Available online at www.sciencedirect.com
SciVerse ScienceDirect
South African Journal of Botany 77 (2011) 908–919
SOUTH AFRICAN JOURNAL OF BOTANY
www.elsevier.com/locate/sajb

An updated review of *Adansonia digitata*: A commercially important African tree

G.P.P. Kamatou, I. Vermaak, A.M. Viljoen *

Department of Pharmaceutical Sciences, Faculty of Science, Tshwane University of Technology, Private Bag X680, Pretoria 0001, South Africa

Abstract

Adansonia digitata L. (Malvaceae) is a majestic tree revered in Africa for its medicinal and nutritional value. The plant parts are used to treat various ailments such as diarrhoea, malaria and microbial infections. It is reported that it is an excellent anti-oxidant due to the vitamin C content which is seven to ten times higher than the vitamin C content of oranges. Baobab has numerous biological properties including antimicrobial, antiviral, anti-oxidant and anti-inflammatory activities amongst others. Phytochemical investigation revealed the presence of flavonoids, phytosterols, amino acids, fatty acids, vitamins and minerals. The seeds are a source of significant quantities of lysine, thiamine, calcium and iron. Baobab is an important commodity which is integral to the livelihood of rural communities. In addition, the global demand for baobab raw material (*e.g.* seed oil, fruit pulp) by the food and beverage, nutraceutical and cosmetic industries has increased dramatically in recent years thereby increasing the commercial value and importance of this coveted African tree. In the past few years, there has been an increased demand for non-timber forest products (NTFPs), specifically baobab seed oil for inclusion in cosmetic formulations due to its high fatty acid composition. This review summarises the botanical aspects, ethnobotany, phytochemistry, biological properties and most importantly the nutritional value and commercial importance of baobab products.

Keywords: Adansonia digitata; Baobab; Biological activity; Commercialisation; Ethnobotany; Nutrition; Phytochemistry

1. Introduction

Baobab (*Adansonia digitata* L.) is a large iconic tree (Fig. 1B) indigenous to Africa where it is found in many countries. It is an emblematic, culturally important and physically majestic sub-tropical tree. The baobab has been referred to as "arbre a palabre", meaning the place in the village where the elders meet to resolve problems. In the past decade, it has attracted the interest of several pharmaceutical companies and researchers due to its various traditional uses (medicinal, nutritional and cosmetic). Recently, the European Commission authorised the import of baobab fruit pulp as a novel food (Buchmann et al., 2010) and it was approved in 2009 by the Food and Drug Administration as a food ingredient in the United States of America (Addy, 2009). Due to the high demand for commercial baobab products in EU and United States, this tree with its edible fruits needs to be conserved and treasured (Sanchez et al., 2010).

Baobab products (*e.g.* fruits, seeds, leaves, bark) contribute to the livelihood of many populations in Africa as it is a source of food, fibre and medicine (Wickens, 1982; Codjia et al., 2001; Sidibe and Williams, 2002; Chadare et al., 2009; De Caluwé et al., 2009). More than three hundred traditional uses have collectively been documented in Benin, Mali, Zimbabwe, Cameroon, the Central African Republic, Kenya, Malawi, South Africa and Senegal (Buchmann et al., 2010). Various plant parts (*e.g.* leaves, bark, fruit pulp), have traditionally been used for immuno-stimulant, anti-inflammatory, analgesic, insect repellent and pesticidal properties, in the treatment of diarrhoea and dysentery in many African countries, and have been evaluated as a substitute for imported western drugs (El-Rawy et al., 1997; Ramadan et al., 1994). Some of the traditional

* Corresponding author. Tel.: +27 12 3826360; fax: +27 12 3826243.
E-mail address: viljoenam@tut.ac.za (A.M. Viljoen).

0254-6299/$ - see front matter © 2011 SAAB. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.sajb.2011.08.010

Fig. 1. (A) A woman gatherer displaying *Adansonia digitata* fruits; (B) The *Adansonia digitata* tree; (C) *Adansonia digitata* fruit and seeds. Photographs courtesy of PhytoTrade Africa.

medicinal uses of baobab are presented in Table 1. Baobab products (*e.g.* seed oil, fruit pulp) are increasingly being commercialised and exported around the world leading to increased pressure on this resource (Sidibe and Williams, 2002). In this review, available data on the nutritional value, phytochemistry, biological activities of different plant parts (*e.g.* fruit pulp, seed oil), plant biology, ethnobotany as well as commercial aspects of baobab are presented.

2. Botanical aspects

2.1. Origin of the name of the plant

The origin of the vernacular name "baobab" is uncertain. However, most scientists believe it is derived from the Arabic name *buhibab* meaning fruit with many seeds (Diop et al., 2005). The genus name *Adansonia* is used in honour of Michel Adanson (1727–1806) who brought seeds to Paris in 1754 and who was the first person to provide a comprehensive description accompanied by a drawing of the plant (Esterhuyse et al., 2001) after a trip to West Africa (Senegal). The species name *digitata* (hand-like) was selected in reference to the shape of the leaves. Several names are used to describe the baobab depending on its geographical location and include "magic tree", "chemist tree", "symbol of the earth", "upside-down tree" and "monkey bread of Africa" amongst numerous others (Wickens, 1982; Diop et al., 2005; Vermaak et al., 2011).

2.2. Botanical description, habitat and distribution in Africa

The baobab is found in many African countries. Eight baobab species have been identified globally and six species found on the island of Madagascar are endemic to that region (Wickens and Lowe, 2008). It is postulated that the centre of evolutionary origin of the genus *Adansonia* is Madagascar (Drake, 2006). The African species *A. digitata* is indigenous to, and widely distributed throughout the savannas and savanna woodlands of sub-Saharan Africa (Wickens and Lowe, 2008). The only species which is not endemic to the African continent is *A. gibbosa* (A.Cunn.) Guymer ex D.A.Baum native to Australia (Drake, 2006; Wickens and Lowe, 2008). In southern Africa, *A. digitata* is commonly found in Malawi, Zimbabwe, Mozambique and South Africa especially in the warm parts of the Limpopo Province, while in West Africa, it is found in Mali, Benin, Senegal, the Ivory Coast, Cameroon and Burkina Faso. In East Africa, the plant is found in countries such as Kenya, Uganda and Tanzania (Watt and Breyer-Brandwijk, 1962; Adesanya et al., 1988; UNCTAD, 2005; Lamien-Meda et al., 2008).

The baobab is a massive deciduous tree easily distinguishable by its huge trunk. It is regarded as the largest succulent

Table 1
Selected traditional medicinal uses of the *A. digitata* tree in Africa.

Therapeutic uses	Plant part used	Country	Preparation	Reference
Fever, diarrhoea	Seeds	South Africa	Mixed with water	Watt and Breyer-Brandwijk (1962)
Dysentery, fever	Seeds, fruits	Cameroon, Central African Republic	Decoction	Watt and Breyer-Brandwijk (1962)
Malaria, fever	Leaves	Sierra Leone	–	Watt and Breyer-Brandwijk (1962)
Coughs	Powdered seeds	South Africa	–	Watt and Breyer-Brandwijk (1962)
Diarrhoea, fever, inflammation, kidney and bladder diseases, blood clearing, asthma	Leaves	South Africa	Infusion	Van Wyk and Gericke (2000)
Fever, dysentery	Leaves, roots	Sudan	–	Gebauer et al. (2002)
Anaemia	Bark	Nigeria	Aqueous extract	Adesanya et al. (1988)
Malaria	Bark, leaves	Nigeria	Powdered bark mixed with porridge	Ajaiyeoba et al. (2004)
Diarrhoea, fever, inflammation, kidney and bladder diseases, blood clearing, asthma	Leaves	Tanzania	Decoction, infusion	Brendler et al. (2003)
Dysentery, fever, haemoptysis, diarrhoea	Fruits, seeds	Tanzania	Decoction	FAO (1993)
Refreshing, tonic, diuretic, cystitis, dysentery, hepatic disorders, hypogalactia	Flesh with peel	Burkina Faso	Decoction	Kerharo and Adam (1974); Nacoulma (1999)
Toothache, gingivitis	Leaves	Burkina Faso	–	Tapsoba and Deschamps (2006)
Diarrhoea, worms	Leaves, seeds, fruit pulp	Côte d'Ivoire	–	Aké Assi (1992)
Wound healing	Stem bark	Mali	Decoction	Inngjerdingen et al. (2004)
Diaphoretic, fever remedy	Leaves	Kenya	Decoction	Abbiw (1990)
Diaphoretic, kidney and bladder diseases, asthma, insect bites	Leaves	–	–	Wickens (1982)
Microbial diseases	Fruits	Nigeria and Senegal	–	Hostettmann et al. (2000)

plant in the world with a diameter of 10–12 m and a height of 23 m or more (Wickens, 1982; Chadare et al., 2009). Some baobab trees bear leaves only for three months per year. During the leafless period physiological processes such as photosynthesis take place in the trunk and branches, utilising water stored in the trunk (Gebauer et al., 2002). The large egg-shaped fruit capsule is covered with velvety hairs, can reach 12 cm and contains many seeds (Fig. 1C) (Wickens, 1982). It is estimated that it takes between eight and twenty-three years before the baobab produces seeds and the mature plant (over 60 years) can produce more than 160–250 fruits per year (UNCTAD, 2005). The baobab produces large pendulous white flowers from October to December (Watson, 2007). Assogbadjo et al. (2005) showed correlation between soil minerals and/or soil type and fruit production. For instance, the higher the pH–KCl, the percentage of total nitrogen, organic carbon and organic matter, the higher the number of seeds produced by an individual baobab. It was also noted that the higher the clay and crude silt content of the soil, the better the fruit production.

