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Sclerocarya birrea: Biochemical Composition, Nutritional and Medicinal Uses—A Review

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ABSTRACT

Wild fruits are being considered because their constituents have unique nutritional and functional properties, Sclerocarya birrea (Anacardiaceae) is a popular African wild fruit distributed in many African countries where the leaves, stem bark, root and fruits are used in food and traditional medicine; the fruit is rich in ascorbic acid and the fruit juice contains sesquiterpene hydrocarbon. It contains a hard brown seed. The seed encloses a soft white kernel rich in oil and protein. The oil contains oleic, palmitic, myristic, and stearic acids; the kernel protein contains amino acids with a predominance of glutamic acid and arginine. The extracts from different parts showed high total phenolic compounds and radical scavenging capacities and antioxidant activities. Sclerocarya birrea is widely studied with regard to its antidiabetic, anti-inflammatory, analgesic, antiparasitic, antimicrobial, and antihypertensive activities.

Keywords: *Sclerocarya birrea*, Oil, Protein, Phenolic compounds, Antioxidant, Antidiabetic, Anti-inflammatory, Antimicrobial.

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Introduction

Botanical Description

Sclerocarya birrea (Anacardiaceae) is a savannah tree, belonging to the family Anacardiaceae, with a plum-like pale yellow fruit of 3-4 cm in diameter with a juicy mucilaginous flesh. *Sclerocarya birrea* is deciduous and mainly dioecious, although there have been reports of monoecious trees. It is a medium sized tree (Coates Palgrave, 1977) reaching heights of between 7 and 17 m, with grey fissured bark, stout branchlets and pale foliage. The leaves are compound, pinnate and the flowers greenish-white or reddish. The fruits are yellow, resembling a mango (Dimo *et al.*, 2007). The rough stem-bark is flaky, with a mottled appearance due to contrasting grey and pale-brown patches. The leaves are divided into 10 or more pairs of leaflets, each about 60 mm long, dark-green above, and sharp point. The flowers are borne in small, oblong clusters. Male and female flowers occur separately, usually but not always on separate trees. The flowers are small, with red sepals and yellow petals (Van Wyk *et al.*, 1997). The fruit, which is the size of a small plum, is pale yellow when ripe. The rounded, slightly flattened fruit is about 30 mm in diameter and borne in profusion in late African summer to mid-winter. *S. birrea* has a variable fruit size, approximately 15–25 g (Shackleton *et al.*, 2003). The leaves are alternate and compound, crowded near the ends of the branches. The leaflets are dark green above and a lighter blue–green below and are ovate to elliptic in shape. The edges of coppice leaves are toothed and often tinged with pink (Coates Palgrave, 1977). It grows in a wide variety of soils but prefers well-drained soil. It exists at altitudes varying from sea level to 1800 m and an annual rainfall range of 200–1500 mm. Its major habitat limitation is probably its sensitivity to frost (Wynberg *et al.*, 2002).

With a widely distributed plant that is valued highly for edible purposes and for treating many other ailments, Marula could be considered a ‘power plant’ (Balick, 1990). The fruit taste is acidic but of a pleasant flavor when fully ripe. The tree produces very large amounts of fruit every year (FAO, 1988). It has multiple uses, the fruits are eaten fresh or fermented to make a beer, the kernels are eaten or the oil extracted, the leaves are browsed by livestock and have medicinal uses, as does the bark (Shackleton, 2002). The wood is carved into utilitarian items such as spoons and plates as well as decorative animal figures. Because of these multiple uses, and its significance in the landscape, several African cultures have specific beliefs and ceremonies associated with this species (Walker, 1989).

Mizrahi and Nerd (1996), mentioned that an effort has been made to domesticate the tree of *Sclerocarya* in South Africa and Israel in order to establish orchards that will supply both fresh fruit and fruit for the canning and beverage industry.

Biochemical Composition and Proximate Analysis

The proximate analysis of *S. birrea* fruit revealed that it is rich in ascorbic acid and the fruit juice contains sesquiterpene hydrocarbons (Pretorius *et al.*, 1985). The fruit kernels yield 54–60 per cent of fixed non-drying oil and contain as much as 28 per cent protein (Watt and Breyer-Brandwijk, 1962). The oil-rich seeds contain 64 per cent oleic acid, myristic, stearic and amino acids with a predominance of glutamic

acid and arginine (Ojewole, 2004). Bark yields 3.5–20.5 per cent tannin, 10.7 per cent tanning matter and traces of alkaloids (Watt and Breyer-Brandwijk, 1962). The gum is rich in tannin. Tannins and flavonoids are present in leaves but no alkaloids, steroids or triterpenoids have been detected (Gueye, 1973).

In general, *S. birrea* seed had adequate quantities of phosphorus, calcium, magnesium, potassium, iron and copper to meet requirements for beef, sheep and goat production. The content of sodium, manganese and zinc were below recommended levels required by ruminants for growth and productivity (Aganga and Mosase, 2001).

Glew *et al.* (2004) reported that the protein content of the edible portion of *S. birrea* seed was surprisingly high (36.4 per cent of dry weight), particularly in light of the fact that it is regarded as a lipid-rich seed. However, when compared with the WHO protein standard, the seeds were found to contain low proportions of several of the essential amino acids, including leucine, lysine, the phenylalanine/tyrosine pair, and threonine. Thus, the pits of *daniya* seed appear to represent a potentially rich source of some, but not all, of the amino acids that are essential for humans.

