

Review

A review of baobab (*Adansonia digitata*) products: Effect of processing techniques, medicinal properties and uses

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Accepted 2 December, 2011

A general literature review including the effect of processing techniques, medicinal value and uses of baobab tree is reported in this manuscript. Baobab tree has multi-purpose uses, as it produces food and non-food products such as medicines, fuel, timber, fodder. Every part of the baobab tree is reported to be useful. The seeds, leaves, roots, flowers, fruit pulp and bark of baobab are edible. Baobab leaves are used in the preparation of soup. Seeds are used as a thickening agent in soups, but they can be fermented and used as a flavouring agent or roasted and eaten as snacks. The pulp is either sucked or made into a drink and was found to be acidic. The acceptability and optimal utilization of baobab parts as nutrient source is limited by the presence of antinutrients such as protease inhibitors, tannins and phytates but the processing techniques may reduce or destroy the antinutrients present in it. Baobab leaves, bark, roots, pulp and seeds are used for multiple medicinal purposes in many parts of Africa and were found to show interesting medicinal properties including antioxidant, prebiotic-like activity, anti-inflammatory, analgesic, antipyretic activity, anti-diarrhoea, anti-dysentery activity and excipient.

Key words: Baobab, antinutritional factors, biological activity, process of seeds, pulps and leaves, uses.

INTRODUCTION

Adansonia digitata (L.) called the baobab tree in both English and French is very characteristic of the Sahelian region (Figure 1a) and belongs to the Malvaceae family (De Caluwé et al., 2010). The plant is a very massive tree (Figure 1b) with a very large trunk (up to 10 m diameter) which can grow up to 25 m in height and may live for hundreds of years. The plant is widespread throughout the hot and drier regions of tropical Africa (FAO, 1988).

Baobab tree has multi-purpose uses and every part of the plant is reported to be useful (Igboeli et al., 1997; Gebauer et al., 2002). The leaves, for instance, are used in the preparation of soup. Seeds are used as a thickening agent in soups, but they can be fermented and used as a flavouring agent, or roasted and eaten as snacks (Addy and Eteshola, 1984). The pulp is either sucked or made into a drink while the bark is used in making ropes (Igboeli et al., 1997). The different parts of the plant provide food, shelter, clothing and medicine as well as material for hunting and fishing (Venter and Venter, 1996; Sidibe and Williams, 2002). Baobab tree provides income and employment to rural and urban

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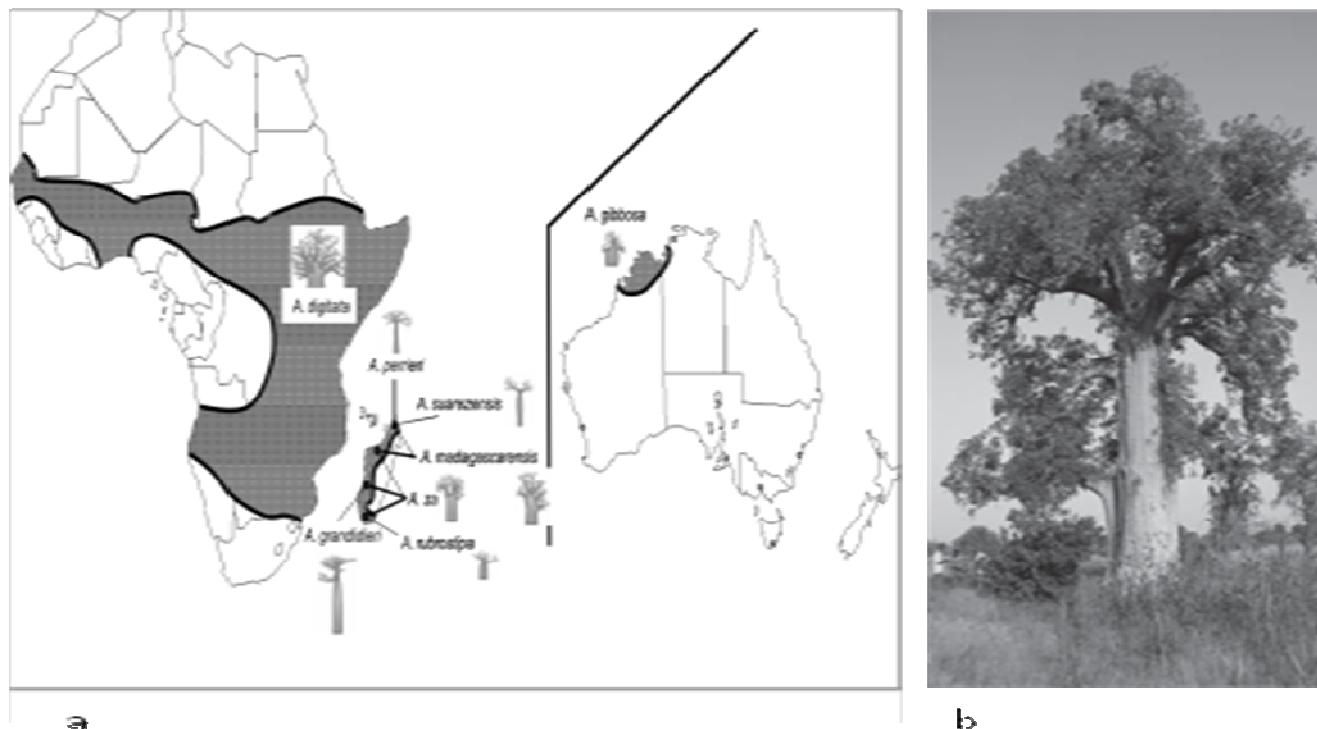