Baobab is restricted to hot, semi-arid regions, dry woodland and stony places with low rainfall (less than 1500 mm annually) (Gebauer et al., 2002) and grows on a wide range of well-drained soils, from clays to sands, but not on deep unconsolidated sands, where it is unable to obtain sufficient moisture or anchorage (Wickens and Lowe, 2008). In Africa, the plant grows at a latitude of 16° N and 26° S in areas not receiving more than one day of frost per year. The tree grows very slowly probably due to low amount of rainfall received (Venter and Venter, 1996).

2.3. Pollination, dispersion and cultivation

The white flowers are pollinated by fruit bats that feed on the nectar at night (Fujita, 1991; Watson, 2007). *A. digitata* is widely spread over the African savanna through natural reproduction (seeds). Many animals will eat the fruit contents once the outer shell has withered and broken, and may at the same occasion assist in seed dispersal (Wickens and Lowe, 2008). Dormancy is broken when the seeds pass through the digestive tract of animals consuming the fruit. Esenowo (1991) found that the most effective method to break the dormancy was scarification, and cultivation requires that the seeds be treated before sowing. The seeds generally take three to five weeks to germinate (Diop et al., 2005), while plants grown from seed start flowering after eight to twenty-three years. The flowering period of baobab which is very long can be reduced to less than five years by grafting (Sidibe and Williams, 2002). Young trees grafted from elite trees with desirable characteristics develop faster than trees grown from seed. Therefore, good possibilities for future vegetative cultivation and commercialisation of baobab products can be expected. The probability of seed germination of baobab is very low (10%) and studies have shown that the probability of germination will increase up to 85% if the seeds are soaked before sowing (Diop et al., 2005). In Burkina Faso, people have started planting baobab trees (Ouedraogo, 2004).

In the past few years, consumer products derived from the seed oil and fruit pulp have been exported to European and

USA markets and the demand for these products are increasing (UNCTAD, 2005). An increased demand can lead to overexploitation of the plant therefore it is important to determine the factors that could lead to the successful cultivation of this commercially important tree. Ecological niche modelling studies were undertaken to determine factors that are crucial to the cultivation of baobab and results indicated that annual precipitation and seasonal temperature fluctuations were two key factors (Sanchez et al., 2010). The results of the ecological modelling also predict that baobab could be widely cultivated in most countries in southern Africa and in the Sudano-Sahelian zone of West Africa from Senegal to Sudan (Sanchez et al., 2010). Furthermore, the modelling prediction showed that Angola and Somalia are highly suited for cultivating baobab in Africa, while India was determined to be the most suitable country for baobab cultivation outside Africa (Sanchez et al., 2010). However, many other factors such as pollinator agents, radiant energy, soil aeration and structure, soil reaction, biotic factors (allelopathy, heavier fertilisation), mineral nutrient supply and pollination agents should be incorporated in the model in order to determine more accurately the potential area of baobab cultivation.

Assogbadjo et al. (2008) investigated the perception and preferences of baobab products in Benin, Burkina Faso, Ghana, and Senegal and the survey included women and men of different ages. According to this study, the easier the bark harvesting, the tastier the pulp and leaves; the slimier the pulp, the less tasty it is; the more closely longitudinally marked the fruit capsules, the tastier the pulp. This study shows that farmers are able to use preferred combinations of traits as a guide in collecting germplasm from trees. The indigenous knowledge can therefore be used to select an appropriate tree candidate for propagation, and planning for a domestication programme.

3. Traditional and modern uses

Throughout Africa the baobab is regarded with awe by most indigenous people; some even consider it bewitched (Wickens and Lowe, 2008). Almost all parts of the tree are used in traditional medicine in Africa although this varies from one country to another. The traditional medicinal uses of baobab in Africa are summarised in Table 1. The various parts of the plant (leaves, bark, seeds) are used as a panacea, that is, to treat almost any disease but specific documented uses include the treatment of malaria, tuberculosis, fever, microbial infections, diarrhoea, anaemia, dysentery, toothache, etc. (Watt and Breyer-Brandwijk, 1962; Adesanya et al., 1988; Abbiw, 1990; Van Wyk and Gericke, 2000; Brendler et al., 2003; Tapsoba and Deschamps, 2006; Wickens and Lowe, 2008; De Caluwé et al., 2009; Nguta et al., 2010). The leaves and fruit pulp are used as febrifuge as well as an immunostimulant (El-Rawy et al., 1997; De Caluwé et al., 2009). In Nigeria, the leaves of baobab are used to overcome fever (Wickens, 1982). In India, it is reported that baobab pulp is used externally with buttermilk for the relief of diarrhoea and dysentery, while the young leaves are crushed and used to treat painful swellings (Sidibe and Williams, 2002). Furthermore, it is reported that the leaves of baobab are used to treat various conditions including internal pains, disease of the urinary tract, otitis, as a tonic and for insect bites and Guinea worms (Sidibe and Williams, 2002). Watt and Breyer-Brandwijk (1962) reported that the leaves of baobab are used against excessive sweating and as astringent. The dried leaves are used in many West African countries as an insect repellent (Denloye et al., 2006). In Ghana, the bark is used as substitute for quinine to relieve fever (Shukla et al., 2001). The oil extracted from the seeds is used against diarrhoea and hiccough (De Caluwé et al., 2009). In Africa, people infected with malaria parasites consume a mash containing dried baobab bark as a febrifuge in order to treat the fever associated with this illness (Wickens and Lowe, 2008). In Mali, it is reported that swollen joints are treated by rubbing a paste made with baobab fruit into the affected area (Wickens and Lowe, 2008).

The baobab is extremely important to humans and animals in the dry areas of Africa because it offers shelter, a source of nutrition, clothing as well as raw material for many useful items. In Benin, the bark has been used for making ropes (De Caluwé et al., 2009). In some villages in West Africa, people store water in the tree trunk and it is estimated more than 120,000 L of water can be stored (Royal Botanic Gardens, Kew, 1999). Baobab is used for several purposes and these include: fruit for food; oil from the seeds; rope, cordage and cloth from the bark fibre; tannin for curing leather from the tree bark; glue from the pollen grain of the flowers; pulp for making paper from the harvested tree (although of low quality), seasoning and as an appetiser (Wickens, 1982; Sidibe and Williams, 2002; Nhukarume et al., 2008). The fresh leaves are cooked as vegetables (Van Wyk et al., 1997). In Madagascar, baobab seeds (including *A. digitata*) have been used for the production of vegetable oil (Bianchini et al., 1982).

In some countries in West Africa, the leaves, fruit pulp and seeds are the main ingredient in sauces, porridges and beverages (Chadare et al., 2009; De Caluwé et al., 2009; Yusha'u et al., 2010). Recently, baobab has been referred to as a "superfruit" based on its nutritional profile (*e.g.* vitamin, fatty acid, mineral) (Gruenwald, 2009). The nutritional value of baobab is only briefly discussed since a comprehensive report on the nutritive aspects is already available (Chadare et al., 2009; De Caluwé et al., 2009). The major interest in baobab products is as a result of its ascorbic acid and dietary fibre content. The level of vitamin C contained in fruit pulp is high and can range from 2.8 to 3 g/kg (Vertuani et al., 2002). It was noted that baobab fruit pulp has a very high vitamin C content (280–300 mg/100 g), which is seven to ten times more than oranges (51 mg/100 g) (Manfredini et al., 2002; Täufel et al., 1993). One study demonstrated that the consumption of 40 g of baobab pulp provides 100% of the recommended daily intake of vitamin C in pregnant women (19–30 years) (Chadare et al., 2009). The ascorbic acid content was evaluated in the fruit of *A. digitata* (Diop et al., 1988) and it was found to contain 337 mg/100 g of ascorbic acid (Eromosele et al., 1991; Gebauer et al., 2002). Sidibe and Williams (2002) recommended that baobab leaves should be stored as whole leaves rather than ground leaf powder in order to preserve the high vitamin content.

The calcium content found in the fruit pulp varies according to authors and the origin of the samples tested. Brady (2011) reported a calcium content of 344.2 mg/100 g sample which differs from the value of 295.0 mg/100 g reported by Osman (2004). Other authors have found different levels of calcium in the fruit (211 to 2160 mg/100 g) (Sena et al., 1998; Lockett et al., 2002). Similarly, the level of potassium in the fruit pulp was found to be 1578.5 mg/100 g sample (Brady, 2011) and 1240.0 mg/100 g (Osman, 2004). The leaves are particularly rich in calcium (307 to 2640 mg/100 g dw), they are known to contain good quality proteins and it is estimated that it contains three to five times more calcium than milk. The seeds have a relatively high lipid content of 11.6 to 33.3 g/100 g dw (Brady, 2011).