Bark yields 3.5–20.5 per cent tannin, 10.7 per cent tanning matter and traces of alkaloids (Watt and Breyer-Brandwijk, 1962). The fruit is rich in ascorbic acid and juice extracts yield 33 sesquiterpene hydrocarbons (Pretorius *et al.*, 1985). The fruit contains 2-3 edible kernels, which contain 53.0, 28.0 and 8.0 per cent of oil, protein and carbohydrates, respectively (Mariod *et al.*, 2005a). Kernels yield 54–60 per cent of non-drying oil and contain as much as 28 per cent protein (Watt and Breyer-Brandwijk, 1962). The gum is rich in tannin. Tannins and flavonoids are present in leaves but no alkaloids, steroids or triterpenoids have been detected (Gueye, 1973). Salama (1973), working on Sudanese *Sclerocarya*, reported a fatty acid composition of the oil markedly different from that of Ogbobe (1992), who studied Nigerian *Sclerocarya* seed oil and reported 50.7 per cent stearic, 22.6 per cent palmitic, 8.4 per cent arachidonic acid, with an iodine value of 102 and 3.1 per cent unsaponifiable matter. The fruit pulp contains citric and malic acids, vitamin C and sugar. The gum from the tree is rich in tannin, and is sometimes used in making an ink substitute (Watt and Breyer-Brandwijk, 1962).

***Sclerocarya birrea* Tree a Promising Source of Food and Energy**

***Sclerocarya birrea* Proteins**

In South Africa the kernels obtained from the seeds by cracking the nuts against a stone slab, and then removing the kernels individually with a sharp needle-like tool (Cunningham, 1988). The kernel from Nigerian *S. birrea* was found to contain very high 36.70 per cent crude protein (Ogbobe, 1992), while Sudanese *S. birrea* contained only 28.0 per cent of protein with lysine as the limiting amino acid. The protein contained good level of sulphur-containing amino acids (methionine and cystine), when compared to that of four different food materials. The *in-vitro* protein digestibility of *Sclerocarya birrea* was almost similar to that of soy bean protein concentrate and lupine. With a chemical score of 33.0 per cent, based on the essential amino acids pattern requirements for children, the limiting amino acid in *Sclerocarya* protein was lysine (Mariod *et al.*, 2005a).

Glew *et al.* (2004) reported a protein content of 36.4 per cent of dry weight however; the protein fraction contained relatively low proportions of leucine, phenylalanine, lysine, and threonine. Because of the widespread occurrence, potentially high fruit production and use of *S. birrea*, many developed products were produced from seed kernels by adding to Halva confectionary 10 per cent unroasted, blanched and roasted kernels and biscuits processed by using the seed oil instead of hydrogenated oils. The results showed a statistically significant difference ($P < 0.05$) between the Halva developed products. Biscuits processed by using the seed oil instead of hydrogenated oils was significantly ($P < 0.05$) found to be less acceptable than the conventional biscuits (Mariod *et al.*, 2005a).

***Sclerocarya birrea* Kernel Oil**

The *S. birrea* nut comprises an average 90 per cent shell and only 10 per cent kernel, making kernel and oil yields relatively low per fruit. However, the oil yield per kernel is high at 56 per cent (Shone, 1979). The oil content of kernels from *S. birrea* amounted to 53 per cent (Mariod *et al.*, 2005a; Mizrahi and Nerd, 1996), which was very high in comparison with conventional oil seeds. Salama (1973) found more oil in the kernels (63.3 per cent), whereas kernels investigated by Ogbobe (1992) contained lower amounts (11.0 per cent).

Marula oil contains a large proportion of mono-unsaturated fatty acids and natural antioxidants. It can be classified as a high-oleic acid (70-78 per cent) with relatively low tocopherol content. The exceptional stability has therefore been suggested to be due to its fatty acid composition (Eromosele and Paschal, 2003; Glew *et al.*, 2004; Houghton, 1999). However, recent studies have mentioned that some of the minor components in the oil may also be contributing to this important antioxidant property (Wynberg *et al.*, 2003). Marula oil contains a similar fatty acid composition to olive oil however it is 10 times more stable to oxidation.

The oil contained 67.2 per cent oleic acid, 5.9 per cent linoleic acid, 14.1 per cent palmitic acid and traces of linolenic acid (Mariod, 2005). Glew *et al.* (2004) reported that the fatty acids of *Sclerocarya birrea* oil accounted for 47 mg/g dry wt of the seed, two-thirds of which was oleic acid. The essential fatty acid linoleic acid was present (24.5 mg/g dry wt), but the other essential fatty acid, α -linolenic acid, was absent. These results were totally in contradiction with the fatty acid reported by Ogbobe (1992), who reported stearic, palmitic and arachidonic acids as the predominant representing 50.7, 22.5 and 8.4 per cent, respectively.

Sclerocarya birrea oil content and fatty acid composition is affected by harvesting time, a quantitative increase in the oil content was observed to reach 63.0 per cent at the end of the last harvesting date. The percentage of total fatty acids had altered and palmitic acid content was found to be 16.8 per cent at the first date of harvesting and dropping for the rest of the dates to reach 14.6 per cent by the end of the harvesting process. In the same manner, stearic acid was found to be 15.2 per cent at the first date and this dropped dramatically to reach 8.8 per cent by the end of the harvesting, while oleic and linoleic acids increased from 58.9 and 4.3 per cent to 67.3 and 5.9 per cent, respectively (Mariod *et al.*, 2010).

The major fraction in *Sclerocarya birrea* seed oil was triacylglycerol, representing 76.5 per cent of the total lipid, followed by polar lipid 12.5 per cent and diacylglycerol 5.6 per cent (Mariod, 2005). Unlike other nut oils, marula oil is a poor source of Vitamin E due a low level of β -tocopherol (Shone, 1979). The tocopherol content of *S. birrea* oil amounted to 13.7 mg/100 g oil, with gammatocopherol as the predominant tocopherol *et al.*, 2004). During harvesting time of *S. birrea* the alpha and gamma tocopherols decreased rapidly, whereas the delta-tocopherol and delta-tocotrienol were 4.8 and 4.9 mg/100 g, respectively at the beginning and had disappeared completely by the last harvesting date (Mariod *et al.*, 2010).

