841–1856. https://doi.org/10.1021/jf030723c.
Hung, Y., de Kok, T. M., & Verbeke, W. (2016). Consumer attitude and purchase intention towards processed meat products with natural compounds and a reduced level of nitrite. *Meat Science, 121*, 119–126. https://doi.org/10.1016/j.meatsci.2016.06.002.
Iwashina, T., López-Sáez, J. A., & Kitajima, J. (2008). Flavonoids from *Osyris alba*. *Biochemical Systematics and Ecology, 36*(2), 146–147. https://doi.org/10.1016/j.bse.2007.06.008.
Joffe, P. (2002). Olea europaea subsp. africana. Retrieved May 6, 2020, from PlantZAfrica website: http://pza.sanbi.org/olea-europaea-subsp-africana.
Kasolo, W., Chemining'wa, G., & Temu, A. (Eds.). (2018). Neglected and underutilized species (NUS) for improved food security and resilience to climate change: A contextualized learning manual for African colleges and universities. Retrieved from http://www.nuscommunity.org/fileadmin/templates/nuscommunity.org/upload/documents/Publications/NUS_teaching_manual_-_PDF_copy.pdf.
Khoo, H. E., Azlan, A., Kong, K. W., & Ismail, A. (2016). Phytochemicals and medicinal properties of indigenous tropical fruits with potential for commercial development. *Evidence-Based Complementary and Alternative Medicine, 2016*(75919), 1–20. https://doi.org/10.1155/2016/7591951.
Kite, G., Veitch, N., Grayer, R., & Simmonds, M. (2003). The use of hyphenated techniques in comparative phytochemical studies of legumes. *Biochemical Systematics and Ecology, 31*, 813–843. https://doi.org/10.1016/S0305-1978(03)00086-3.
Komane, B., Vermaak, I., Summers, B., & Viljoen, A. (2015). Safety and efficacy of *Sclerocarya birrea* (A.Rich.) Hochst (Marula) oil: A clinical perspective. *Journal of Ethnopharmacology, 176*, 327–335. https://doi.org/10.1016/j.jep.2015.10.037.
Kucich, D. A., & Wicht, M. M. (2016). South African indigenous fruits - Underutilized resource for boosting daily antioxidant intake among local indigent populations? *South African Journal of Clinical Nutrition, 29*(4), 150–156. https://doi.org/10.1080/16070658.2016.1219470.
Kurek, A., Nadkowska, P., Pliszka, S., & Wolska, K. I. (2012). Modulation of antibiotic resistance in bacterial pathogens by oleanolic acid and ursolic acid. *Phytomedicine, 19*(6), 515–519. https://doi.org/10.1016/j.phymed.2011.12.009.
Lestario, L. N., Howard, L. R., Brownmiller, C., Stebbins, N. B., Liyanage, R., & Lay, J. O. (2017). Changes in polyphenolics during maturation of Java plum (*Syzygium cumini* Lam.). *Food Research International, 100*, 385–391. https://doi.org/10.1016/j.foodres.2017.04.023.
Long, H. S., Tilney, P. M., & Van Wyk, B.-E. (2010). The ethnobotany and pharmacognosy of *Olea europaea* subsp. *africana* (Oleaceae). *South African Journal of Botany, 76*(2), 324–331. https://doi.org/10.1016/j.sajb.2009.12.005.
Loots, D. T., van der Westhuizen, F. H., & Jerling, J. (2006). Polyphenol composition and antioxidant activity of Kei-Apple (*Dovyalis caffra*) juice. *Journal of Agricultural and Food Chemistry, 54*(4), 1271–1276. https://doi.org/10.1021/jf052697j.
López-Alarcón, C., & Denicola, A. (2013). Evaluating the antioxidant capacity of natural products: A review on chemical and cellular-based assays. *Analytica Chimica Acta, 763*, 1–10. https://doi.org/10.1016/j.aca.2012.11.051.
Mabhaudhi, T., Chimonyo, V. G. P., Hlahla, S., Massawe, F., Mayes, S., Nhamo, L., & Modi, A. T. (2019). Prospects of orphan crops in climate change. *Planta, 250*, 695–708. https://doi.org/10.1007/s00425-019-03129-y.
Magaia, T., Uamusse, A., Sjöholm, I., & Skog, K. (2013). Proximate analysis of five wild fruits of Mozambique. *The Scientific World Journal, 2013*(60143), 1–6. https://doi.org/10.1155/2013/601435.