Several studies have revealed that baobab is rich in fibre (approximately 44%) which can balance the intestinal flora. However, the fibre content varied considerably between studies which could be due to several factors such as the origin of the plant material and the extraction procedure used. Additional information on the nutritional value of baobab products can be obtained in other works (*e.g.* Nordeide et al., 1996; Barminas et al., 1998; Soloviev et al., 2004; De Caluwé et al., 2009).

Several studies have demonstrated a significant correlation between the intake of fruits and vegetables and the occurrence of inflammation and diseases such as cardiovascular disease and cancer (Aruoma, 1998; Willet, 2001). Natural anti-oxidants, including polyphenolic compounds from plants, vitamins E and C, and carotenoids, are believed to be effective nutrients in the prevention of these oxidative stress-related diseases (Besco et al., 2007).

The oil obtained from seeds is used to treat skin ailments, thus it may have some cosmetic applications (Sidibe and Williams, 2002). Fixed oils are important ingredients in cosmetic products and amongst these is baobab seed oil. It is suitable for use on the skin as it is non-irritating and non-allergenic (Wren and Stucki, 2003). Other properties of pharmaceutical/cosmetic importance include that it is excellent for restoring and remoisturising the skin due to its high penetrability and nourishing properties. It can also be used to treat eczema and psoriasis (PhytoTrade Africa).

Baobab oil or fruit pulp contains several vitamins (Nkafamiya et al., 2007) that are essential for skin care. These include vitamins A and F (rejuvenation and cell renewal); vitamin E (anti-oxidant and anti-ageing effects) (Nyam et al., 2009) and vitamin D3 which increases calcium absorption and decreases blood pressure in the elderly (Wasserman, 2004). The oil is said to alleviate pain from burns and regenerates the epithelial tissues in a short time, thereby improving skin tone and elasticity (Murunga Products).

The oil can be used as a protecting, nourishing, moisturising, soothing and regenerating agent. Studies have also shown that the oil contains anti-oxidants (Nkafamiya et al., 2007), can protect the skin against premature ageing and prevents the appearance of wrinkles (Africajou). Alone or combined with other ingredients, it is also used to aid in skin healing (small cuts, chapping) or as a mask for hair care (dry, brittle hair, split ends) (Africajou). Linoleic acid (found in baobab seed oil) is the most frequently used fatty acid in cosmetic products as it moisturises the skin, aids in the healing process of dermatoses and sunburns and is used for the treatment of *Acne vulgaris* (Lautenschläger, 2003).

4. Phytochemistry

Several classes of compounds have been identified from various parts of baobab (fruit pulp, seed oil, leaves, roots) including terpenoids, flavonoids, sterols, vitamins, amino acids, carbohydrates and lipids (Chauhan et al., 1984; Chauhan et al., 1987; Shukla et al., 2001).

The chemical structures of selected compounds are shown in Fig. 2. Ten aromatic compounds including isopropyl myristate and nonanal were identified in the fruit pulp using GC–MS (Cisse et al., 2009). Several compounds have been isolated from the pericarp using column chromatography and include: (−)-epicatechin, epicatechin-(4β→8)-epicatechin (B2), epicatechin-(4β→6)-epicatechin (B5), epicatechin-(2β→O→7, 4β→8)-epicatechin (A2), and epicatechin-(4β→8)-epicatechin-(4β→8)-epicatechin (C1) (Shahat, 2006). Epicatechin is a flavonol (flavonoid) found in many plants such as grapes, cocoa and tea. This class of compound may prevent coffee berry disease by inhibition of appressorial melanisation. Epicatechin is known to exhibit strong anti-oxidant activity (Lee et al., 2003) and can also promote survival in diabetic mice (Si et al., 2011). Other compounds such as 3,7-dihydroxy-flavan-4-one-5-*O*-β-D-galactopyranosyl (1→4)-β-D-glucapyroside and a flavonone 3,3′,4′-trihydroxy flavan-4-one-7-*O*-α-L-rhamnopyranoside and quercetin-7-*O*-β-D-xylopyranoside were isolated from the roots of *A. digitata* (Chauhan et al., 1984; Chauhan et al., 1987; Shukla et al., 2001).

Compounds such as campesterol, cholesterol, isofucosterol, β-sitosterol, stigmasterol and tocopherol (α, β, γ, and δ) have been detected in the seed oil. Bianchini et al. (1982) investigated the lipid composition of the seed oil using GC–MS. The major hydrocarbons in the seed oil were *n*-alkanes (57.3%) and squalene (39.5%). Fatty acids present in the seed oil include linoleic and oleic acids in high concentration as well as lesser amounts of palmitic, linolenic, stearic and arachidic acids (Yazzie et al., 1994; Glew et al., 1997; Codjia et al., 2001; Sidibe and Williams, 2002; Osman, 2004; Nkafamiya et al., 2007).

The presence of organic acids such as citric, tartaric, malic, succinic and ascorbic acid in the fruit pulp was first highlighted in the early fifties. The pulp represents 14 to 28% of the total fruit weight and the pulp water content is low (less than 15%) (Soloviev et al., 2004). Studies have shown that the fruit pulp contains high amounts of carbohydrate (≈70%), crude fibre (≈11.2%), a low amount of ash (≈5.7%) and protein (≈2.2%), and a very low amount of fat (≈0.4%) (Lockett et al., 2002). Several amino acids such as alanine, arginine, glycine, lysine, methionine, proline, serine, valine (from fruit pulp) (Glew et al., 1997), vitamins (B1, B2, B3, A, C) (from fruit pulp and/or leaves) (Sidibe et al., 1996; UNCTAD, 2005) and minerals (Cu, Fe, K, Mg, Mn, Na, P, Zn) (from fruit pulp) (Glew et al., 1997) have also been identified.

5. Biological activity

5.1. Analgesic and antipyretic activities

The analgesic effect of the fruit of *A. digitata* extracted with hot water was tested *in vivo* (mice). It was noted that the extract exhibited analgesic activity 2 h after administration. At 800 mg/kg, the reaction time was 15.4 min in comparison to the negative control (10.2 min) (Ramadan et al., 1994). The petroleum ether extract containing seed oil of *A. digitata* was investigated for analgesic activity. The extract exhibited analgesic activity with the tail flick response in 6.1 s which was not statistically different from aspirin used as positive control (Khan et al., 2006). The antipyretic activity of *A. digitata* extract was evaluated on twenty rats. Hyperthermia was induced by subcutaneous injection of a 12% yeast suspension and the temperature of each rat was monitored. After a 4 h treatment period, at a concentration of 800 mg/kg, the rectal temperature of the rats showed a slight decrease (37.3 °C) in comparison to the initial temperature of 38.6 °C, suggesting that baobab extract exhibited antipyretic activity (Ramadan et al., 1994). A clinical investigation was conducted to compare the efficacy of a baobab fruit solution to the WHO standard solution in the treatment of children (161 children, 6 months old) with acute diarrhoea. The results demonstrated that the WHO solution was superior to the solution made from *A. digitata* in terms of duration of diarrhoea, weight gain and rehydration. However, the difference was not statistically significant suggesting that the baobab solution could be used as treatment in children with acute diarrhoea (Tal-Dia et al., 1997).

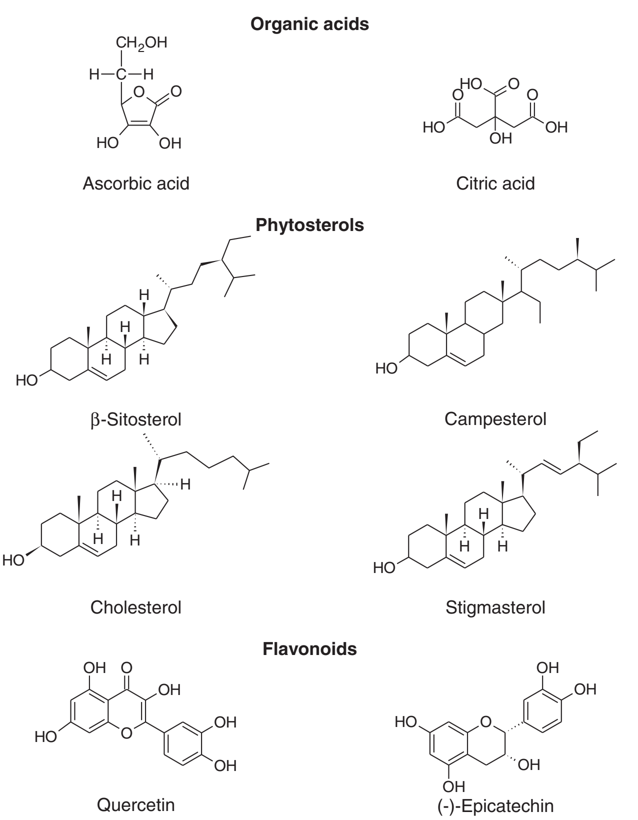

Fig. 2. Chemical structures of selected compounds isolated from *A. digitata*.