The sterol fraction in oils is analyzed for the identification of a fat or oil to distinguish between oils of similar fatty acid composition, for the detection of the addition of non-declared cheap oils to more expensive or to distinguish between different qualities of the same (Holser *et al.*, 2004; Fischer *et al.*, 1991). The total content of sterols in *S. birrea* oil was 287 mg/100 g oil with β -sitosterol as the main compound with about 60 per cent of the total sterols and a high amount of D5-avenasterol which was found at 16 per cent of the total sterols, it is known to act as an antioxidant and as an antipolymerization agent in frying oils (Mariod *et al.*, 2004). *S. birrea* oil is believed to preserve meat (Palmer, 1977). When compared with other oils *Sclerocarya birrea* kernel oil could serve as a source of edible stable oil, and of fatty acids of technical grade, mainly conjugated linoleic acid (CLA) as an antioxidant, anticarcinogenic and antiatherogenic (Mariod *et al.*, 2004).

Oils containing fatty acids of low molecular weight are slightly less viscous than oils of an equivalent degree of unsaturation containing only high molecular weight acids (Hidalgo and Zamora, 2005). The viscosity of *S. birrea* was measured by the viscotester between 25 and 125 °C. In general, the viscosity of the oil decreased slightly with increase in unsaturation and it decreased with increase of temperature and *S. birrea* oil was found less viscous compared with the other oils (Mariod, 2005).

Oxidative stability is an important parameter for evaluating the quality of oils and fats, as it gives a good estimation of their susceptibility to oxidative deterioration, the main cause of their alteration (Mateos *et al.*, 2005). The oxidative stability of *S. birrea* oil, as measured by the Rancimat test at 120°C, was 43 h, and this high oxidative stability might be due to high percentage of monosaturated fatty acids besides other minor bioactive components (Mariod *et al.*, 2004). Kleiman *et al.* (2008) investigated the oxidative stability of marula oil and compared it to with *Moringa pterygosperma* (moringa) oil which is well known stable oil they reported 3.5 times higher stability of moringa over marula oil. The behavior of crude *Sclerocarya birrea* kernel oil during deep-frying of par-fried potatoes was studied concerning chemical, physical and sensory parameters, such as content of free fatty acids, tocopherols, polar compounds, oligomer triglycerides, volatile compounds, oxidative stability and totox value. Potatoes fried in *S. birrea* oil were found suitable for human consumption after 24 hours of deep-frying at 175°C considering the sensory evaluation (Mariod *et al.*, 2006a). *Sclerocarya birrea* oil as it shows high stability it was used in blending with sunflower oil to increase its stability which was measured by Rancimat and peroxide value, the blending resulted in a remarkable improvement of the oxidative stability by 147 per cent. The results revealed a good correlation between the content of oleic acid and the

oxidative stability of oils (Mariod *et al.*, 2005b). Another method to compare the oxidative stability of oils is the storage under accelerated conditions at 70 °C and measurement of the peroxide value at certain times. When *S. birrea* was stored at 30°+/-2 °C in the dark for 24 months, the fatty acid composition in the oil remained almost unaltered with no significant change in its oxidative stability (Mariod *et al.*, 2008).

Phenolic compounds from *S. birrea* oil seed cake were extracted by overnight and ultra-sound extraction which resulted in a higher amount of total phenolic compounds; the addition of the extracts obtained to sunflower oil showed an inhibition of oxidation and a remarkable antioxidative activity, reducing oil deterioration (Mariod *et al.*, 2006b).

Crude oils obtained by oilseed processing have to be refined before consumption in order to remove undesirable accompanying substances (Pokorny, 2000). In laboratory refining experiments crude oil from *Sclerocarya birrea* was processed by refining. Changes in composition and also the stability against oxidation were determined. It becomes clear that phosphatides, peroxides, tocopherols, sterols as well as the oxidative stability were reduced during processing, while free fatty acids were nearly totally removed. The total amounts of volatiles as well as the amounts of hexanal were decreased during the different processing steps as well (Mariod *et al.*, 2007).

The antioxidant activity of 3,4-dihydroxyphenylethanol and phenyl-acids (caffeic acid, p-coumaric acid, ferulic acid, syringic acid, and vanillic acid) that found in virgin olive oil has been studied, and their high antioxidant activity has been demonstrated (Baldioli *et al.*, 1996). Six phenolic compounds were identified as vanillic, sinapic and t-cinnamic acid, callistephin, quercetin and luteolin, in the methanol extract of *S. birrea* oil using HPLC (Mariod, 2005).

***Sclerocarya birrea* Oil as Biodiesel**

The transesterification of vegetable oils constitutes an efficient method to provide a fuel with chemical properties that are similar to those of diesel fuel. More than 350 oil-bearing crops have been identified to produce biodiesel (Dorado *et al.*, 2004). *Sclerocarya birrea* stable oil was transesterified using methanol and ethanol in presence of sulfuric acid; the obtained biodiesel characteristics met the DIN specifications (water content, iodine number, phosphorus content), with oxidative stability higher than the required limit (Mariod *et al.*, 2006c).

Multiple Uses, including the Fruits, Kernels, Leaves, Bark, and Wood

The Fruits and Kernels

The tree has a pale yellow fruit, which is plum-like with a plain tough skin, and a juicy mucilaginous flesh. The taste is acidic with a pleasant flavour when fully ripe (FAO, 1988). Humans have used the marula tree as a source of nutrition for at least 10,000 years; the tree produces more than 600 kg of fruits per year with an average yield of 550–1000 kg with a current value of US\$1 per kg of fruit (Nwonwu, 2006).

The fruit is edible and contains a hard brown seed. In South Africa, *Sclerocarya birrea* has become a commercial fruit crop in recent years, the fruit pulp being used to produce a jelly and to flavour liqueur (Van Wyk *et al.*, 1997). The seed encloses a soft white kernel 1.0-1.5 cm in length and 0.5-0.75 cm in width. The fruit pulp is eaten raw and known to make jelly. Fruit and leaves are utilized by both wild and domesticated animals (Aganga *et al.*, 2001).