Mahomoodally, M. F. (2013). Traditional medicines in Africa: An appraisal of ten potent African medicinal plants. *Evidence-Based Complementary and Alternative Medicine, 2013*(61745), 1–14. https://doi.org/10.1155/2013/617459.
Makumbele, F. P., Taylor, M., Stander, M., Anyasi, T. A., & Jideani, A. I. O. (2019). Polyphenolic and physicochemical properties of simple-spined num-num (*Carissa edulis*) fruit harvested at ripe stage of maturation. *Molecules, 24*(14), https://doi.org/10.3390/molecules24142630.
Malan, C., & Notten, A. (2006). Carpobrotus edulis. Retrieved May 10, 2020, from PlantZAfrica website: http://pza.sanbi.org/carpobrotus-edulis.
Manning, J. (2018). *Field guide to Fynbos* (2nd). Cape Town: Penguin Random House South Africa237.
Maroyi, A. (2019). Medicinal uses, biological and chemical properties of wild plum (*Harpephyllum caffrum*): An indigenous fruit plant of Southern Africa. *Journal of Pharmacy and Nutrition Sciences, 9*(5), 258–268.
Masoko, P., & Makgapeetja, D. M. (2015). Antibacterial, antifungal and antioxidant activity of *Olea africana* against pathogenic yeast and nosocomial pathogens. *BMC Complementary and Alternative Medicine, 15*(409), 1–9. https://doi.org/10.1186/s12906-015-0941-8.
Mokoka, T. A., Mcgaw, L. J., Eloff, J. N., Mcgaw, L. J., & Programme, P. (2010). Antifungal efficacy of ten selected South African plant species against *Cryptococcus neoformans*. *Pharmaceutical Biology, 48*(4), 397–404. https://doi.org/10.3109/13880200903150393.
Moodley, R., Chenia, H., Jonnalagadda, S. B., & Koorbanally, N. (2011). Antibacterial and anti-adhesion activity of the pentacyclic triterpenoids isolated from the leaves and edible fruits of *Carissa macrocarpa*. *Journal of Medicinal Plants Research, 5*(19), 4851–4858. http://www.academicjournals.org/JMPR.
Moodley, R., Koorbanally, N. A., Shahidul Islam, M., & Jonnalagadda, S. B. (2014). Structure and antioxidant activity of phenolic compounds isolated from the edible fruits and stem bark of *Harpephyllum caffrum*. *Journal of Environmental Science and Health, Part B, 49*(12), 938–944. https://doi.org/10.1080/03601234.2014.951578.
Morton, J. (1987). Carissa. Retrieved May 4, 2020, from Fruits of warm climates website: https://hort.purdue.edu/newcrop/morton/carissa.html.
Moyo, M., Finnie, J. F., & Van Staden, J. (2011). Antimicrobial and cyclooxygenase enzyme inhibitory activities of *Sclerocarya birrea* and *Harpephyllum caffrum* (Anacardiaceae) plant extracts. *South African Journal of Botany, 77*(3), 592–597. https://doi.org/10.1016/j.sajb.2010.12.001.
Mpai, S., du Preez, R., Sultanbawa, Y., & Sivakumar, D. (2018). Phytochemicals and nutritional composition in accessions of Kei-apple (*Dovyalis caffra*): Southern African indigenous fruit. *Food Chemistry, 253*, 37–45. https://doi.org/10.1016/j.foodchem.2018.01.099.
Mphaphuli, T., Manhivi, V. E., Slabbert, R., Sultanbawa, Y., & Sivakumar, D. (2020). Enrichment of mango fruit leathers with Natal plum. *Foods, 9*(431), 1–14. https://doi.org/10.3390/foods9040431.
Msomi, N. Z., & Simelane, M. B. C. (2017). Olea europaea subsp. africana (Oleaceae). In H. El-Shemy (Ed.), Active Ingredients from Aromatic and Medicinal Plants (pp. 159–174). https://doi.org/10.5772/65725.
Mudimba, T. N., & Nguta, J. M. (2019). Traditional uses, phytochemistry and pharmacological activity of *Carpobrotus edulis*: A global perspective. *The Journal of Phytopharmacology, 8*(3), 111–116. https://doi.org/10.31254/phyto.2019.8305.
Mutshinyalo, T., & Tshisevhe, J. (2003). Sclerocarya birrea. Retrieved May 11, 2020, from PlantZAfrica website: http://pza.sanbi.org/sclerocarya-birrea.
Naidoo, S. (2019). Limpopo plans multi-million rand marula hub. Retrieved May 21, 2020, from Moneyweb website: https://www.moneyweb.co.za/news/industry/limpopo-plans-multi-million-rand-marula-hub/.