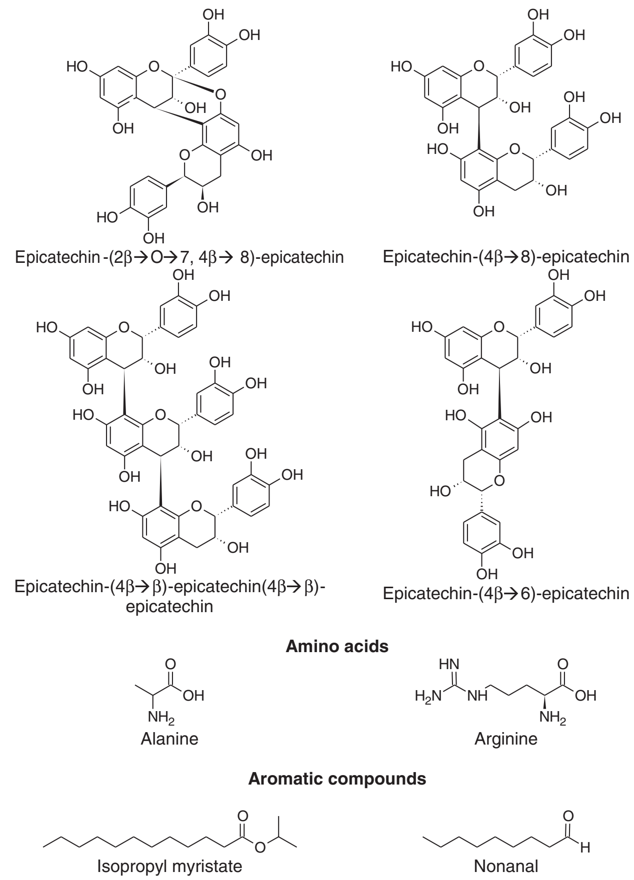

Fig. 2 (*continued*).

5.2. Antibacterial activity

Baobab plant parts have been used for centuries to treat microbial infections both in humans and animals and many scientific studies have been carried out in order to validate its traditional antimicrobial uses. Kubmarawa et al. (2007) found that *A. digitata* extract was not active against *Candida albicans* (ATCC 10231), *Staphylococcus aureus* (ATCC 13709), *Pseudomonas aeruginosa* (ATCC 27853), *Escherichia coli* (ATCC 9637) and *Bacillus subtilis* (NCTC 8236). This was in contrast to a study carried out by Yagoub (2008) who investigated the antibacterial activity of a solvent extract of *A. digitata* against *E. coli* isolated from urine and water. The results clearly indicated that the solvent extract inhibited bacterial growth with the inhibition zone ranging from 20 to 30 mm depending on the concentration at which the sample was tested (Yagoub, 2008). In a recent study, Masola et al. (2009) investigated the antimicrobial activity of baobab plant parts (stem and root barks) against Gram-positive bacteria, Gram-negative bacteria and yeast. The results indicated that the aqueous and ethanolic root and stem bark extracts inhibited the growth of various micro-organisms with the MIC values ranging from 1.5 to 6 mg/ml. The antibacterial activity of the plant could be attributed to the presence of tannins, phlobatannins, terpenoids and saponins in the stem bark (Masola et al., 2009).

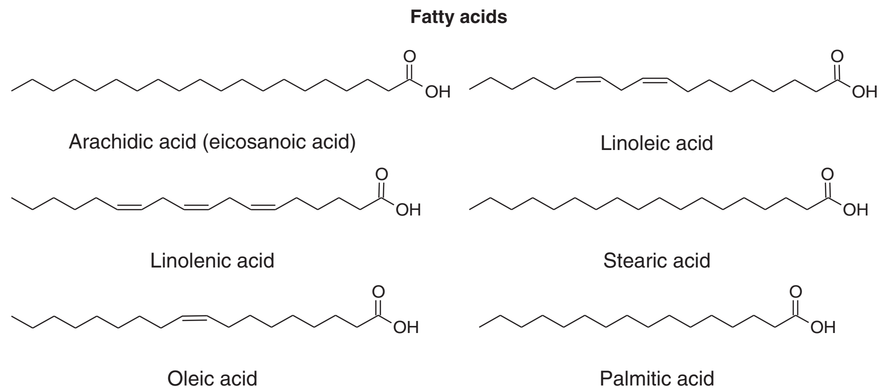

Fig. 2 (*continued*).

5.3. Anti-inflammatory activity

The anti-inflammatory activity of the fruit extracted with hot water was tested *in vivo* using the rat paw formalin-induced oedema test. The extract tested at a dose of 400 and 800 mg/kg inhibited formalin-induced oedema. After 24 h administration of the aqueous extract, the mean swelling of the foot was 1.81 and 1.75 mm for 400 mg/kg and 800 mg/kg, respectively, in comparison to the negative control (6.35 mm) (Ramadan et al., 1994). The DMSO fruit pulp extract and aqueous leaf extract showed significant inhibition against cytokine IL-8 (Vimalanathan and Hudson, 2009).

5.4. Anti-insecticidal activity and repellency

Smoke from pellets of *A. digitata* leaves was assayed for toxicity and repellency against adult (0–7 days old) *Anopheles gambiae* (African malaria mosquito), *Musca domestica* (housefly) and *Periplaneta americana* (American cockroach) insects. The results indicated that the smoke caused the death of *A. gambiae* and *M. domestica*, but not *P. americana*. The median lethal dose for *A. gambiae* was 0.47, 0.50 and 0.20 g for the pellets containing 0, 0.01 and 0.05 g of d-allethrin, respectively, while it was 0.46, 0.52 and 0.46 g for *M. domestica* (Denloye et al., 2006).

5.5. Phenolic and flavonoid content and anti-oxidant activity

Phenolic and flavonoid compounds are well known for their good anti-oxidant activity. The total phenolic levels in fresh ripe fruits were significantly higher in the aqueous methanol than in the aqueous acetone extracts (4057.5 and 3518.3 mg GAE (gallic acid equivalents)/100 g of fruit for total phenolics, respectively). Similarly, the flavonoid level was higher in the aqueous methanol extract of the fresh ripe fruit than in the aqueous acetone extract (42.7 and 31.7 mg QE (quercetin equivalents)/100 g of fruit for total flavonoids, respectively). The anti-oxidant activity of fresh ripe fruit of *A. digitata* was 1000 mg AEAC/100 g (ascorbic acid equivalent anti-oxidant content) (Lamien-Meda et al., 2008). In a separate investigation, Nhukarume et al. (2008) showed that phenolic content of baobab fruit pulp (≈52 mg/100 ml GAE) was not statistically different from that of *Citrus sinensis* Pers. (Nhukarume et al., 2008) suggesting the use of baobab fruit pulp as an anti-oxidant botanical dietary supplement. Brady (2011) found that the anti-oxidant capacity of the hydrophilic extract of fruit pulp was higher (7.65 mg ascorbic acid equivalent/g) compared to the lipophilic extract of fruit pulp (3.32 mg ascorbic acid equivalent/g). Carlsen et al. (2010) summarised the anti-oxidant activity of various fruits and vegetables. The anti-oxidant activity of the baobab varies according to the plant part used. The anti-oxidant content of dried leaves was 48.1 mmol/100 g which was almost five times higher than that of fruit pulp. The anti-oxidant content of fruit or dried leaves was higher than that of orange (0.9 mmol/100 g); mango (1.7 mmol/100 g); apple (3.8 mmol/100 g) and papaya (0.6 mmol/100 g). Vertuani et al. (2002) showed that the fruit pulp exhibited strong anti-oxidant activity corresponding to 6–7 mmol/g of Trolox®, in comparison to the fruit pulps of orange (0.1 mmol/g), strawberry (0.90 mmol/g), apple (0.16 mmol/g) and kiwi (0.34 mmol/g). Nhukarume et al. (2008) investigated the ability of solvent extracts of various fruits including baobab to inhibit the peroxidation of lipids. The results showed a significant difference in the activity of the beverage extracts with *A. digitata* having the greatest activity. The order of activity was *A. digitata* > ascorbic acid > *C. sinensis* Pers. (orange) > *Strychnos spinosa* Lam. > *Parinari curatellifolia* Planch. ex Benth. > baobab nectar.

Besco et al. (2007) evaluated the anti-oxidant activity of baobab red fibre. The lipid soluble anti-oxidant capacity, the water-soluble anti-oxidant content and the ascorbic acid anti-oxidant capacity were determined. The results obtained clearly demonstrated the lipid soluble anti-oxidant capacity of baobab red fibre was high (508.0 ± 0.008 μmol/g, Trolox® equivalent). Similarly, the water-soluble anti-oxidant capacity, corresponding to the activity expressed as μmol/g equivalents of ascorbic acid for each gram showed the same pattern with the ascorbic acid equivalents of baobab red fibre particularly high (386.0 μmol/g). The same study also showed that the integral anti-oxidant capacity (sum of the anti-oxidant capacity of hydrophilic and lipophilic anti-oxidants) of baobab red fibre (1617.3 μmol/g) was 66 times higher than that of orange pulp (24.3 μmol/g) (Besco et al., 2007).

5.6. Inhibitory effects of Trypanosoma by baobab products

The capacity of *A. digitata* to reduce the mobility of *Trypanosoma brucei*, which causes sleeping sickness, was evaluated using four different extracts (petroleum ether, chloroform, water and methanol) obtained from the leaves and the bark. The time at which mobility stops ranged between 10 and 45 min for the root bark, while with the leaves, the mobility seized between 25 and 45 min, when various extracts were tested at 2 mg/ml (Atawodi, 2005). In another study, the *in vitro* trypanocidal activity of baobab was microscopically investigated against *T. brucei brucei* and *T. congolense*, which causes nagana in animals. The methanol root extract exerted a noticeable effect on motility after 50 and 55 min for *T. brucei brucei* and *T. congolense*, respectively (Atawodi et al., 2003).

