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A review of the proximate composition and nutritional value of Marula (*Sclerocarya birrea* subsp. *caffra*)

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Abstract This review critically evaluated literature on proximate composition and nutritional value of Marula in comparison with other tropical and indigenous fruits in order to identify areas for future research. It was found that nutrients content and processing methods of Marula fruit varied greatly from study to study and according to place of origin, soil, climate, handling, analytical methods used and time that lapsed after harvesting before analysis took place. Marula fruit pulp is reported to have vitamin C content higher than that of most fruits, ranging from 62 mg/100 g to over 400 mg/100 g. Additionally, Marula fruit is reported to have an antioxidant capacity of between 8 and 25 mM, (ascorbic acid equivalents) and a total phenolic content ranging from 7.5 to 24 mg/g dry weight gallic acid equivalent. Marula kernels are also a good source of protein, oil, magnesium, phosphorus and potassium and their oil is used in food preparations. Marula fruits could play a vital role in terms of nutrition to rural community who rely on the usage of the fruits, as they do not have easy access to other sources of nutrients. Recommendation given for future research includes improving Marula fruits juice extraction and yields, investigating the effect of processing and storage on the retention of nutrients such as vitamin C and its antioxidant capacity in processed and unprocessed Marula products and further identifying Marula fruits flavor compounds and their effect on processing and storage.

Keywords *Sclerocarya birrea* subsp. *Caffra* · Marula · Composition · Vitamin C · Antioxidant

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Introduction

Marula (*Sclerocarya birrea* subsp. *caffra*) is one of the most commonly utilized indigenous wild fruits in Africa (Shackleton et al. 2001). The marula tree is a multipurpose tree highly appreciated by local people, mainly for its fruits, but also for its cosmetic oil from the seed and medicinal purpose from the bark and leaves (von Teichman 1983; Mutshinyalo and Tshisevhe 2003). Female trees bear plum-sized fruits with a thick yellow peel and a translucent, white, highly aromatic sweet-sour fruit (Nerd and Mizrahi 1993; Nerd et al. 1990, 1994; Mizrahi and Nerd 1996). Marula fruit has a thick, soft leathery exocarp with tiny, round or oval spots, enclosing a juicy, mucilaginous flesh that adheres tightly to the seed and can be removed only by sucking (von Teichman 1982).

Fruits are eaten raw, like a small mango, or used to prepare juices, jams, conserves, dry fruit rolls and also fermented to make alcoholic beverages like beer, wine and liquor called Amarula (Nerd and Mizrahi 1993; Nerd et al. 1990, 1994; Mizrahi and Nerd 1996; Mojeremane and Tshwenyane 2004). The flesh fruit tastes tart, sweet and refreshing, although the fruit has a slight turpentine-like aroma and can give off a very unpleasant smell when decaying. According to Ogbobe (1992) the taste of the fruit is described as being acidic and bitter but of pleasant flavor when fully ripe.

The fruits are much sought by humans and animals for their nutritious pulp with high vitamin C content and their edible nuts. It has become a commercial fruit crop in recent years, the fruit pulp being used to produce jelly/jam and to flavor liqueur (Van Wyk et al. 2002). In Southern and some other parts of Africa, the stem-bark, roots and leaves of *Sclerocarya birrea* are used as traditional medicines that are believed to treat an array of human disorders including: malaria and fevers, diarrhea and dysentery, stomach ailments, headaches, toothache, backache and body pains, infertility, schistosomiasis, epilepsy and diabetes mellitus (Watt and Breyer-Brandwijk 1962; Pujol 1993; Hutchings et al. 1996; Van Wyk et al. 2002). In Namibia, the use of Marula as a medicinal plant is known and promoted by the Ministry of Agriculture and natural resources. Nowadays, the tree is classified as a medicinal plant like *hoodia gordonii* and devil's claw (*Harpagophytum procumbens*), which are the two indigenous natural plants with popular usage. Marula is described as a rich source of various nutrients (Eromosele et al. 1991). The present review critically evaluates literature on proximate composition and nutritional value of Marula in comparison with other tropical and indigenous fruits, in order to identify areas for future research.