The fruits are aromatic and edible, and are much sought after by baboons, monkeys, elephants and human beings for their delicious pulp and edible nuts. The outer skin of the fruit has a rather pungent, apple-like odour, and its flavour has been described as resembling that of litchi, apple, guava or pineapple. It makes an excellent conserve. In Mozambique, the fruit is used for making a “national” fermented beverage. The nut has a very thick shell, containing a kernel. The consumption of the kernels just by children in Niger highlights the need to better understand the cultural context of how wild plant foods are used in a particular local context (Glew *et al.*, 2004). The kernel is edible and very tasty, especially when cooked. Its flavour resembles that of the groundnut.

***Sclerocarya birrea* Bark and Wood**

In Southern Africa sub-region, the stem-bark of *S. birrea* is used for an array of human ailments, including: malaria and fevers, diarrhoea and dysentery, stomach ailments, headaches, toothache, backache and body pains, infertility, schistosomiasis, hypertension, epilepsy, proctitis, gastric and duodenal ulcers, diabetes mellitus, asthma, urinary tract infections, arthritis and other inflammatory conditions, and so forth (Ojewole, 2003a). The Zulus of South Africa use a decoction of *Sclerocarya birrea* bark as a prophylactic remedy against gangrenous rectitis (Dimo *et al.*, 2007). In South and East Africa, the stem-bark of *S. birrea* is used as a potent remedy for dysentery and proctitis (Eloff, 2001). The Vendas of South Africa usually administer powdered bark of the plant to pregnant women to regulate the sex of babies. The bark from a male tree is administered for a boy, while the bark of a female tree is administered for a girl (Ojewole, 2003b).

The Hausas in West Africa use a cold infusion of the bark along with native natron as a remedy for dysentery (Oliver-Bever, 1986). Chemical and pharmacological studies on the bark have reported antidiarrheal activity of the decoction and the isolation of phenolic compounds such as procyanidins and (-) epicatechin-3-galloylester. A number of African traditional healers have claimed that *Sclerocarya birrea* stem-bark extracts are effective in the management and/or control of adult-onset, type-2 diabetes mellitus (Ojewole, 2004).

The Zulus and Thongas of South Africa also use a decoction of *S. birrea* bark as a ritual cleansing emetic before marriage. Branches of the tree are also used in the funeral rites of the Thongas. The divining dice of the Shangana diviners include a *Sclerocarya* nut which represents the ‘vegetable kingdom’ or ‘medicine’ (Van Wyk *et al.*, 1997; Hutchings *et al.*, 1996; Pujol, 1993). In most African countries, the wood of *S. birrea* is used for making dishes, mealie stamping mortars, drums, toys, curios, divining bowls and carvings (Watt and Breyer-Brandwijk, 1962).

Leaves

No research was done on the chemical composition of the plant leaves, although it was found that their extract is able to exhibit the activity with Ca^{2+} mobilizing systems in muscle cells (Braca *et al.*, 2003). In western Sudan the new leaves are used in salad dishes together with onion and groundnut paste. Different leaf extracts of *S. birrea* possess active constituents capable of inhibiting calcium release from sarcoplasmic reticulum (Itoh *et al.*, 1982), the ethanolic extract was found to inhibit angiotensin converting enzyme (ACE). Clearly this might explain the antihypertensive effect in traditional medicine like in other muscular systems (Galvez *et al.*, 1993)

Roots

Roots are used for many purposes including sore eyes in Zimbabwe (Gelfand *et al.*, 1985). In East Africa, roots are an ingredient in an alcoholic medicine taken to treat an internal ailment known as *kati* (Kokwaro, 1993). Decoction, infusions, or steam from boiled roots is used to treat heavy menstruation, bilharzias, coughs, weakness, sore eyes, heart pains and as an antiemetic (Shackleton *et al.*, 2002).

Pharmacology of *Sclerocarya birrea*

Although many biological studies on *Sclerocarya birrea* have been performed on the basis of its chemical constituents and traditional uses; a lot more are still to be exploited, explored and utilized. Important pharmacological findings Table 5.1 are summarized below:

Table 5.1: Some investigated biological activities of *Sclerocarya birrea*.

<i>Biological Activities</i>	<i>Plant Part and Extracting Solvent</i>	<i>Authors</i>
Antidiabetic properties	Stem-bark aqueous extract	(Laurens <i>et al.</i> , 1984)
	Stem-bark aqueous extract	(Ojewole, 2003b)
	Stem bark	(Dimo <i>et al.</i> , 2007)
	Methylene chloride/methanol extract	
	stem-bark aqueous extract	(Dieye <i>et al.</i> , 2008)
	stem-bark aqueous extract	(Ojewole, 2004)
	Cold dichloromethane: methanol (1:1) and water extract	(van de Venter <i>et al.</i> , 2008)
	Stem-bark aqueous extract	(Musabayane <i>et al.</i> , 2006)
Antagonistic effect on caffeine-induced calcium	Crude decoction, aqueous, ethanolic and chloroformic extracts	(Belemtougri <i>et al.</i> , 2001)
Anti-plasmodial and anti-malarial activity	Stem bark aqueous and methanol extracts aqueous leaf, stem-bark and fruit extracts	(Gathirwa <i>et al.</i> , 2008) (Nundkumar and Ojewole, 2002)
Antioxidant activity	Leaves methanol extract 50 per cent aqueous methanol of the peel and pulp of the fruits	(Braca <i>et al.</i> , 2003) (Ndhlala <i>et al.</i> , 2006)

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Table 5.1–Contd...