5.7. Antiviral activity

Several *in vitro* and *in vivo* studies have been carried out to determine the antiviral activity of various baobab plant parts. Ananil et al. (2000) investigated the antiviral activity of several plants against the herpes simplex, sindbis and polio viruses. The baobab extract from leaves was found to have the most potent effect. Vimalanathan and Hudson (2009) investigated the antiviral activity of *A. digitata* leaves, fruit-pulp and seed extracted with water, DMSO and methanol. The study was conducted using the minimum inhibitory concentration method against influenza virus, herpes simplex virus and the respiratory syncytial virus. The influenza virus was very susceptible, while the respiratory syncytial virus was resistant. The leaf extract exhibited the most promising activity against the influenza virus with the MIC value ranging from 0.12 μg/ml (DMSO) to 2.8 μg/ml (water). The activity of the leaf extract was promising against the herpes simplex virus (MIC value: 1.0 to 11.7 μg/ml), while the pulp and the seed exhibited much lower activity (MIC value >72.5 μg/ml). The study clearly demonstrated variation in biological activity when different plant parts are investigated. Furthermore, the anti-HSV activity was considerably enhanced by light, especially long wavelength UV although they all showed 'dark' antiviral activity as well. Thus, all the extracts contained antiviral photosensitisers (Hudson et al., 2000; Vimalanathan and Hudson, 2009).

5.8. Hepatoprotective activity

The hepatoprotective activity of a water extract of the fruit pulp was evaluated *in vivo* against chemical-induced toxicity with CCL_4 in rats. The results clearly showed that the water extract exhibited significant hepatoprotective activity. The liver protective ability of *A. digitata* extract was 76, 77, and 87% for alanine transferase, aspartate transferase and alkaline phosphatase activity, respectively when the plant extract was administered at the start of CCl_4 toxicity. The results suggest that consumption of *A. digitata* fruit may play an important part in resistance to liver damage in areas where baobab is consumed (Al-Qarawi et al., 2003). Although the mechanism of action of liver protection could not be established, this protective activity could be due to triterpenoids, β-sitosterol, β-amyrin palmitate, and/or α-amyrin and ursolic acid present in the fruit (Al-Qarawi et al., 2003). The acute toxicity of baobab fruit pulp extract was tested *in vivo* on rats and the results showed that the LD_{50} was 8000 mg/kg following parenteral administration suggesting low toxicity (Ramadan et al., 1994).

The effects of baobab seed oil on drug metabolising enzymes (cyclopropenoid fatty acids) were evaluated *in vivo* in rats fed either with baobab seed oil (1.27% cyclopropenoid fatty acids) or heated baobab seed oil (0.046% cyclopropenoid fatty acids in the diet). The rats fed baobab oil showed retarded growth when compared to other groups of animals. Furthermore, the relative liver weights were markedly increased whereas cytochrome P-450 content and NADPH cytochrome C reductase and NADH cytochrome C reductase activities were decreased (Andrianaivo-Rafehivola et al., 1995).

5.9. Use as drug permeation enhancer (excipient)

The mechanism through which *A. digitata* exerts its effect, the kinetics of drug delivery and the use of *A. digitata* mucilage in the formulation of matrix tablets were investigated *in vitro* using aminophylline as positive control. The drug release retardation efficiency of *A. digitata* mucilage at equal polymer concentrations was higher than those of plasma concentration but less than that of hydroxypropyl methylcellulose in simulated intestinal fluid and simulated gastrointestinal fluid. Furthermore, it was found that the mechanism of release of aminophylline from *A. digitata* mucilage in hydroxypropyl methylcellulose was by diffusion (Builders et al., 2007).

5.10. Other biological activities

The growth performance of guinea fowl keets that were feed with baobab seed cake diets was investigated. The diets consisted of different amounts of the baobab seed cake (0, 5, 10 and 15%). The fed intake and body weight gain of the keets was found to be high when the amount of baobab seed cake added to their diet was between 0 and 5% (Mwale et al., 2008). The ethanolic extract of the bark was investigated for antihyperglycaemic and antilipidaemic activities in alloxan-induced diabetic female rats. Baobab bark extract was administered orally for seven days in doses of 250 and 500 mg/kg bw to diabetic rats, while the antidiabetic drug glipizide (500 μg/kg bw) was administered to the control group. The bark extract exhibited hypoglycaemic activity as they decreased plasma glucose levels by 26.7% and 35.9% and increased glycogenesis by 11.3% and 32%, respectively. Furthermore, the extracts significantly decreased plasma and hepatic lipid profiles suggesting that the solvent extract of the stem bark of *A. digitata* exhibited antidiabetic and hypolipidaemic effects on type I diabetic animals (Bhargav et al., 2009). The methanol extract of *A. digitata* was investigated for *in vitro* antimalarial properties using the lactate dehydrogenase technique, with a multiresistant strain of *Plasmodium falciparum* K1. However, the study did not have significantly positive results (IC_{50} value: 429.9 μg/ml)

(Ajaiyeoba et al., 2004). Köhler et al. (2002) investigated the anti-plasmodial activity of aqueous extract of baobab pulp against the chloroquine-sensitive and resistant strains of *P. falciparum*. Poor activity was noted (IC_{50} value >50 μg/ml). The results of an investigation on the cytotoxicity of the baobab plant varied according to the plant parts (seed, leaves, fruits) and solvents used. The toxicity against Vero monkey kidney cells ranged from 130 μg/ml (leaves) to ≈ 1900 μg/ml (fruit pulp) (Vimalanathan and Hudson, 2009).

6. Commercialisation

Interest in non-timber forest products (NTFPs) is increasing rapidly and the use of these products constitute a source of income of many rural people in Africa. NTFPs of baobab (seeds oil, leaves and fruits) are beneficial not only for rural communities but also because NTFPs are natural products that can be used in pharmaceutical and cosmetic industries. Baobab is highly sought after in several market segments such as; food and beverages (Germany, France and The Netherlands), botanical remedies (Germany, France and The Netherlands) and nutraceuticals as well as natural cosmetics (EU, USA and Japan) (UNCTAD, 2005). Baobab fruit is an ideal candidate in the functional food market as it is very high in vitamin C and the powder may be used as a thickener due to its high pectin and fibre content. The import value of the product class of rare edible dried fruit, which includes baobab fruit pulp, grew by 13% in 2003 (Eurostat, European Statistics, 2004).

A survey revealed that 73% of the German public would buy food and drinks with anti-oxidant properties (UNCTAD, 2005). Several biological properties have been proven for baobab products (*e.g.* seed oil, fruit pulp, leaves) as described above lending credence to its use as a botanical remedy with possible medical applications.

Natural health and cosmetic products are in great demand especially in North America, Europe and Japan (UNCTAD, 2005). The turnover of botanical remedies and dietary supplements almost doubled from US$12.4 billion in 1994 to US $20.3 billion in 2003 (UNCTAD, 2005). The oils extracted from baobab seeds have a history of use in skin and healthcare recognised by cosmetic industries that incorporate this oil into their products (Sidibe and Williams, 2002; UNCTAD, 2005). Anti-oxidant substances, such as baobab fruit pulp, are in significant demand due to anti-ageing properties (UNCTAD, 2005; IFAD, 2008).

Baobab is one of the important commercial non-timber forest products (NTFPs). NTFPs are of major significance in international trade. In 2008, 150 important NTFPs were recognised including essential oils, medicinal plants, bamboo, wild nuts and seeds, various types of fibres and mushrooms amongst others. These NTFPs have received much attention and the emphasis has been on developing the value chain to contribute towards income generation for rural households. For women especially, the gathering of NTFPs (Fig. 1A) represents the sole source of food and income for their families (IFAD, 2008; Le Breton and Nemarundwe, 2009).

Non-profit community-based organisations (such as PhytoTrade Africa) play a major role in the baobab market in terms of marketing and supply chain development of NTFPs. Baobab fruits are harvested in rural areas, especially in Malawi and Zimbabwe. Processing then takes place where the seed is separated from the pulp. The pulp is graded by particle size and the raw material is sold as such. The seeds are retained and processed into oil which is sold to cosmetic companies (UNCTAD, 2005; IFAD, 2008). These community-based organisations and businesses aim to deliver high quality products to global markets. In 2008, close to 20,000 primary producers sold raw or value-added NTFPs worth US$774,353, a 42% increase from 2007 (IFAD, 2008; Le Breton and Nemarundwe, 2009). PhytoTrade Africa submitted a Generally Recognised As Safe (GRAS) notification concerning baobab fruit pulp to the FDA during 2008. According to the Federal Food, Drug and Cosmetic Act (sections 201(2) and 409) any substance that is intentionally added to food as an additive is subject to premarket review and approval by the FDA. On 25 July 2009, the FDA's decision was that baobab (*A. digitata*) dried fruit pulp (BDFP) is GRAS, through scientific procedures, for use as an ingredient in blended fruit drinks and fruit cereal bars at levels of up to 10% and 15%, respectively (FDA, U.S. Food and Drug Administration, 2009).