Food uses of Marula

Ripe marula fruit can be consumed by biting or cutting through the thick, leathery skin and sucking the juice or chewing the mucilaginous flesh after removal of the skin (von Teichman 1982). A popular fermented alcoholic beverage is prepared from the ripe fruit. In some cases the skin is removed and the juice is fermented together with the pulp still on the seed (Carr 1957). Other methods include the cutting of the skin and allowing the whole fruit to ferment (Carr 1957). Yeasts, naturally occurring on the fruit, are traditionally utilized for spontaneous fermentation. This beverage is commonly known as Marula-beer or Marula-wine (Shone 1979) with an alcohol content of 2–5 % (Dlamini and Dube 2008) and is used for making the famous South African "Amarula Cream Liqueur".

Marula kernels found inside the nut of the fruit are regarded as a delicacy in regions of the tree's natural inhabitant; they are commonly used to supplement the diet during winter (Shone 1979). They make good snacks and can be consumed raw or roasted for the purpose of adding a unique special flavor to the food (Du Plessis 2002). The nuts are mixed with vegetables or meat or may be grounded by pounding and formed into a cake before consumption (Du Plessis 2002). In some households, the grounded nuts are used in baking of traditional breads (Shone 1979). Oil for human consumption and for cosmetic purposes can also be extracted from the nuts (Du Plessis 2002).

More recently, the fruit have been used to prepare jelly or jam, which is sold on a small-scale at open markets (Bille and Steppich 2003). The taste of marula jam and jelly is reported to be good, and the color is attractive (waxy yellow) without the need for addition of artificial food colors (Bille and Steppich 2003). The skin of marula fruits can be dried in order to use it as substitute for coffee. The leaves are cooked as relish. During drought, branches of *Sclerocarya birrea* are cut by livestock owners to use leaves as fodder for livestock (Mojeremane and Tshwenyane 2004).

Like many traditional food plants, the tree species provide food at all times and at times of food scarcity. In times of food shortages, such as a season of hunger preceding the first harvest, or in times of famine and drought, *Sclerocarya birrea* can become a crucial source of nutrition (Mojeremane and Tshwenyane 2004).

Problems encountered during processing

There are however, several disadvantages with the Marula when it comes to processing. It is said by several users that the skin of the fruit is rather too thick and is of little value at present. It is also argued by Gous et al. (1988) that the flesh (pulp) of the fruit is very difficult to remove from the central pit. In addition, the percentage of flesh to skin and pit is rather small (about 20 %) (Gous et al. 1988). The traditional way of making Marula juice is by using a cow horn to puncture the leathery skin of the Marula fruit after which the juice is squeezed out of the marula (den Adel 2002). This squeezing process is not efficient to gain a high juice yield, because part of the flesh is attached to the central pit and skin. Nowadays, the hydraulic press is used, and it is still hard to press all the juice out from Marula fruits because the pulp is bound by pectin into a gel form. Therefore, finding a way to obtain higher juice yield and one that is clarified will be an area for further research.

Another major problem in assessing Marula fruit for processing is the difficulty in obtaining consistently ripe and undamaged samples. This usually results in using fruits with different degrees of ripeness. This could result in the final product being too sour to be palatable. Very little is known in the scientific literature and almost nothing has been published on the acceptability and preference for the texture and flavour characteristics of the product (Schäfer and McGill 1986). Schäfer and McGill (1986) published on flavor profiling of juice of the Marula as an index for cultivar selection, and further suggested to undertake an investment in processing and the responses of potential consumers of all cultural groups in the market area must be evaluated.

Schäfer and McGill (1986) showed that there was not much difference in respect of odor, flavor and aftertaste of juices prepared from different cultivars. One prominent attribute that has been noted concerning flavor of Marula juice is the extreme sourness in combination with a lack of sweetness (Schäfer and McGill 1986). The relatively low sugar to acid ratios may have to be adjusted to make juices acceptable for consumption (Gous et al. 1988). The flavor of the Marula fruit is mainly concentrated in the peel (von Teichman 1983). That could be the reason why most of the Marula products available in the marked do not contain the typical Marula flavor since the skin is not incorporated in juice processing. Therefore, investigations still need to be done to identify the important flavor components and add them back to the juice to obtain a product of full and natural Marula flavor.