Ndhlala, A. R., Kasiyamhuru, A., Mupure, C., Chitindingu, K., Benhura, M. A., & Muchuweti, M. (2006). Phenolic composition of *Flacourtia indica*, *Opuntia megacantha* and *Sclerocarya birrea*. *Food Chemistry, 103*, 82–87. https://doi.org/10.1016/j.foodchem.2006.06.066.
Ndhlala, A. R., Mupure, C. H., Benhura, C. K., & Muchuweti, M. A. N. (2006). Antioxidant potentials and degrees of polymerization of six wild fruits. *Scientific Research and Essay, 1*(3), 87–92. http://www.academicjournals.org/SRE.
Ndou, P. (2003). Dovyalis caffra. Retrieved May 11, 2020, from PlantZAfrica website: http://pza.sanbi.org/dovyalis-caffra.
Ngemakwe, P. H. N., Remize, F., Thaoge, M. L., & Sivakumar, D. (2017). Phytochemical and nutritional properties of underutilised fruits in the southern African region. *South African Journal of Botany, 113*, 137–149. https://doi.org/10.1016/j.sajb.2017.08.006.
Nguyen, T. L., Rusten, A., Bugge, M. S., Malterud, K. E., Diallo, D., Paulsen, B. S., & Wangensteen, H. (2016). Flavonoids, gallotannins and ellagitannins in *Syzygium guineense* and the traditional use among Malian healers. *Journal of Ethnopharmacology, 192*, 450–458. https://doi.org/10.1016/j.jep.2016.09.035.
Nkosi, N. N., Mostert, T. H. C., Dzikiti, S., & Ntuli, N. R. (2020). Prioritization of indigenous fruit tree species with domestication and commercialization potential in KwaZulu-Natal, South Africa. *Genetic Resources and Crop Evolution, 67*, 1567–1575. https://doi.org/10.1007/s10722-020-00932-5.
Ojewole, J. A. O., & Amabeoku, G. J. (2007). Anticonvulsant and analgesic effects of *Harpephyllum caffrum* Bernh. ex C.F. Krauss [Anacardiaceae] stem-bark aqueous extract in mice. *International Journal of Pharmacology, 3*(3), 241–247. https://doi.org/10.3923/ijp.2007.241.247.
Ojewole, J. A. O., Mawoza, T., Chiwororo, W. D. H., & Owira, P. M. O. (2010). *Sclerocarya birrea* (A. Rich) Hochst. ['Marula'] (Anacardiaceae): A review of its phytochemistry, pharmacology and toxicology and its ethnomedicinal uses. *Phytotherapy Research, 24*, 633–639. https://doi.org/10.1002/ptr.3080.
Omotayo, A. O., & Aremu, A. O. (2020). Underutilized African indigenous fruit trees and food–nutrition security: Opportunities, challenges, and prospects. *Food and Energy Security, 9*(3), https://doi.org/10.1002/fes3.220.
Omotayo, A. O., Ncama, K., & Aremu, A. O. (2018). Potentials of the underutilized Kei-apple (Dovyalis caffra L.): Beyond its nutritional and functional value. 2018120094 *Preprints*, 1–17. https://doi.org/10.20944/preprints201812.0094.v1.
Oroian, M., & Escriche, I. (2015). Antioxidants: Characterization, natural sources, extraction and analysis. *Food Research International, 74*, 10–36. https://doi.org/10.1016/j.foodres.2015.04.018.
Oyebode, O., Kandala, N.-B., Chilton, P. J., & Lilford, R. J. (2016). Use of traditional medicine in middle-income countries: A WHO-SAGE study. *Health Policy and Planning, 31*, 984–991. https://doi.org/10.1093/heapol/czw022.
Papuc, C., Goran, G. V., Predescu, C. N., & Nicorescu, V. (2017). Mechanisms of oxidative processes in meat and toxicity induced by postprandial degradation products: A review. *Comprehensive Reviews in Food Science and Food Safety, 16*(1), 96–123. https://doi.org/10.1111/1541-4337.12241.
Patel, S. (2013). Food, pharmaceutical and industrial potential of *Carissa* genus: An overview. *Reviews in Environmental Science and Biotechnology, 12*, 201–208. https://doi.org/10.1007/s11157-012-9306-7.
Pervaiz, T., Songtao, J., Faghihi, F., Haider, M. S., & Fang, J. (2017). Naturally occurring anthocyanin, structure, functions and biosynthetic pathway in fruit plants. *Journal of*