The properties and phytochemical composition of baobab has led to its inclusion in various patent applications in recent years. However, the first patent application concerning baobab titled "Process for manufacturing plastic mass" was filed on 5 July 1904 and granted on 26 September 1905. It described the process of producing a pulp-like mass by alkali treatment of the fibre or inner bark of the monkey-bread tree. This mass can then be cast and pressed into any shape before drying to manufacture objects such as buttons, pulleys, handles for tools, pedestals and so forth (Geipel, 1905). Since then, patents involving baobab have mostly focused on dermatological as well as nutritional applications. One patent on the use of baobab as an additive in cosmetic, skincare and dermatological emulsions describes the use of fruit pulp, leaves, bark, seeds, flowers and roots or a mixture of these plant parts to produce cosmetic and dermatological emulsions for skin protection and skin care which have a high stability of the UV filters incorporated in the preparations (Engels, 2009a). Redness and burning of the skin is alleviated and regeneration of the skin is promoted. Baobab itself has a photoprotective effect and used in combination with other UV filters, the stability of the UV filters were improved (dibenzoylmethane derivatives, benzophenone derivatives) (Engels, 2009a). Another patent claims that a component or extract from the baobab plant can be used for the treatment, care, and prophylaxis of skin problems or skin diseases, particularly of allergic and/or inflammatory diseases in humans and animals (Engels, 2009b). It is also claimed that baobab used on the skin, hair, eyelashes or nails produces an effect which can be softening, insulating, hydrating, soothing, emulsifying, regenerative, anti-free radical, anti-inflammatory, protective, photoprotective, anti-pollutant, anti-toxic or anti-sensitising (Pauly, 2001).

In addition, baobab is included as an ingredient in a nutraceutical combination also containing *Borojoa patinoi* Cuatrec.

(borojo), *Cyclanthera pedata* (L.). Schrad. (caigua) and *Aframomum melegueta* K. Schum. (grains of paradise) for human consumption to promote well-being, provide nutritional value and to aid in preventative health management. According to the patent, it has been established that each of the plants has a nutritional and medicinal value and it may be useful as a dietary supplement to be sprinkled over food as a dry powder, as a capsule, a ready to drink juice or a food additive. Baobab is described as a good source of vitamin C, micronutrients and soluble fibres with a pre- and probiotic effect thereby serving as an intestinal regulator in the case of gastric disorders (Shatkina and Gurevich, 2010). The use of baobab is not restricted to humans; another invention is intended to market baobab as an animal food or animal food additive to provide a high-value food or food supplement which is tasty and counteracts malnutrition (Engels, 2009c). Baobab is also listed in various patent documents as a possible ingredient in various cosmetic and other formulations (Engels, 2009a). Scientific studies are not available to support most of these patent applications, especially related to cosmetic uses.

7. Conclusions

It is evident that the iconic African tree, baobab, is an important nutritional and medicinal resource. Studies on the nutritional value are abundant but the use of various methods highlighted significant variations in the content of some compounds. However, the major trend found is that baobab fruit pulp is rich in vitamin C and the anti-oxidant capacity of the fruit pulp is greater than that of other common fruits known for high anti-oxidant activity. Baobab fruit pulp has been approved by statutory bodies for use in certain nutritional products. Although no recent turnover figures for baobab products could be located, it is certain that commercialisation of baobab products (*e.g.* seed oil, fruit pulp) has increased especially after the FDA and EU have recognised the fruit pulp as a food supplement. The global demand for baobab has increased dramatically as more sectors, such as the cosmetic industry, developed an interest in this multipurpose plant. This in turn contributes significantly to the income of rural communities, positively affecting the livelihoods of many people. Seed oils have been used for topical skin application since ancient times and due to the toxic effects of synthetic oils, there is a growing trend to replace them and revert to the use of natural oils in the cosmetic and pharmaceutical industries. Baobab seed oil is used in pharmaceutical and cosmetic industries due to its fatty acid content known to have beneficial effects when applied onto the skin as such. Numerous studies on the biological activities of baobab have been conducted with promising results. However, conclusive results on beneficence cannot always be established and for several areas of study there is a lack of information.

Due to the increased interest in baobab products and slow growth of the plant, research should be directed on how to develop a new cultivar with a short maturation period. Variation in chemical composition of the fruit pulp was found, highlighting the need to set quality standards for seed oil and fruit pulp as they are important commercial commodities.

Acknowledgements

We are grateful to PhytoTrade Africa for supplying the photographs.

References

Abbiw, D.K., 1990. Useful Plants of Ghana. Intermediate Technology Publications and the Royal Botanical Gardens, Kew, London.

Addy, R., 2009. Baobab Fruit Approved as Food Ingredient in US. Available at: http://www.nutraingredients-usa.com/content/view/print/2595742009 [Accessed on: 16/04/2011].

Adesanya, S.A., Idowu, T.B., Elujoba, A.A., 1988. Antisickling activity of *Adansonia digitata*. Planta Medica 54, 374.

Africajou, Natural Oil, African Earth. Available at: http://www.africajou.com/index.php?option=com_content&task=view&id=29&Itemid=24&lang=en [Accessed on: 30/07/2011].

Ajaiyeoba, E., Ashidi, J., Abiodun, O., Okpako, L., Ogbole, O., Akinboye, D., Falade, C., Bolaji, O., Gbotosho, G., Falade, M., Itiola, O., Houghton, P., Wright, C., Oduola, A., 2004. Antimalarial ethnobotany: *in vitro* antiplasmodial activity of seven plants identified in the Nigerian Middle Belt. Pharmaceutical Biology 42, 588–591.

Aké Assi, Y.A., 1992. Contribution au Recensement des Espèces Végéetales Utilisées Traditionnellement sur le Plan Zootechnique et Vétérinaire en Afrique de l'Ouest. PhD Thèse, Université Claude-Bernard Lyon I, France.

Al-Qarawi, A.A., Al-Damegh, M.A., El-Mougy, S.A., 2003. Hepatoprotective influence of *Adansonia digitata* pulp. Journal of Herbs Spices and Medicinal Plants 10, 1–6.

Ananil, K., Hudson, J.B., De Souzal, C., Akpaganal, K., Tower, G.H.N., Amason, J.T., Gbeassor, M., 2000. Investigation of medicinal plants of Togo for antiviral and antimicrobial activities. Pharmaceutical Biology 38, 40–45.

Andrianaivo-Rafehivola, A.A., Siess, M.-H., Gaydou, E.M., 1995. Modifications of hepatic drug metabolizing enzyme activities in rats fed baobab seed oil containing cyclopropenoid fatty acids. Food and Chemical Toxicology 33, 377–382.

Aruoma, O.I., 1998. Free radicals, oxidative stress and anti-oxidants in human health and disease. Journal of the American Oil Chemists' Society 75, 199–212.

Assogbadjo, A.E., Sinsin, B., Codjia, J.T.C., Van Damme, P., 2005. Ecological diversity and pulp, seed and kernel production of the baobab (*Adansonia digitata*) in Benin. Belgian Journal of Botany 138, 47–56.

Assogbadjo, A.E., Glèlè Kakaï, R., Chadare, F.J., Thomson, L., Kyndt, T., Sinsin, B., Van Damme, P., 2008. Folk classification, perception, and references of baobab products in West Africa: consequences for species conservation and improvement. Economic Botany 62, 74–84.

Atawodi, S.E., 2005. Comparative *in vitro* trypanocidal activities of petroleum ether, chloroform, methanol and aqueous extracts of some Nigerian savannah plants. African Journal of Biotechnology 4, 177–182.

Atawodi, S.E., Bulus, T., Ibrahim, S., Ameh, D.A., Nok, A.J., Mamman, M., Galadima, M., 2003. *In vitro* trypanocidal effect of methanolic extract of some Nigerian savannah plants. African Journal of Biotechnology 2, 317–321.

Barminas, J.T., Charles, M., Emmanuel, D., 1998. Mineral composition of non-conventional leafy vegetables. Plant Foods for Human Nutrition 53, 29–36.

Besco, E., Braccioli, E., Vertuani, S., Ziosi, P., Brazzo, F., Bruni, R., Sacchetti, G., Manfredini, S., 2007. The use of photochemiluminescence for the measurement of the integral anti-oxidant capacity of baobab products. Food Chemistry 102, 1352–1356.

Bhargav, B., Rupal, A.V., Reddy, A.S., Narasimhacharya, A.V.R.L., 2009. Antihyperglycemic and hypolipidemic effects of *Adansonia digitata* L. on alloxan induced diabetic rats. Journal of Cell and Tissue Research 9, 1879–1882.

Bianchini, J.-P., Ralaimanarivo, A., Gaydou, E.M., Waegell, B., 1982. Hydrocarbons, sterols and tocopherols in the seeds of six *Adansonia* species. Phytochemistry 21, 1981–1987.

Brady, O., 2011. The characterisation and bioactivity determination of *Adansonia digitata* L. Baobab fruit pulp, for commercial product development. Bachelor of Science, Dublin Institute of Technology, Ireland.