Vitamin C

Marula fruit juice is known for its very high vitamin C content, ranging from 62 mg/100 g (Carr 1957), to more than 2,100 mg/100 g in the fresh fruit (Eromosele et al. 1991; Hillman et al. 2008) and thus the fruit serves as an important source of vitamin C for many rural people (Nerd et al. 1990, 1994). Even the lowest reported values for vitamin C are comparable to the content of vitamin C in other fruits such as orange juice but still higher than that of other citrus juices (Pretorius et al. 1985). Hillman et al. (2008) found very high contents of ascorbic acid in marula fruit juice, as high as between 700 and 2,100 mg/100 g, more than 10 times higher than in orange juice and pomegranate juice, while Eromosele et al. (1991), Dlamini and Dube (2008), and Borochov-Neori et al. (2008) recorded values that were 3–4 times the amounts found in oranges juice. In Leakey (1999) according to Eromosele et al. (1991), stated that the vitamin C content of Marula fruits in Nigeria was 403 mg/100 g and to be twice that found in Botswana, although Eromosele et al. (1991) stated that the variation can be considerable depending on the stage of ripening, the content being highest in ripe fruits with 403 and 201 mg/100 g in unripen fruits. According to Leakey (1999), the proximate analyses for different fruits from southern Africa reveal some variation, which may be either genetically or environmental, or both, or due to different analytical methods. The causes of this variation are still not known and need to be investigated, as genetic variation of this magnitude would be of importance to domestication programmes. Hillman et al. (2008) found the variation to be due to differences among clones of Marula and fruits ripening stage.

Most fruits such as grapes, oranges, apple, lemon and papaya, amongst many others, have a lower vitamin C content compared to marula fruit as shown in Table 1. In Table 1, vitamin C contents vary greatly with different studies. This could be due to different analytical methods used, variation in the place of origin, soil, climate, ripening stage of the fruits and time that lapsed after harvesting before analyses were carried out.

Table 1 Vitamin C content of marula fruit in comparison to some fruits

Type of fruit	Vitamin C (mg 100 g^{-1})		Source
	Pulp	Juice	
Marula (*Sclerocarya birrea*)		700–2,100	Hillman et al. (2008)
		403	Eromosele et al. (1991)
		200	Nerd et al. (1990)
	62–179.1	275	Carr (1957)
		267	Borochov-Neori et al. (2008)
		133	Dlamini and Dube (2008)
Orange (*Strychnos spinosa*)		50	Eromosele et al. (1991), Takeda (2009)
		60	Dlamini and Dube (2008)
		33	Hillman et al. (2008)
Strawberries (*Fragaria ananassa*)	60		Eromosele et al. (1991), Takeda (2009)
Grapes *(Vitis vinifera)*		38	Eromosele et al. (1991)
Guava (*Psidium guajava*)		300	Takeda (2009)
Baobab (*Adansonia digitata L.*)		283	Chadare et al. (2009)
Parinari mobola (hissing tree)	64.1		Carr (1957)
Kiwi *(Actinidia deliciosa)*		52	Hillman et al. (2008)
		67	Vinci et al. (1995)
Wild grape (*Lannea edulis*)	14		Carr (1957)
Sour plum (*Ximenia caffra)*	49.2		Carr (1957)
Wild mango (*cordyla Africana*)	75.6		Carr (1957)
Avocado pear (*Persea americana*)		10	Vinci et al. (1995)
Kumquat (Citrus japonica)		55	Vinci et al. (1995)
Litchi *(Litchi chinensis)*		22	Vinci et al. (1995)
Mango (*Mangifera indica L*)		25	Vinci et al. (1995)
Papaya *(Vasconcellea pubescens)*		88	Vinci et al. (1995)
Passion fruit (Passiflora edulis)		65	Vinci et al (1995)
Pineapple *(Ananas comosus)*	25		Takeda (2009)
		31	Vinci et al. (1995)
Apple (Malcus domestica)	6		Takeda (2009)
Lemon *(Citrus Limon)*	50		Takeda (2009)
		51	Vinci et al. (1995)
Apricot *(Prunus armeniaca)*	25		Takeda (2009)
Lime (*Citrus aurantifolia)*	25		Takeda (2009)
Cantaloupe (Cucumis melo var. cantalupensis)	40		Takeda (2009)
Cherry (*Prunus avium)*	6.5		Takeda (2009)
Grapefruit *(Citrus paradisi)*	45		Takeda (2009)
		65	Vinci et al. (1995)
Peach *(Prunus persica)*	7		Takeda (2009)
Pear (*Pyrus)*	4		Takeda (2009)
Tomato *(Solanum lycopersicum)*	25		Takeda (2009)

Antioxidant activity

Borochov-neori et al. (2008) found that Marula juice had 56 mg/100 ml of pyrogallol equivalence of phenols and an antioxidant capacity of 382 mg/100 ml of vitamin C equivalence. The antioxidant activity remained after pasteurization and only 14 % was lost during freezing at −18 °C after 4 weeks. Hillman et al. (2008) reported antioxidant capacity of Marula juice to be 141–440 mg/100 ml (ascorbic acid equivalent), compared to 44–76 mg/100 ml (ascorbic acid equivalent) for orange and 44–132 mg/100 ml (ascorbic acid equivalent) for pomegranate.