Plant Biochemistry & Physiology, 05(02), 1–9. https://doi.org/10.4172/2329-9029.1000187.

Rached, W., Calhelha, R. C., Fernandes, Â., Carvalho, A. M., Bennaceur, M., Marouf, A., ... Ferreira, I. C. F. R. (2016). Phytochemical characterization and bioactive properties of *Osyris quadripartita* Salzm. ex Decne. leaves from Algeria. *RSC Advances, 6*(76), 72768–72776. https://doi.org/10.1039/c6ra11787b.

Rauf, A., Uddin, G., Patel, S., Khan, A., Halim, S. A., Bawazeer, S., ... Mubarak, M. S. (2017). *Diospyros*, an under-utilized, multi-purpose plant genus: A review. *Biomedicine and Pharmacotherapy, 91*, 714–730. https://doi.org/10.1016/j.biopha.2017.05.012.

Rocha, M. I., Rodrigues, M. J., Pereira, C., Pereira, H., da Silva, M. M., da Neng, N. R., ... Custódio, L. (2017). Biochemical profile and in vitro neuroprotective properties of *Carpobrotus edulis* L., a medicinal and edible halophyte native to the coast of South Africa. *South African Journal of Botany, 111*, 222–231. https://doi.org/10.1016/j.sajb.2017.03.036.

Saka, J. D. K., & Msonthi, J. D. (1994). Nutritional value of edible fruits of indigenous wild trees in Malawi. *Forest Ecology and Management, 64*, 245–248.

Sánchez-Quesada, C., López-Biedma, A., Warleta, F., Campos, M., Beltrán, G., & Gaforio, J. J. (2013). Bioactive properties of the main triterpenes found in olives, virgin olive oil, and leaves of *Olea europaea*. *Journal of Agricultural and Food Chemistry, 61*, 12173–12182. https://doi.org/10.1021/jf403154e.

Sarkar, R., Chaudhary, S. K., Sharma, A., Yadav, K. K., Nema, N. K., Sekhoacha, M., ... Sen, T. (2014). Anti-biofilm activity of Marula - A study with the standardized bark extract. *Journal of Ethnopharmacology, 154*(1), 170–175. https://doi.org/10.1016/j.jep.2014.03.067.

Schaich, K. M., Tian, X., & Xie, J. (2015). Reprint of “Hurdles and pitfalls in measuring antioxidant efficacy: A critical evaluation of ABTS, DPPH, and ORAC assays”. *Journal of Functional Foods, 18*, 782–796. https://doi.org/10.1016/j.jff.2015.05.024.

Schulze-Kaysers, N., Feuereisen, M. M., & Schieber, A. (2015). Phenolic compounds in edible species of the *Anacardiaceae* family-a review. *RSC Advances, 5*, 73301–73314. https://doi.org/10.1039/c5ra11746a.

Sharma, K., Mahato, N., Cho, M. H., & Lee, Y. R. (2017). Converting citrus wastes into value-added products: Economic and environmently friendly approaches. *Nutrition, 34*, 29–46. https://doi.org/10.1016/j.nut.2016.09.006.

Shoko, T., Maharaj, V. J., Naidoo, D., Tselanyane, M., Nthambeleni, R., Khorombi, E., & Apostolides, Z. (2018). Anti-aging potential of extracts from *Sclerocarya birrea* (A. Rich.) Hochst and its chemical profiling by UPLC-Q-TOF-MS. *BMC Complementary and Alternative Medicine, 18*, 1–14. https://doi.org/10.1186/s12906-018-2112-1.

Shyaula, S. L. (2012). A review on genus *Osyris* : Phytochemical constituents and traditional uses. *Journal of Natural Pharmaceuticals, 3*(2), 61–70. https://doi.org/10.4103/2229-5119.102747.

Silva, S., Gomes, L., Leitão, F., Coelho, A. V., & Vilas Boas, L. (2006). Phenolic compounds and antioxidant activity of *Olea europaea* L. fruits and leaves. *Food Science and Technology International, 12*(5), 385–396. https://doi.org/10.1177/1082013206070166.

Souilem, F., Dias, M. I., Barros, L., Calhelha, R. C., Alves, M. J., Harzallah-Skhiri, F., & Ferreira, I. C. F. R. (2019). Amantagula fruit (*Carissa macrocarpa* (Eckl.) A.DC.): Nutritional and phytochemical characterization. *Plant Foods for Human Nutrition, 74*, 76–82. https://doi.org/10.1007/s11130-018-0703-0.