<i>Biological Activities</i>	<i>Plant Part and Extracting Solvent</i>	<i>Authors</i>
	Extracts from kernel oil cake	(Mariod <i>et al.</i> , 2006)
	Methanolic extracts from leaves, roots, barks and kernel oil cake	(Mariod <i>et al.</i> , 2008)
	Methanolic and acetone extract of fruit	(Lamien-Meda <i>et al.</i> , 2008)
	Aqueous methanolic extracts of fruits	(Ndhlala <i>et al.</i> , 2006)
Antibacterial activity	Bark and leaves	(Eloff, 2001)
Antifungal activity		(Masoko <i>et al.</i> , 2008)
	Methanolic extract of leaves and roots	(Hamza <i>et al.</i> , 2006)
Anti-inflammatory properties	Stem bark aqueous and methanol extracts	(Fotio <i>et al.</i> , 2009)
	Stem-bark aqueous and methanolic extracts	(Ojewole, 2003a)
	Stem-bark aqueous extract	(Ojewole, 2004)
Antidiarrheic activity	Lyophilized decoction of bark extract	(Galvez <i>et al.</i> , 1991)
	Procyanidin (Pure compound)	(Galvez <i>et al.</i> , 1993)
Modulation of glomerular filtration rate	Stem-bark ethanolic extract	(Gondwe <i>et al.</i> , 2008)
Modulation of mean arterial blood pressure	Stem-bark ethanolic extract	(Gondwe <i>et al.</i> , 2008)
Molluscicidal activity	Methanolic and water extract	(Kela <i>et al.</i> , 1989)
Analgesic activity	Stem-bark aqueous extract	(Ojewole, 2004)
Antihypertensive	Stem bark aqueous extract	(Ojewole, 2006)
Pesticidal properties		(Fatope <i>et al.</i> , 1993)
Anticonvulsant	Stem-bark aqueous extract	(Ojewole, 2007)
Antispasmodic	Lyophilized decoction of leaves extract	(Belemtougri <i>et al.</i> , 2007)
Hepatoprotective	Aqueous stem bark extract	(Garba <i>et al.</i> , 2006)
Trypanocidal effect	Methanolic extract of leaves	Mikail, 2009
Antiamoebic activity	Ethanol and water extracts of plants	(Fennell <i>et al.</i> , 2004)

Antioxidant Activity

Research has pointed out that the most effective method to reduce stress is antioxidant supplementation. When added to foods, antioxidants minimise rancidity, retard the formation of toxic oxidation products, maintain nutritional quality, and increase shelf life (Jadhav *et al.*, 1996). The methanolic extracts from *Sclerocarya birrea* leaves, roots, barks, and kernel oil cake were examined for radical scavenging capacities and antioxidant activities. The extracts showed high total phenolic compounds and they were markedly effective in inhibiting the oxidation of linoleic acid and subsequent bleaching of β -carotene in comparison with the control. Based on that, the seedcake extract is the most effective followed by root, leaves and bark

extract. The antioxidant activity determined by the DPPH (1,1-diphenyl-2-picrylhydrazyl) method revealed that the seedcake extract had the highest antioxidant activity (Mariod *et al.*, 2008). *Sclerocarya birrea* juice was found to be a potent antioxidant, its effects were attributed to high contents of flavonoids, the polyphenolic compounds that, besides having high antioxidant and free radical scavenging activities, appear to regulate signalling pathways involved in cellular survival, growth, and differentiation (Borochoy-Neori *et al.*, 2008). Thus, diets with a high content of such phenolic-rich antioxidants emerge as a promising approach to help strengthen the physiological antioxidant defence system and to improve chronic diseases. The marula fruit juice, with its high antioxidative capacity, is a potential candidate for this approach.

Antidiabetic Activity

Sclerocarya birrea is most widely studied with regard to its antidiabetic effect and the plant has shown hypoglycemic activity in normal and hypoglycemic animals and cultured cells (Braca *et al.*, 2003; Dieye *et al.*, 2008; Dimo *et al.*, 2007; Gondwe *et al.*, 2008; Laurens *et al.*, 1984; Musabayane *et al.*, 2006; Ojewole, 2003b; Ojewole, 2004; van de Venter *et al.*, 2008). Available evidence suggests that *Sclerocarya birrea* stem-bark extract which possesses hypoglycaemic activity may be useful in the treatment and management of diabetes mellitus (Musabayane *et al.*, 2006). *Sclerocarya birrea* was evaluated among 11 plants traditionally used in South Africa for the treatment of Type II diabetes (van de Venter *et al.*, 2008) using *in vitro* models. The aqueous and organic (dichloromethane:methanol, 1:1) extracts of different parts of this plants (stem, bark and roots) were tested against Chang liver, 3T3-L1 adipose and C2C12 muscle cells measuring glucose utilization in all three cell lines and toxicity in the hepatocytes and adipocytes only. The results of van de Venter (2008) showed that the organic bark extract caused a marked increase in glucose utilization in Chang liver cells and in C2C12 muscle cells, suggesting a different mechanism to that proposed by (Dimo *et al.*, 2007), which indicated that *Sclerocarya birrea* treatment may improve glucose homeostasis in streptozotocin-induced diabetes which could be associated with stimulation of insulin secretion. Whereby, that *in vivo* study of Dimo and his colleagues in Cameroon revealed the stem bark methanol/methylene chloride extract of *Sclerocarya birrea* exhibited a significant reduction in blood glucose and increased plasma insulin levels in diabetic rats. The extract also prevented body weight loss in diabetic rats. The effective dose of the plant extract (300 mg/kg) tended to reduce plasma cholesterol, triglyceride and urea levels toward the normal levels. Four days after diabetes induction, an oral glucose tolerance test was also performed in experimental diabetic rats. The results showed a significant improvement in glucose tolerance in rats treated with *Sclerocarya birrea* extract.

Complications are frequently encountered in diabetes and these are associated with irreversible functional and structural changes in various organs particularly the kidneys, eyes, nerves, heart and blood vessels (Grover and Yadav, 2004). Cardioprotective role of *Sclerocarya birrea* in the management of diabetes mellitus was studied (Musabayane *et al.*, 2006) in normoglycaemic and streptozotocin-(STZ)-treated diabetic rats. *Sclerocarya birrea* dose-dependently decreased blood glucose within the first 30 minutes in non-diabetic and STZ-diabetic rats. The extract caused significant

reduction in blood pressure in anaesthetized and conscious normal and diabetic rats. The plant also produced concentration-dependent, significant negative inotropic and chronotropic effects on guinea-pig isolated, electrically-driven left-, and spontaneously-beating right-, atrial muscle preparations, respectively (Musabayane *et al.*, 2006).