Mdluli and Owusu-Apenten (2003) found total antioxidant capacity (TAC) of Marula fruit in terms of equivalent concentration of L-ascorbic acid (L-ASC-eq.) to be 2,960 mg/100 g L ASC-eq (pH 4.5) and 1,872 mg /100 g L-ASC-eq. (pH 7) respectively. Vitamin C accounted for about 70 % of TAC of the Marula fruit, which is 20–40 times higher than those reported for most common fruits (Mdluli and Owusu-Apenten 2003).

It is clear that Marula fruit and its juice have higher antioxidant activity than other fruits like pomegranate and orange juice, but further investigation will be necessary in this aspect since different analysis methods have been used and that makes it difficult to draw up a concrete conclusion towards the content of antioxidant obtained from different fruits. Antioxidant stability towards heat treatment is important but seems not to have been studied, even though thermal treatment is always applied in the food industry as important processing steps for inhibiting spoilage caused by microorganisms and increasing shelf life. The other area that is not described in literature is the effect of storage conditions; storage might cause many changes in the unprocessed or processed Marula juice and its products.

Phenolics and flavonoids

Gous et al. (1988) found that all seven Marula juice products (from different trees) contained large amounts of polyphenols, ranging between 226 and 414 mg/100 ml tannic acid equivalence for three consecutive years (1985–1987). Hillman et al. (2008) evaluated polyphenol contents using gallic acid as a standard and found from 17 clones that the content ranged from 700 to 2,500 mg gallic acid equivalent (GAE)/100 g dry weight. In pineapple, banana and guava, the phenolic and flavonoid content were measured and given in terms of Gallic acid equivalent and Catechin equivalents (CEQ), respectively (Alothman et al. 2009). These ranged from 35 to 55 mg/100 g for different concentrations of methanol, ethanol, acetone and water for pineapple. The phenolic content of banana ranged from 24 to 72 mg/100 g while phenolic content for guava ranged from 109 to 191 mg/100 g (Alothman et al. 2009). The content of soluble phenolic in Marula fruit juice was 56/100 g (Borochov-Neori et al. 2008). The flavonoid CEQ content of pineapple ranged from 1 to 4 mg/100 g, in banana it ranged from 5 to 24 mg/100 g and in guava it ranged from 14 to 45 mg/100 g (Alothman et al. 2009).

The variation among the phenolic contents obtained could be due to different extraction procedures used and to different clones and fruit quality of the selected clones. According to Alothman et al. (2009), the recovery of phenols was dependent on the fruit type and the extraction solution used, indicating that some fruit can be efficiently extracted using 100 % methanol or acetone while others were extracted with 50 % of the same extraction solution of methanol or acetone. Therefore, optimising the method of extraction should be the starting point. From three authors who analysed the phenolic content of Marula, their results varied within and between authors, indicating that different results can be obtained from tree to tree, year to year and author to author. According to Borochov-neori et al. (2008), in comparison to other fruits, Marula contains high phenolic contents and this could be contributing toward health status of the marula consumers.

Minerals

The mineral composition of Marula fruit varies with its geographical origin where trees are found as shown in Table 2. Table 3 shows the mineral content of Marula fruit in comparison to other fruits. The most abundant minerals found in Marula are calcium, magnesium, potassium and phosphorus, whereas sodium, iron, copper, zinc, cobalt, lead and manganese were present in smaller amounts (Gous et al. 1988; Holtzhausen et al. 1990; Eromosele et al. 1991).