Brendler, T., Gruenwald, J., Jaenicke, C., 2003. Herbal Remedies. Medpharm GmbH Scientific Publishers (CD-ROM), Stuttgart.

Buchmann, C., Prehsler, S., Hartl, A., Vogl, C.R., 2010. The importance of baobab (*Adansonia digitata* L.) in rural West African subsistence—suggestion of a cautionary approach to international market export of baobab fruits. Ecology of Food and Nutrition 49, 145–172.

Builders, P.F., Okeke, U., Egieye, A.S., 2007. Evaluation of the controlled release potential of *Adansonia digitata* mucilage: a super gel forming polymer. Journal of Phytomedicine and Therapeutics 12, 22–30.

Carlsen, M.H., Halvorsen, B.L., Holte, K., Bøhn, S.K., Dragland, S., Sampson, L., Willey, C., Senoo, H., Umezono, Y., Sanada, C., Barikmo, I., Berhe, N., Willett, W.C., Phillips, K.M., Jacobs, D.R., Blomhoff, R., 2010. The total anti-oxidant content of more than 3100 foods, beverages, spices, herbs and supplements used worldwide. Nutrition Journal 9, 3.

Chadare, F.J., Linnemann, A.R., Hounhouigan, J.D., Nout, M.J.R., Van Boekel, M.A.J.S., 2009. Baobab food products: a review on their composition and nutritional value. Critical Reviews in Food Science and Nutrition 49, 254–274.

Chauhan, J.S., Cahturvedi, R., Kumar, S., 1984. A new flavonol glycoside from the root of *A. digitata*. Planta Medica 50, 113.

Chauhan, J.S., Kumar, S., Cahturvedi, R., 1987. A new flavonone glycoside from the root of *A. digitata*. National Academy of Science Letters 10, 177–179.

Cisse, M., Sakho, M., Dornier, M., Mar Diop, C., Reynes, M., Sock, O., 2009. Characterization of the baobab tree fruit and study of its processing into nectar [Caractérisation du fruit du baobab et étude de sa transformation en nectar]. Fruits 64, 19–34.

Codjia, J.T.C., Fonton, B.K., Assogbadjo, A.E., Ekue, M.R.M., 2001. Le Baobab (*Adansonia digitata*). Une Espèce à Usage Multiple au Bénin. Cecodi, CBDD, Veco, SNV, FSA.

De Caluwé, E., Halamová, K., Van Damme, P., 2009. Baobab (*Adansonia digitata* L.): a review of traditional uses, phytochemistry and pharmacology. In: Rodolfo, H., Simon, J.E., Ho, C.-T. (Eds.), African natural plant products: new discoveries and challenges in chemistry and quality. Oxford University Press, USA, pp. 51–84.

Denloye, A.A.B., Teslim, K.O., Fasasi, O.A., 2006. Insecticidal and repellency effects of smoke from plant pellets with or without D-allethrin 90 EC against three medical insects. Journal of Entomology 3, 9–15.

Diop, P.A., Franck, D., Grimm, P., Hasselmann, C., 1988. High-performance liquid chromatographic determination of vitamin C in fresh fruits from West Africa. Journal of Food Composition and Analysis 1, 265–269.

Diop, A.G., Saho, M., Dornier, M., Cisse, M., Reynes, M., 2005. Le baobab Africain (*Adansonia digitata* L.): principales caracteristiques et utilisations. Fruits 61, 55–69.

Drake, E., 2006. A Book of Baobabs. Aardvark Press, Cape Town.

El-Rawy, E.M., Gergis, S.M., Bazaid, S., El-Mougy, S.A., 1997. The immunostimulant effect of *Adansonia digitata* on the immune response of chicken vaccinated with avian cholera vaccine. Journal of Egyptian Veterinary Medical Association 57, 959–970.

Engels, P., 2009a. Cosmetic preparations with an additive from the baobab tree. US Patent 2009/0324656 A1.

Engels, P., 2009b. Use of a component or extract from the baobab plant for skin diseases. Patent WO/2009/115216.

Engels, P., 2009c. Use of parts of the baobab plant as animal food or as additive in animal food. US Patent 2009/0258112 A1.

Eromosele, I.C., Eromosele, C.O., Kuzhkuzha, D.M., 1991. Evaluation of mineral elements and ascorbic acid contents in fruits of some wild plants. Plant Foods for Human Nutrition 41, 151–154.

Esenowo, G.J., 1991. Studies on germination of *Adansonia digitata* seeds. Journal of Agricultural Science (Cambridge) 117, 81–84.

Esterhuyse, N., Von Breitenbach, J., Söhnge, H., 2001. Remarkable Trees of South Africa. Briza Publications, Pretoria.

Eurostat (European Statistics), 2004. Available at: http://europa.eu.int/comm/eurostat2004 [Accessed on: 09/05/2011].

FAO, 1993. Indigenous Multipurpose Trees of Tanzania: Uses and Economic Benefits for People. Available at: http://www.fao.org/docrep/x5327e/x5327e0g.htm1993 [Accessed on: 09/05/2011].

FDA (U.S. Food and Drug Administration), 2009. Agency Response Letter GRAS Notice No. GRN 000273. Available at: http://www.fda.gov/Food/FoodIngredientsPackaging/GenerallyRecognizedasSafeGRAS/GRASListings/ucm174945.htm2009 [Accessed on: 09/05/2011].

Fujita, M.S., 1991. Flying fox (Chiroptera: Pteropodidae) pollination, seed dispersal, and economic importance: a tabular summary of current knowledge, resource publication 2. Bat Conservation International.

Gebauer, J., El-Siddig, K., Ebert, G., 2002. Baobab (*Adansonia digitata* L.): a review on a multipurpose tree with promising future in Sudan. Gartenbauwissenschaft 67, 155–160.

Geipel, A., 1905. Process for manufacturing plastic mass. US Patent 800,563.

Glew, R.H., Vanderjagt, D.J., Lockett, C., Grivetti, L.E., Smith, G.C., Pastuszyn, A., Millson, M., 1997. Amino acid, fatty acid, and mineral composition of 24 indigenous plants of Burkina Faso. Journal of Food Composition and Analysis 10, 205–217.

Gruenwald, N., 2009. Novel botanical ingredients for beverages. Clinics in Dermatology 27, 210–216.

Hostettmann, K., Marston, A., Ndjoko, K., Wolfender, J.L., 2000. The potential of African plants as a source of drugs. Current Organic Chemistry 4, 973–1010.

Hudson, J.B., Ananil, K., Lee, M.K., De Souza, C., Arnason, J.T., Gbeassor, M., 2000. Further investigations on the antiviral activities of medicinal plants of Togo. Pharmaceutical Biology 38, 46–50.

IFAD, 2008. Gender and non-timber forest products. Promoting Food Security and Economic Empowerment. International Fund for Agricultural Development (IFAD). Available at: http://www.ifad.org/gender/pub/timber.pdf. [Accessed on: 09/02/2011].

Inngjerdingen, K., Nergård, C.S., Diallo, D., Mounkoro, P.P., Paulsen, B.S., 2004. An ethnopharmacological survey of plants used for wound healing in Dogonland, Mali, West Africa. Journal of Ethnopharmacology 92, 233–244.

Kerharo, J., Adam, J.G., 1974. La pharmacopée Sénégalaise traditionnelle: plantes Médicinales et Toxiques. Editions Vigot Frères, p. 1012.

Khan, M., Shingare, M.S., Zafar, R., Ramesh, D., Siddiqui, A.R., 2006. Analgesic activity of fixed oil of *Adansonia digitata*. Indian Journal of Natural Products 22, 20–21.

Köhler, I., Jenett-Siems, K., Kraft, C., Siems, K., Abbiw, D., Bienzle, U., Eich, E., 2002. Herbal remedies traditionally used against malaria in Ghana. Zeitschrift für Naturforschung. Section C 57, 1022–1027.

Kubmarawa, D., Ajoku, G.A., Enwerem, N.M., Okorie, D.A., 2007. Preliminary phytochemical and antimicrobial screening of 50 medicinal plants from Nigeria. African Journal of Biotechnology 6, 1690–1696.

Lamien-Meda, A., Lamien, C.E., Compaoré, M.M.Y., Meda, R.N.T., Kiendrebeogo, M., Zeba, B., Millogo, J.F., Nacoulma, O.G., 2008. Polyphenol content and antioxidant activity of fourteen wild edible fruits from Burkina Faso. Molecules 13, 581–594.

Lautenschläger, H., 2003. Essential fatty acids — cosmetic from inside and outside. Beauty Forum 2003, 54–56.

Le Breton, G., Nemarundwe, N., 2009. Linking southern African producers of non-timber forest products to global markets. XIII World Forestry Congress, Buenos Aires, Argentina. Available at: http://www.cfm2009.org/es/programapost/trabajos/. [Accessed on: 09/05/2011].

Lee, K.W., Kim, Y.J., Lee, H.J., Lee, C.Y., 2003. Cocoa has more phenolic phytochemicals and a higher anti-oxidant capacity than teas and red wine. Journal of Agricultural and Food Chemistry 51, 7292–7295.

Lockett, C.T., Calvert, C.C., Grivetti, L.E., 2002. Energy and micronutrient composition of dietery and medicinal wild plants consumed during drought. Study of rural Fulani, Northeastern Nigeria. International Journal of Food Science and Nutrition 51, 195–208.