Stem-bark aqueous extract of *Sclerocarya birrea* was investigated in normal (normoglycemic) and in streptozotocin (STZ)-treated, diabetic fasted Wistar rats (Ojewole, 2003b). Graded doses of (100-800 mg/kg p.o.) relatively moderate to high doses of *Sclerocarya birrea* produced dose-dependent, significant reductions in the blood glucose concentrations of both fasted normal and fasted diabetic rats. Single dose of the plant aqueous extract (800 mg/kg p.o.) significantly reduced the blood glucose levels of both normoglycemic and STZ-treated, diabetic rats. The hypoglycemic effect of this plant was comparable with that of chlorpropamide, the standard antidiabetic drug. Similar group in 2004 studied also the stem-bark aqueous extract for its antidiabetic effect on rats (Ojewole, 2004).

Diabetic patients are 17 times more prone to kidney disease and diabetes is now the leading cause of end stage renal and cardiac disease (Grover *et al.*, 2004). *Sclerocarya birrea* stem-bark ethanolic extract was found by Gondwe and his group to modulate blood glucose, glomerular filtration rate (GFR) and mean arterial blood pressure (MAP) of STZ-induced diabetic rats (Gondwe *et al.*, 2008). *Sclerocarya birrea* extract (60, 120 and 240 m/gkg) exhibited dose-dependent reduction in blood glucose concentration in fasted normal and diabetic rats. The extract did not affect plasma insulin secretion in non-diabetic rats. The hypoglycemic effect of *Sclerocarya birrea* was also observed to be associated with increased hepatic glycogen synthesis. This study confirmed that acute administration of *Sclerocarya birrea* did not significantly alter kidney function, but chronically led to decreased plasma urea and creatinine concentrations of STZ-diabetic rats with concomitant increase in glomerular filtration rate. The extract also reduced blood pressure in all groups of animals. The authors speculated that this improvement could be associated with stimulation of insulin secretion, reno- and cardio-protective effects in diabetes mellitus (Gondwe *et al.*, 2008).

Anti-inflammatory and Analgesic Properties

Sclerocarya birrea is used in folk medicine for the treatment of inflammatory disorders. In order to justify this traditional uses of the plant, some studies have performed (Fotio *et al.*, 2009; Ojewole, 2003a; Ojewole, 2004). Ojewole (2003a) evaluated the anti-inflammatory effect of stem-bark aqueous and methanolic extracts of *Sclerocarya birrea* in rats paw oedema as experimental animal model for inflammatory disorders. Both the aqueous and methanolic extracts (500 mg/kg p.o.) progressively and time-dependently reduced rat paw oedema induced by subplantar injections of fresh egg albumin. However, the methanolic extract of the plant produced relatively greater and more pronounced anti-inflammatory effect than its aqueous extract counterpart. Moreover, Ojewole (2004) has also investigated the analgesic effect of the stem-bark aqueous extract in mice, while he investigated the anti-inflammatory in rats. The aqueous extract (100-800 mg/kg p.o.) produced dose-dependent protection against electrical heat-induced pain. The plant extract (25-800 mg/kg p. o.) also

produced dose- and time-related and sustained reductions ($p < 0.05-0.001$) in the fresh egg albumin-induced acute inflammation of the rat hind paw oedema (Ojewole, 2004). However, author did not show any mechanistic study on how the plant extract has shown these remarkable anti-inflammatory and analgesic properties.

The effect of the stem bark aqueous and methanol extracts of *Sclerocarya birrea* (150 or 300 mg/kg) was studied on *in vivo* model. Carrageenan-, histamine- or serotonin-induced paw oedema in rats was used (Fotio *et al.*, 2009). The methanol extract of *Sclerocarya birrea* exhibited a maximum inhibition on both carrageenan- and histamine-induced inflammation. When administered at 300 mg/kg, the methanol extract of *Sclerocarya birrea* also exhibited time and dose dependent inhibition in formalin- or complete Freund's adjuvant-induced paw oedema in rats. Authors suggest that the anti-inflammatory activity of the aqueous and methanol extracts of *Sclerocarya birrea* is due to the inhibition of histamine and prostaglandin pathways and to its antioxidant activity as they measured the glutathione and malondehayde level in rats.

Antiparasitic and Antimicrobial Activities

In Africa, folk medicine in the form of herbal treatment has a long tradition and still holds a strong position in medical and veterinary care (Feierman, 1981), however, several studies have shown the usability of medicinal plants in the treatment of trypanosomiasis, which causes economical and epidemiological hazards (Jensen *et al.*, 2008; Mikail, 2009). Moreover, several reports on the evaluation of different chemicals/ drugs for trypanocidal activity have appeared (Bodley *et al.*, 1995) just as interesting reports on the antitrypanosomal effects of plant extracts and plant derivatives. The methanolic extract of *Sclerocarya birrea* showed complete mortality of *Trypanosoma brucei brucei in vitro* (Mikail, 2009). Although complete mortality of the organism was observed but these studies did not provide neither mechanism by which this extract exhibit nor the responsible pure compound (Bodley *et al.*, 1995; Mikail, 2009). Ethanol and water extracts of marula, which used by South African traditionally to treat dysentery, were also showed antiamoebic activity when tested using the microtitre plate and *Entamoeba histolytica* (Fennell *et al.*, 2004).