Table 2 Mineral composition of Marula fruit from different regions in Africa

Origin	Burkina Faso		Niger	South Africa		Sibasa	SWA-Namibia[a]		SWA-Namibia[b]	
Part of the fruit	Fruit	Seed	Seed	Fruit	Seed	Fruit	Flesh	Skin	Flesh	Skin
Magnesium	310	193	421	10.5	467	14.8	25.3	33.5	74.7	41.5
Calcium	481	156	154	6.2	106	10.4	20.1	44.7	117.9	126.7
Iron	2.5	2.8	2.8	0.10	0.42	0.24	0.5	0.55	0.30	0.27
Copper	–	–	2.5	0.04	2	0.11	0.07	0.08	0.45	0.07
Zinc	–	2.7	6.2		–	0.17	0.10	0.17	0.34	0.12
Sodium	1.5	1.2	4.3	Trace	338	0.64	2.2	1.7	2.5	2.0
Potassium	212	264	364	548	677	163	317	345	490	417

Sources Fox and Hallowes (1982), Venter and Venter (2002), Glew et al. (1997, 2004), Wehmeyer (1967), Arnold et al. (1985), Bille and Steppich (2003)

The values are given in mg 100 g^{-1} (fresh fruit)

[a] sample from north central Namibia

[b] sample from north west Namibia

Table 3 Mineral content in mg/100 g fresh weight of marula in comparison to other fruits

Type of fruit	Cu	Fe	Mg	Mn	Zn	P	Ca	K	Na	References
Marula fruit	0.04	0.1	10.5			18.7	6.2	54.8	Trace	Wehmeyer (1967), Carr 1957
Marula juice		0.71	44	0.05	0.19		40	328	10	Borochov-neori et al. (2008)
Marula fruit		2.5	310			262	480			Mojeremane and Tshwenyane (2004)
Marula nut		2.8	193		2.7	212.0	156.0			Mojeremane and Tshwenyane (2004)
Marula nut	2.81	4.87	462		5.19		808	601	3.81	Arnold et al. (1985)
African plum	0.29	2.9	35.5	0.47	1.23					Smith et al. (1996)
African grapes	0.32	1.3	84.5	0.06	0.34					Smith et al. (1996)
Flour tree pulp	0.25	0.3	56.8	0.12	0.74					Smith et al. (1996)
Baobab pulp		4.3	195	0.7	1.7	106	302	1,794		Chadare et al. (2009)
Christ thorn	0.64	2.86	91	0.61	1.18		225			Eromosele et al. (1991)
Blood plum	0.18	2	53.3	0.76	0.72		50.5			Eromosele et al. (1991)
Wild olive	0.17	1.97	25.3	0.51	0.63		3.3			Eromosele et al. (1991)
Wild Annon		1.33	42.4	0.43	0.64		28.9			Eromosele et al. (1991)
Shea butter	0.11	1.93	26.3	0.24	0.47		36.4			Eromosele et al (1991)
Chinese date tree	0.6	6.3	227	3.5	1.55		712.5			Eromosele et al. (1991)
Date palm	0.12	1.07	16.7	0.36	0.37		13			Eromosele et al. (1991)
Grewia retinervis	0.4	4.7	172		1.6	60	157	655	31	Taylor (1985)

The values are given in mg 100 g^{-1}

Studies by Bille and Steppich (2003) concur with those of other authors (Gous et al. 1988; Holtzhausen et al. 1990; and Eromosele et al. 1991) in that pulp from the Marula fruit is high in potassium, calcium and magnesium. It was also concluded that the climate played a bigger role in influencing the mineral concentration of all Marula products slightly more than the origin of the tree and this is mostly due to draught or being a wet year. Additionally, the processing method like heat treatment before puree is prepared or before pressing the juice out could also contribute to the mineral content. The concentration of minerals is important to know, but next to that it is also necessary to know their bioavailability since if the minerals are not absorbed in the gut, the nutritional value is nil. Compounds such as oxalic acid or phytic acid may bind minerals and form insoluble complexes that are not absorbed and this area is not well covered on marula. According to Gous et al. (1988) the relatively low sugar and high potassium content of Marula juice can further add to health benefits since potassium is an essential nutrient to maintain fluid and electrolyte balance in the body. On the other hand, whether or not low sugar is healthy it is debatable, for instance if your diet is low in energy it may be very healthy to have sugars. Apart from the variation arising from geographical origin where trees are found, it might be also due to other factors like the method used for extraction by different researchers and handling of sample prior to analysis and the analytical method used. Geographical origin is also broader in the sense that other factors like soil type, soil fertility and climatic conditions like rainfall and sun intensity, genetic variation from region to region and country to country varies.