Manfredini, S., Vertuani, S., Buzzoni, V., 2002. *Adansonia digitata*. Il baobab farmacista. L'integratore nutrizionale 5, 25–29.

Masola, S.N., Mosha, R.D., Wambura, P.N., 2009. Assessment of antimicrobial activity of crude extracts of stem and root barks from *Adansonia digitata* (Bombacaceae) (African Baobab). African Journal of Biotechnology 8, 5076–5083.

Murunga Products. Available at: http://www.murunga.com/quality.html [Accessed on: 09/05/2011].

Mwale, M., Mupangwa, J.F., Mapiye, C., Saina, H., Chimvuramahwe, J., 2008. Growth performance of guinea fowl keets fed graded levels of baobab seed cake diets. International Journal of Poultry Science 7, 429–432.

Nacoulma, O.G., 1999. Plantes Médicinales et Pratiques Médicales Traditionnelles au Burkina-Faso: Cas du Plateau Central. Thèse doctorat d'État. Université de Ouagadougou, Burkina-Faso, Tome II, p. 261.

Nguta, J.M., Mbaria, J.M., Gakuya, D.W., Gathumbi, P.K., Kiama, S.G., 2010. Antimalarial herbal remedies of Msambweni, Kenya. Journal of Ethnopharmacology 128, 424–432.

Nhukarume, L., Chikwambi, Z., Muchuweti, M., Chipurura, B., 2008. Phenolic content and antioxidant capacities of *Parinari curatelifolia*, *Strychnos spinosa* and *Adansonia digitata*. Journal of Food Biochemistry 34, 207–221.

Nkafamiya, I.I., Osemeahon, S.A., Dahiru, D., Umaru, H.A., 2007. Studies on the chemical composition and physicochemical properties of the seeds of baobab (*Adasonia digitata*). African Journal of Biotechnology 6, 756–759.

Nordeide, M.B., Hatloy, A., Folling, M., Lied, E., Oshaug, A., 1996. Nutrient composition and nutritional importance of green leaves and wild food resources in an agricultural district, Koutiala, in Southern Mali. International Journal of Food Sciences and Nutrition 47, 455–468.

Nyam, K.L., Tan, C.P., Lai, O.M., Long, K., Che Man, Y.B., 2009. Physicochemical properties and bioactive compounds of selected seed oils. LWT — Food and Science Technology 42, 1396–1403.

Osman, M.A., 2004. Chemical and nutrient analysis of baobab (*Adansonia digitata*) fruit and seed protein solubility. Plant Foods for Human Nutrition 59, 29–33.

Ouedraogo, Y., 2004. A letter from the Sahara. The Independent, 2, p. 13 (January).

Pauly, F., 2001. Use of an extract of the genus *Adansonia*. US Patent 6,274,123 B1.

PhytoTrade Africa. Baobab oil. Available at: http://www.phytotradeafrica.com/products/BaobabOil.htm [Accessed on: 30/07/2011].

Ramadan, A., Harraz, F.M., El-Mougy, S.A., 1994. Anti-inflammatory, analgesic and antipyretic effects of the fruit pulp of *Adansonia digitata*. Fitoterapia LXV, 418–422.

Royal Botanic Gardens, Kew, 1999. Survey of economic plants for arid and semi arid lands (SEPASAL) database. Available at: http://www.rbgkew.org.uk/ceb/sepasal1999 [Accessed on: 10/04/2011].

Sanchez, A.C., Osborne, P.E., Haq, N., 2010. Identifying the global potential for baobab tree cultivation using ecological niche modeling. Agroforestry Systems 80, 191–201.

Sena, L.P., VanderJagt, D.J., Rivera, C., Tin, A.C., Muhamadu, I., Muhamadou, O., Millton, M., Pastuszyn, A., Glew, R.H., 1998. Analysis of nutritional components of eight famine foods of the Republic of Niger. Plant Foods for Human Nutrition 52, 17–30.

Shahat, A.A., 2006. Procyanidins from *Adansonia digitata*. Pharmaceutical Biology 44, 445–450.

Shatkina, R., Gurevich, S.D., 2010. Nutraceutical composition. US Patent 2010/0136064 A1.

Shukla, Y.N., Dubey, S., Jain, S.P., Kumar, S., 2001. Chemistry, biology and uses of *Adansonia digitata* — a review. Journal of Medicinal and Aromatic Plant Sciences 23, 429–434.

Si, H., Fu, Z., Babu, P.V.A., Zhen, W., LeRoith, T., Meaney, M.P., Voelker, K.A., Jia, Z., Grange, R.W., Liu, D., 2011. Dietary epicatechin promotes survival of obese diabetic mice and *Drosophila melanogaster*. Journal of Nutrition 141, 1095–1100.

Sidibe, M., Williams, J.T., 2002. Baobab. *Adansonia digitata*. Fruits for the Future, 4. International Centre for Underutilised Crops, Southampton, UK, p. 100.

Sidibe, M., Sheuring, J.F., Tembely, D., Hofman, P., Frigg, M., 1996. Baobab, homegrown vitamin C for Africa. Agroforestry Today 8, 13–15.

Soloviev, P., Niang, T.D., Gaye, A., Totte, A., 2004. Variabilité des caracteres physico-chimiques des fruits de trois especes ligneuses de cueillette, recoltes au Sénegal: *Adansonia digitata*, *Balanites aegytiaca* et *Tamarindud indica*. Fruits 59, 109–119.

Tal-Dia, A., Toure, K., Sarr, O., Sarr, M., Cisse, M.F., Garnier, P., Wone, I., 1997. A baobab solution for the prevention and treatment of acute dehydration in infantile diarrhoea. Dakar Médical 42, 68–73.

Tapsoba, H., Deschamps, J.-P., 2006. Use of medicinal plants for the treatment of oral diseases in Burkina Faso. Journal of Ethnopharmacology 104, 68–78.

Täufel, A., Tunger, L., Ternes, W., Zobel, M., 1993. Le-bensmittel-Lexikon 3. Aufl. Behrs'Verlag, Hamburg.

UNCTAD (United Nations Conference on Trade and Development), 2005. Market brief in the European union for selected natural ingredients derived from native species. *Adansonia digitata* L. Baobab. Available at: http://www.biotrade.org/ResourcesPublications/biotradebrief-baobab.pdf2005 [Accessed on: 20/04/2011].

Van Wyk, B.-E., Gericke, N., 2000. People's plants — A guide to useful plants of Southern Africa. Briza Publications, Pretoria.

Van Wyk, B.-E., Van Oudtshoorn, B., Gericke, N., 1997. Medicinal plants of South Africa. Briza Publications, Pretoria.

Venter, F., Venter, J.-A., 1996. Making the Most of Indigenous Trees. Briza Publications, Pretoria.

Vermaak, I., Kamatou, G.P.P., Komane-Mofokeng, B., Viljoen, A.M., Beckett, K., 2011. African seed oils of commercial importance — cosmetic applications. South African Journal of Botany 16, 41.

Vertuani, S., Braccioli, E., Buzzoni, V., Manfredini, S., 2002. Anti-oxidant capacity of *Adansonia digitata* fruit pulp and leaves. Acta Phytotherapeutica 2, 86–91.

Vimalanathan, S., Hudson, J.B., 2009. Multiple inflammatory and antiviral activities in *Adansonia digitata* (Baobab) leaves, fruits and seeds. Journal of Medicinal Plants Research 3, 576–582.

Wasserman, R.H., 2004. Vitamin D and the dual processes of intestinal calcium absorption. Journal of Nutrition 134, 3137–3139.

Watson, R., 2007. The African Baobab. Struik Publishers, Cape Town.

Watt, J.M., Breyer-Brandwijk, M.G., 1962. The medicinal and poisonous plants of Southern and Eastern Africa, 2nd ed. E and S. Livingstone, Edinburgh.

Wickens, G.E., 1982. The baobab, Africa's upside-down tree. Kew Bulletin 37, 171–202.

Wickens, G.E., Lowe, P., 2008. The baobabs: pachycauls of Africa. Madagascar and Australia, Springer, UK.

Willet, W.C., 2001. Eat, drink, and be healthy. The Harvard Medical School guide to healthy eating. Simon and Schuster, New Work.

Wren, S., Stucki, A., 2003. Organic essential oils, indigenous cold pressed oils, herbs and spices in Sub-Saharan Africa. International Journal of Aromatherapy 23, 71–81.

Yagoub, S.O., 2008. Anti-microbial activity of *Tamarindus indica* and *Adansonia digitata* extracts against *E. coli* isolated from urine and water specimens. Research Journal of Microbiology 3, 193–197.

Yazzie, D., Vanderjagt, D.J., Pastuszyn, A., Okolo, A., Glew, R.H., 1994. The amino acid and mineral content of baobab (*Adansonia digitata* L.) leaves. Journal of Food Composition and Analysis 7, 189–193.

Yusha'u, M., Hamza, M.M., Abdullahi, N., 2010. Antibacterial activity of *Adansonia digitata* stem bark extracts on some clinical bacterial isolates. International Journal of Biomedical and Health Sciences 6, 129–135.

Edited by B-E Van Wyk