Malaria remains a major public health problem in Africa, and is responsible for the death of over 1 million annually. Drug resistance has been implicated in the enhanced mortality, and is a factor in the economic constraints of malaria control (Gathirwa *et al.*, 2008). Based on data obtained through interview in Kenya it was revealed the use of *Sclerocarya birrea* as one of the traditional treatment for Malaria. *Sclerocarya birrea* was tested for *in vitro* anti-plasmodial and *in vivo* anti-malarial activity against *Plasmodium falciparum* and *Plasmodium berghei*, respectively. *P. falciparum* was more sensitive to the plant extracts than *P. berghei*. *Sclerocarya birrea* methanol extract being more active than aqueous one (Gathirwa *et al.*, 2008).

In Tanzania, *Sclerocarya birrea* reported to be used by traditional healers for the treatment of oral candidiasis and fungal infections of the skin. In the laboratory of Hamza (2006), the plant roots methanolic extract was screened against *Candida albicans*, *Candida glabrata*, *Candida tropicalis*, *Candida parapsilosis*, *Candida krusei* and *Cryptococcus neoformans* using the broth microdilution method. Strong antifungal

activity was exhibited by *Sclerocarya birrea* for all tested microbes except for *C. glabrata*. The most susceptible yeasts were *C. krusei* and *C. tropicalis*. The least susceptible were *C. albicans* and *C. neoformans*. In a different study, *Sclerocarya birrea* bark extract was investigated against three dermatopathogenic yeasts; *Candida parapsilosis*, *Cryptococcus albidus* and *Rhodoturula mucilaginosa*. However, authors in this study used several polar and non-polar solvents such hexane, dichloromethane, chloroform, ethyl acetate, acetone, methanol and ethanol. All tested organisms were resistant against all non-polar extracts. Acetone, ethanol and methanol *S. birrea* extracts have shown antifungal activity with all tested yeasts while *C. albidus* was the most sensitive organism (Masoko *et al.*, 2008).

A study was undertaken to investigate the ethnobotanical use of *Sclerocarya birrea* as antibacterial agent in South Africa (Eloff, 2001). Microplate serial dilution technique with *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Enterococcus faecalis* as test organisms were used to assess the acetone extract of the bark and leaves. All extracts were active and inner bark extracts tended to be the most potent followed by outer bark and leaf extracts. It is of great significance that those living in tropical countries be encouraged to consume plant as it protects against organisms that cause diseases prevalent in these areas.

Gastro-intestinal and Antihypertensive Activities

Sclerocarya birrea is one of plant species used widely in traditional medicine in Africa against many diseases and affections such as hypertension, dysentery, stomach-ache or gastro-enteritis (Belemtougri *et al.*, 2001). Some studies have been carried out on the effect of this plant on body smooth and skeletal muscles (Belemtougri *et al.*, 2001, 2007; Galvez *et al.*, 1991, 1992, 1993; Garba *et al.*, 2006; Gondwe *et al.*, 2008; Musabayane *et al.*, 2006; Ojewole, 2006, 2007). In this the lyophilized decoction of this plant demonstrated antidiarrhoeic activity in experimental models of diarrhoea induced by magnesium sulphate and sodium picosulphate (Galvez *et al.*, 1991). The authors speculated that this antidiarrhoeic activity was related to an inhibition of intestinal transit rather than to inhibition of net secretion of fluid and electrolytes provoked by the laxative agents. A condensed tannin was isolated from the crude drug which produced inhibition in intestinal motility, and the monomer of which was identified as procyanidin (Galvez *et al.*, 1991). In this respect, procyanidin was investigated by Galvez (1993) also using four models of experimentally induced diarrhoea in rats. At doses of 150 mg/kg, the procyanidin showed antidiarrhoeal activity in all the models of experimentally induced diarrhoea. The procyanidin (2.5 µg/mL-0.64 mg/mL) dose-dependently inhibited the phasic contractions of the isolated guinea-pig ileum spontaneous activity. This antidiarrheal effect can be related to an interference with the subsequent events evoked after muscarinic stimulation. On the other hand, the antispasmodic effect of *Sclerocarya birrea* extract was studied on isolated rat duodenum whereby, the extract has exhibited an inhibitory effect on the dose-response curves induced by acetylcholine (Ach) on rat duodenum and reduced the maximal response of Ach in a concentration-dependent manner (Belemtougri *et al.*, 2007). On the other hand, (-)-epicatechin-3-galloyl ester which was isolated from the bark of *Sclerocarya birrea* has shown secretagogue activity (Galvez *et al.*, 1992).

A study done by Garba and his group demonstrated that the aqueous extract of the stem bark of *Sclerocarya birrea* extract possess possible hepatoprotective activity investigated against alcohol-carbon tetrachloride induced hepatocellular injury in rats (Garba *et al.*, 2006). In addition to the pharmacological effects of *Sclerocarya birrea* on gastrointestinal muscles and liver, its effect on cardiac and skeletal muscles was also studied based on the popular traditional usages of this plant in Africa. In a study conducted in Burkina Faso (Belemtougri *et al.*, 2001), the effects of leaf extracts (crude decoction, aqueous, ethanolic and chloroformic extracts) were investigated on calcium signalling in rat cultured skeletal muscle cells and showed antagonistic effect on caffeine-induced calcium release from sarcoplasmic reticulum. Crude decoction is the most active followed by ethanolic, aqueous and chloroformic extracts in dose-dependent manner (Belemtougri *et al.*, 2001).

Effects of *Sclerocarya birrea* on mean arterial blood pressure were studied in anesthetized rats challenged with hypotonic saline. In such study, the ethanolic extract of this plant exhibited dose-dependent reduction in blood glucose concentration and reduced blood pressure in all groups of animals. This suggests that the hypotensive effect of the extract is mediated in part through influences on components of the cardiovascular system (Gondwe *et al.*, 2008). Evidence indicates that the hypotensive effects of this plant may be due to the reduction of endothelium-synthesized nitric oxide concentration (Ojewole, 2006). This was concluded when the stem bark aqueous extract was tested for its vasorelaxant and hypotensive effects in rat isolated aortic rings and anaesthetised normotensive and hypertensive Dahl salt-sensitive rats.