Lipids and fatty acids

Marula nut has higher lipid/oil content than Baobab, *Adansonia digitata Carissa edulis* and *Hibiscus esculentus* nuts as shown in Table 4. Shone (1979) and Von Teichman (1983) reported 5.7/100 g of lipids found in the nut of Marula and Glew et al. (1997) found 19.5/100 g dry weight of lipids in the nut. The lipid content of marula nut varied from 50 to 85 % of dry weight according to (Eromosele et al. 1991; Leakey 1999; Arnold et al. 1985). According to Glew et al. (2004), the fatty acid composition and content of the Marula seed (daniya seed) was high (47.0 % of dry weight) with the major fatty acid being monoenoic oleic acid (18:1 n-9) accounting for 63 % of the total fatty acid content (47/100 g dry weight). Ogbobe (1992) reported that Marula seed contained stearic, palmitic and archidonic acids as predominant, representing 50.7, 23, and 8 % of total fat, respectively. In addition to that, Wehmeyer (1967) stated that the Marula oil itself is high in unsaturated fatty acids containing 70 % oleic acid and 8 % linoleic acid of total fat. According to Mariod and Abdelwahab (2012), fatty acid and oil composition can be affected by harvesting time and an increase in the oil content up to 63 % of dry weight was obtained at the end of the last harvesting date, whereas only 17 % of dw was obtained at the first harvesting date (first harvest date March and last harvest date June).

Table 4 Lipid content in marula fruit in comparison to other fruits

Lipid content (g 100 g^{-1} dry weight)			
Part of fruit	Pulp	Nut	References
Marula	13.5	19.5	Glew et al. (1997)
	–	5.7	Shone (1979), Von Teichman (1983)
		50–85 %	Eromosele et al. (1991), Leakey (1999)
Baobab	3.6	28	Chadare et al. (2009)
Adansonia digitata	15.5	9	Glew et al. (1997)
Carissa edulis	3	–	Glew et al. (1997)
Hibiscus esculentus	19	–	Glew et al. (1997)

Macronutrients

Protein and amino acids content

Marula fruits and seeds contain 3,600 and 5,600 mg/100 g dry weight of total protein, respectively (Glew et al. 1997), indicating that the seeds of Marula contain more protein than the fruits. The protein from the seeds varies from country to country, for instance the kernel from Nigerian Marula was found to contain 36.7 % crude protein, which is much more than 5.6 % obtained by Glew et al. (1997), whereas the Sudanese one contained only 28.0 % with lysine as the limiting amino acid. The protein from Marula kernel contains sulfur-containing amino acids like methionine and cysteine and its in vitro protein digestibility was almost similar to that of soy bean protein (Mariod and Abdelwahab 2012): 79 % of Marula seed protein and soybean protein could be digested by pancreatic enzymes. Additionally, Wehmeyer (1967) indicated that the kernel contains considerable amounts of protein ranging between 23 and 31 %. Furthermore, Quin (1959) indicated that Marula kernels had a higher protein and oil content than most other popular nuts, including walnuts, hazelnuts, chestnuts and almonds. The amino acid content of marula fruit and seed is lower than in baobab as shown in Table 5. The content of amino acids in Marula was comparable to amounts

Table 5 Amino acid content in g/100 g of dry weight of marula fruit in comparison to baobab content

Amino acid	Marula nut	Baobab seed	Marula pulp	Baobab pulp
Alanine	2.53	8.0	2.66	5.6
Arginine	6.76	11.5	2.12	6.8
Aspartic acid	5.17	16.9	3.77	7.5
Cysteic acid	1.95	2.8	.97	1.3
Glutamic acid	13.1	35.9	4.52	8.4
Glycine	2.68	8.8	1.98	6.2
Histidine	1.22	3.4	.8	2
Isoleucine	–	5.8	–	3.6
Leucine	3.78	10.6	2.74	5.4
Lysine	1.29	6.9	1.57	4
Methonine	.68	1.9	.51	1.9
Phenylalanine	2.37	7.2	1.6	3.5
Proalanine	–	6.9	–	3.7
Proline	2.52	9.1	3.28	7
Serine	2.64	8.3	1.91	–
Threonine	1.79	5.8	1.45	–
Tryptophan	.83	2.6	.52	3.5
Tyrosine	1.47	3.9	1.32	8.5
Valine	3.03	8.5	2.17	4.9

Source Glew et al. (1997)

The values are given in g/100 g^{-1} dry weight

found in other fruits (Glew et al. 1997). Glew et al. (1997) reported that several essential amino acids like leucine, lysine, the phenylalanine/tyrosine pair, and threonine in Marula seeds were rated lower than the World Health Organization protein standard. It should be noted that others like isoleucine, methionine, cysteine, tryptophan and valine were rated higher than the World Health Organization standard.