Stadlmayr, B., Charrondière, U. R., Eisenwagen, S., Jamnadass, R., & Kehlenbeck, K. (2013). Nutrient composition of selected indigenous fruits from sub-Saharan Africa. *Journal of the Science of Food and Agriculture, 93*(11), 2627–2636. https://doi.org/10.1002/jsfa.6196.

Stevenson, P. C., Isman, M. B., & Belmain, S. R. (2017). Pesticidal plants in Africa: A global vision of new biological control products from local uses. *Industrial Crops and Products, 110*, 2–9. https://doi.org/10.1016/j.indcrop.2017.08.034.

Stratistics Market Research Consulting Pvt Ltd. (2017). Food Preservatives - Global Market Outlook (2017–2026). Retrieved from https://www.researchandmarkets.com/reports/4655806/food-preservatives-global-market-outlook-2017.

Suman, S. P., Hunt, M. C., Nair, M. N., & Rentfrow, G. (2014). Improving beef color stability: Practical strategies and underlying mechanisms. *Meat Science, 98*(3), 490–504. https://doi.org/10.1016/j.meatsci.2014.06.032.

Szakiel, A., Paczkowski, C., & Henry, M. (2011). Influence of environmental biotic factors on the content of saponins in plants. *Phytochemistry Reviews, 10*(4), 493–502. https://doi.org/10.1007/s11101-010-9164-2.

Tadesse, S., Abebe, A., Chebude, Y., Garcia, I. V., & Yohannes, T. (2012). Natural dye-sensitized solar cells using pigments extracted from *Syzygium guineense*. *Journal of Photonics for Energy, 2*(1), Article 027001. https://doi.org/10.1117/1.jpe.2.027001.

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

Treutter, D. (2006). Significance of flavonoids in plant resistance: A review. *Enviromental Chemistry Letters, 4*, 147–157. https://doi.org/10.1007/s10311-006-0068-8.

Van Der Watt, E., & Pretorius, J. C. (2001). Purification and identification of active antibacterial components in *Carpobrotus edulis* L. *Journal of Ethnopharmacology, 76*(1), 87–91. https://doi.org/10.1016/S0378-8741(01)00197-0.

Van Vuuren, S., & Frank, L. (2020). Review: Southern African medicinal plants used as blood purifiers. *Journal of Ethnopharmacology, 249*, Article 112434. https://doi.org/10.1016/j.jep.2019.112434.

Van Wyk, B.-E. (2011). The potential of South African plants in the development of new food and beverage products. *South African Journal of Botany, 77*, 857–868. https://doi.org/10.1016/j.sajb.2011.08.003.

Verschaeve, L., Kestens, V., Taylor, J. L. S., Elgorashi, E. E., Maes, A., Van Puyvelde, L., ... Van Staden, J. (2004). Investigation of the antimutagenic effects of selected South African medicinal plant extracts. *Toxicology in Vitro, 18*, 29–35. https://doi.org/10.1016/S0887-2333(03)00131-0.

Vila, M., & D’Antonio, C. M. (1998). Fruit choice and seed dispersal of invasive vs. noninvasive *Carpobrotus* (Aizoaceae) in coastal California. *Ecology, 79*.

Viljoen, C. (2002). Diospyros whyteana. Retrieved May 11, 2020, from PlantZAfrica website: http://pza.sanbi.org/diospyros-whyteana.

Voigt, W., & Notten, A. (2006). Colpoon compressum. Retrieved May 11, 2020, from PlantZAfrica website: http://pza.sanbi.org/colpoon-compressum.

Zenze, K. (2013). Syzygium guineense. Retrieved May 7, 2020, from PlantZAfrica website: http://pza.sanbi.org/syzygium-guineense.

Zhang, L. L., & Lin, Y. M. (2009). Antioxidant tannins from *Syzygium cumini* fruit. *African Journal of Biotechnology, 8*(10), 2301–2309. https://doi.org/10.4314/ajb.v8i10.60578.

Zhou, H.-C., Fung-Yee Tam, N., Lin, Y.-M., Ding, Z.-H., Chai, W.-M., & Wei, S.-D. (2014). Relationships between degree of polymerization and antioxidant activities: A study on proanthocyanidins from the leaves of a medicinal mangrove plant Ceriops tagal. *PLoS ONE, 9:e107606*(10), 1–10. https://doi.org/10.1371/journal.pone.0107606.

Zoratti, L., Karppinen, K., Luengo Escobar, A., Häggman, H., Jaakola, L., Damiani, F., ... Schmeda-Hirschmann, G. (2014). Light-controlled flavonoid biosynthesis in fruits. *Frontiers in Plant Science, 5*, 534. https://doi.org/10.3389/fpls.2014.00534.