Miscellaneous Activities

Sclerocarya birrea is traditionally used in South African for the treatment, management and control of childhood convulsions and epilepsy. The anticonvulsant activity of stem-bark aqueous extract against pentylenetetrazole-, picrotoxin-, and bicuculline-induced seizures in mice. Phenobarbital and diazepam were used as reference anticonvulsant drugs for comparison. Like the reference anticonvulsant agents used, *Sclerocarya birrea* delayed the onset of, and inhibited mice experimentally induced seizures (Ojewole, 2007). Three-week administration of the *Sclerocarya birrea* juice as a food supplement to healthy subjects significantly reduced their serum total cholesterol (by 8 per cent), LDL-cholesterol concentration (by 17 per cent), and triglyceride level (by 7 per cent), increased their serum HDL-cholesterol level (by 10 per cent), and attenuated serum oxidative stress, which collectively suggest the use of this plant as protection against atherosclerosis risk factors (Borochoy-Neori *et al.*, 2008).

Toxicity

The successful toxicological studies of *Sclerocarya birrea* despite its positive effects on in vitro and in vivo models (Musabayane *et al.*, 2006; van de Venter *et al.*, 2008); made some authors to withdraw attention on concerning the medicinal uses of the plant as antidiabetic (Ojewole, 2003b; van de Venter *et al.*, 2008). However, methanolic and aqueous bark extracts of *Sclerocarya birrea* had high LD50 values in mice (median LD50 value 1215±38 mg/kg), suggesting no acute toxicity (Ojewole, 2003). Moreover,

Ojewole (2003b) stated that some chemical constituents previously identified in bark extracts could be potentially toxic to mammals and this potential harmful effect was further mentioned when the plant extract showed unfavorable *in vitro* effect on cultured hepatocytes and adipocytes (van de Venter *et al.*, 2008). The differences in activity of the different parts of the plant are noteworthy, with the organic stem extract being the most active and at the same time it appeared to be non-toxic. The plant leaf aqueous extract showed toxicological effects on mice in dose dependent manner and showed no lethal effect up to 700 mg/kg i.p. with LD50 of 850 mg/kg (Belemtougri *et al.*, 2007). Moreover, the plant showed genotoxicity in the micronucleus test, in the form of structural and numerical chromosome aberrations on cultured human white blood cells (Fennell *et al.*, 2004).

Ethnomedicinal and Ethnonutritional Uses

In some African countries, the stem-bark, roots and leaves of *Sclerocarya birrea* are used for an array of human ailments, including: malaria and fevers, diarrhoea and dysentery, stomach ailments, headaches, sore eyes, toothache, backache and body pains, infertility, schistosomiasis, constipation, abdominal cramps and some other unspecified gastro-intestinal problems, toothaches and swollen or infected gums, cough, hypertension, arthritis, proctitis, epilepsy, diabetes mellitus, sores, boils, carbuncles, abscesses and certain other bacterial infections, etc. (Ojewole, 2003a, 2003b; Van Wyk *et al.*, 1997; Watt and BreyerBrandwijk, 1962). The Tonga people of South Africa celebrate the feast of the first fruits by pouring its fresh juices of their chief's graves (Eloff, 2001; Holtzhausen *et al.*, 1989). The pulp of the fruit is delicious and the large nut is also edible. Some South African tribes such as the Pedi make a relish from the leaves (Eloff, 2001). The Zulu people use bark decoctions administered as enemas for diarrhoea. Traditional Zulu healers wash in bark decoctions before treating patients with gangrenous rectitis (Watt *et al.*, 1962). In East Africa, roots are an ingredient in an alcoholic medicine taken to treat an internal ailment known as kati while bark is used for stomach disorders (Kokwaro, 1976). The Hausas in West Africa use a cold infusion of the bark along with native natron as a remedy for dysentery (Eloff, 2001). The tree is used in folk Malian medicine for the cure of several animal and human diseases. The leaves and the pulp of fruit are used for hypertension, and the leaves are used against diabetes, dysentery, snake and scorpion bites, malaria, and inflammations. Further on, the plant is also utilized as a tonic, and the fruits are often fermented to give a refreshing drink. In Ghana, the leaves are used to treat snakebite, and pruritus (filarial); the stem bark, the root and the fruits are used to treat pharyngitis, splenomegaly and goitre, respectively (Dimo *et al.*, 2007). Information provided by practitioners of traditional medicine in North Cameroon suggest that *Sclerocarya birrea* possesses useful antidiabetic properties (Dimo *et al.*, 2007).

The outer skin of *Sclerocarya birrea* fruit has a rather pungent, apple-like odor, and its flavor has been described as resembling some other fruits. It makes an excellent conserve. In Mozambique, the fruit is used for making a "national" fermented beverage. The nut has a very thick shell, containing a kernel. The kernel is edible and very tasty, especially when cooked. Its flavour resembles that of the groundnut. The fruit pulp contains citric and malic acids, vitamin C and sugar, while the nut is rich in non-

drying oil, protein and some iodine. The gum from the tree is rich in tannin, and is sometimes used in making an ink substitute. In Zimbabwe and South Africa, the wood of *Sclerocarya birrea* is used for making dishes, mealie stamping mortars, drums, toys, curios, divining bowls and carvings (Watt *et al.*, 1962).

Conclusions

Sclerocarya birrea has been part of a supplemental diet in many African countries and its leaves, fruits, and kernels consumption is becoming increasingly popular with less information on the phytochemicals in this tree. These phytochemicals has significant effects on multiple biological systems, and were used in nutraceutical and functional foods. Crude fixed seed oil is a valuable source of essential fatty acids, tocopherols, phytosterols and phospholipids. The high levels of those bioactive lipids are of importance in nutritional applications. On the contrary, different parts from *Sclerocarya birrea* has significant effects on multiple biological systems. The pharmacological activities are attributed to the presence of different active component.

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