Moisture

The reported moisture content of Marula fruit juices varies between 82 and 93 % (Gous et al. 1988; Shone 1979) as shown in Table 6. These variations were ascribed to differences in growing conditions of the trees (Gous et al. 1988). It could be also due to the difficulty in obtaining a representative sample for moisture of juice or pulp since the flesh adheres tightly to the skin and stone, and information on how the sample was prepared is not documented. Oranges, banana, papaya, mango and pineapple when ripe, have moisture contents of 83, 74, 90, 80 and 85 %, respectively (Hernandez et al. 2006).

Carbohydrates

In Table 6 the carbohydrate fraction of the marula juice is reported to range between 7 and 14 % of the fresh weight; consisting mainly of sucrose, glucose and fructose and the edible portion (pulp) of marula had 2.3 % invert sugar (glucose and fructose) and 5.9 % sucrose (Gous et al. 1988; von Teichman 1983). In South Africa and Botswana, the Brix values for marula fruit can vary between 10.4° and 16.0° according to Leakey (1999). It implies that in some trees the fruit pulp is sweet and in others very sour. It was also found that the variation in total soluble solids of puree and juices varied over three seasons with the lower value corresponding with a drought and the higher value with a wet year. In addition to that, Gous et al. (1988) found the total soluble solid fraction of marula puree and juices to vary between 7 and 16 degree brix and appeared to be influenced by severe drought that occurred between 1983 and 1986. According to Taylor and Kwerepe (1995), as quoted by Leakey (1999), Marula contained 3.7 % carbohydrate at 96 % dry matter of the kernel but information on the method of analysis was not documented.

Energy

The energy value of the Marula fruit is approximately 130 kJ/100 g of fruit flesh (von Teichman 1983). Wehmeyer (1967) reported that the Marula nuts represent 3,138 kJ/100 g and Wynberg et al. (2002) indicated that the energy value of the kernel is approximately 2,699–2,703 kJ/100 g. Marula fruit flesh energy value is lower than the compared fruits but the kernel is one with the highest. For instance, Baobab pulp contains between 848.9 and 1,494.9 kJ/100 g energy Chadare et al. (2009), *Grewia retinervis* has about 293–1,010 kJ/100 g of energy in the flesh while *Citrullus lanatus* has 4 kJ/100 g in the flesh and 415 kJ/100 g in the seed (Taylor 1985).

Dietary fibers

Marula fruit contained more than 2.9 % of the fresh weight of crude dietary fiber (Taylor and Kwerepe 1995). Marula fruit juice contained 0.7/100 g dietary

Table 6 Micronutrient composition in comparison to other fruits

Type of fruit	Pulp	Reference	Juice	Reference
Moisture content (g/100 g fresh weight)				
Marula	85–87	Carr (1957), Borochov-Neori et al. (2008)	82–93	Gous et al. (1988), Shone (1979)
Orange			83	Hernandez et al. 2006
Baobab	2–28	Chadare et al. (2009)		
Parinari mobola (hissing tree)	69.1	Carr (1957)		
Wild grape (*Lannea edulis*)	70.5	Carr (1957)		
Sour plum (*Ximenia caffra)*	66.4	Carr (1957)		
Wild mango (*cordyla Africana)*	80.9	Carr (1957)		
Papaya			90	Hernandez et al. (2006)
Pineapple			85	Hernandez et al. (2006)
Banana			74	Hernandez et al. (2006)
Grewia retinervis	10.6–11.7	Taylor (1985)		
Citrullus lanatus	86.9–97.9	Taylor (1985)		
Carbohydrate content (g/100 g fresh weight)				
Marula	0.7–1.2	Shone (1979), Gous et al. (1988), von Teichman (1983)	1.2–1.4	Gous et al. (1988)
Baobab	4.7–8.8	Chadare et al. (2009)		
Grewia retinervis	6.8	Taylor (1985)		
Citrullus lanatus	0.09	Taylor (1985)		
Dietary fibre (g/100 g dry weight)				
Marula	2.9	Taylor (1985)	7.95	Aganga and Mosase (2001), Borochov-Neori et al. (2008)
Grewia retinervis	12.6–24.7	Taylor (1985)		
Citrullus lanatus	2.3	Taylor (1985)		
Baobab	13.7	Chadare et al. (2009)		
Ash content (g/100 g dry weight)				
Marula	0.2	Taylor (1985)	0.09	Taylor (1985), Borochov-Neori et al. (2008), Gous et al. (1988)
Grewia retinervis	0.37	Taylor (1985)		
Citrullus lanatus	0.11	Taylor (1985)		
Baobab	0.19–0.64	Chadare et al. (2009)		

fiber (Borochov-Neori et al. 2008). Table 6 shows the dietary fiber content of Marula in comparison to other fruits.

Ash content

The amount of ash that is found in marula juice is 1/100 g (Borochov-Neori et al. 2008). However, Taylor (1985) found the ash content of the Marula pulp to be 0.2/100 g and for the juice to be 0.09/100 g. Aganga and Mosase (2001) found the ash content for the seed of Marula fruit to be 1.7 %. The amount found varied a lot and that could be due to different method of analysis used by the authors in respect to combination of time and temperature. How the ash content was determined is not documented by some authors, but Gous et al. (1988), used 2–5 g of Marula samples and these were ashed for approximately 16 h at 520 °C until light in colour, and found the ash to vary between 0.5 and 0.9/100 g. The way the ash was determined by Gous et al. (1988) indicated that they were not precise with time taken and they also used the color as an indicator for sample readiness.

Conclusions and recommendations

Marula fruit mineral and nutrient content varied greatly from study to study. This could be due to variation in place of origin, soil, climate and time that lapsed after harvesting before analysis were carried out. Due to the variation found in reported data, it is recommend that collection, handling, storage mechanisms and conditions under which the samples were handled and methods used to analyze the samples must be described in detail. Marula juice sample preparation could also be the cause of variation, since the way of pressing the juice out of the fruit is different from country to country. It also depends on the strength of the presser/processor. In some cases authors did not make clear which part of the fruit was used for their analysis. It is very confusing when author use terms like flesh, pulp and juice or edible portion. For the variation arising due to environmental factors, it cannot easily be controlled since most of the Marula trees grow naturally and under no irrigation and fertilizer added and it can grow in open woodlands, bushes, in clay or sandy soil, survives in hot dry climatic conditions with a mean annual rainfall of 200–1,500 mm. For instance, in some countries like Namibia and South Africa there are extreme variations in rainfall, year to year and place to place.

Nonetheless, Marula fruit is a rich source of antioxidants and vitamin C, which can be eight times higher than that in an orange fruit. The nuts of these trees are also rich in oleic acid, protein, energy and minerals like iron, magnesium, zinc, phosphorus and copper, which contribute to the importance of these nuts in the diets of rural communities. Marula fruits could play a vital role to the rural populations who rely on the usage of the fruits and do not have access to other sources of nutrients.

Future research recommended

Even though some studies reported on the contents of nutrients found in Marula fruit, the results reported show great variation in the measured values. What is clear is that Marula is a rich source of various nutrients, especially of vitamin C. However, the way it is processed is of absolute importance as this may have influence on the retention of nutrients such as vitamin C and its antioxidant capacity. This area is not well documented and there is very limited information available in literature. In addition to that, different analytical methods have been used and that makes it difficult to draw up a concrete conclusion toward the antioxidant obtained from different fruits and their stability toward heat treatment and storage conditions. Therefore, further investigation on the thermal degradation of vitamin C in Marula products is needed. In addition, the most made product from Marula fruit is its fermented juice. Little is known about the antioxidant activity and about theirs content in processed Marula products like fermented juice; this need further research. Furthermore, it is clear that pressing all the juice out from Marula fruits is not easy, neither efficient because the pulp is bound by pectin into a gel form. Further work on this will be required to improve yields and to get a better-clarified juice. The nonclarified juice is very cloudy, contains a lot of pulp and that is not appealing to a lot of Marula juice consumers. The skin of the fruit is rather too thick and is of little value at present. It is also apparent that most of the characteristic flavor of the fruit is contained within the skin, which is lost during processing. That could be the reason why most of the Marula containing products available in the market do not contain Marula flavor components since the skin is not incorporated in the juice processing. Therefore, investigations need to be done to identify the important flavor components and further investigate the effect of processing or storage towards Marula flavor.

The proximate analyses for different fruits from southern Africa revealed some variation, which may be either genetic or environmental or both or due to different analytical methods. The causes of this variation are still not known and need to be investigated, as genetic variation of this magnitude would be of importance to domestication programmes.

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