Figure 1. a, Distribution of baobab tree in Africa (Diop et al., 2005); b Baobab tree (Parkouda et al., 2009).

households. For instance, about 92 445 t of baobab leaf were produced in Burkina Faso in 1990, corresponding to a value of US\$18.1 million (Coulibaly, 1993). Previously published biochemical analyses revealed that the leaves, the seeds and the pulp from baobab are rich in nutrients (Becker, 1983; Glew et al., 1997; Diop et al., 2005; Nkafamiya et al., 2007; Chadare et al., 2009).

Literature reviews on baobab provided information on the species taxonomy, distribution, utilization, agronomy, agro-ecology, phytochemistry and pharmacology (Sidibe and Williams, 2002; Diop et al., 2005; De Caluwé et al., 2010). Gebauer et al. (2002) brought out information on baobab botany, ecology, origin, propagation, main uses, genetic improvement and especially its importance for nutrition and poverty alleviation. Literature review revealed a great variation in reported values of nutrient contents of baobab part which may be due to the quality of the sample, the provenance of the sample, the age of the sample, the treatment before analysis, the storage conditions, the processing methods, a probable genetic variation, and the soil structure and its chemical composition (Chadare et al., 2009). However these reviews did not detail the medicinal properties of baobab tree. Moreover the reviews did not deal with the effect of processing techniques on baobab food products. Information on the effect of processing techniques on baobab food products is essential to improve present day

practices as a measure to support the nutritional status of rural populations that incorporate baobab food products in their diet. To fill in this gap, we have compiled an up-to-date and comprehensive review of *Adansonia digitata* that covers its botany, medicinal properties and traditional uses and the effects of processing techniques on baobab food products. We hope the information presented in this manuscript will be a useful tool for teachers, students, policy makers, fruit tree growers and more importantly traders. We also hope that this work may encourage further production, processing and marketing of baobab particularly at the village level, and researchers and scientists to further explore the benefits of baobab.

BOTANICAL DESCRIPTION OF BAOBAB TREE

Baobab (*A. digitata* L.), a tree plant belonging to the Malvaceae family, is widespread throughout the hot, drier regions of tropical Africa (FAO, 1988). It is a deciduous, massive and majestic tree up to 25 m high, which may live for hundreds of years (Gebauer et al., 2002). The trunk is swollen and stout, up to 10 m in diameter, usually tapering or cylindrical and abruptly bottle-shaped; often buttressed. Branches are distributed irregularly and large. The bark is smooth, reddish brown to grey, soft and fibrous (Gebauer et al., 2002). The tree produces an

Table 1. Common names for African baobab (Sidibe and Williams, 2002).

Language	Country	Name
English	United States of America and United Kingdom	Baobab, Monkey bread tree, Ethiopian sour gourd, Cream of tartar tree, Senegal calabash (fruit) and Upside-down tree
French	France	Baobab, pain de singe (fruit), arbre aux calebasses, arbre de mille ans and calebassier du Sénégal
Portuguese	Portugal	Cabaçevre
Arabic	United Arab Republic	Buhibab, hamao-hamaraya, gangoleis (fruit)
More	Burkina Faso	Trega, twega, toayga
Dogon	Mali	Oro
Dierma	Niger	Konian
Bambara	Mali	Sira
Peulh	Mali	Babbe, boki and olohi
Hausa	Nigeria, Niger	Kouka, kuka
Wolof	Senegal	Goui, gouis, goui, lalo and boui
Amhara	Ethiopia	Bamba
Yao	Malawi	Mlonje
Kamba	Kenya	Mwambo
Swahili	Somalia to Mozambique	Mbuyu, majoni ya mbuyu (Tanzania)
Zulu	South Africa	Isimuhu and umshimulu
Hindi	India	Gorakh-imli and hathi-khatiyan

extensive lateral root system and the roots end in tubers. Leaves are alternate and foliate. Leaves of young tree are often simple. Overall mature leaf size may reach a diameter of 20 cm. Flowers are pendulous, solitary or paired in leaf axils, large and showy. Flower bud is globose, sometimes ovoid (Sidibe and Williams, 2002). The fruit of the baobab tree hangs singly on long stalks with an ovoid, woody and indehiscent shell 20 to 30 cm long and up to 10 cm in diameter (Nnam and Obiakor, 2003). The shell contains numerous hard, brownish seeds, round or ovoid, up to 15 mm long, which are embedded in a yellowish-white, floury acidic pulp (Nnam and Obiakor, 2003). The ripe fruit pulp appears as naturally dehydrated, powdery, whitish colored and with a slightly acidulous taste (Vertuani et al., 2002). The common names of baobab are shown in Table 1.

MEDICINAL PROPERTIES OF BAOBAB

Anti-oxidant properties

As a result of its high natural vitamin C content, baobab fruit pulp has a well-documented antioxidant capability (Vertuani et al., 2002; Besco et al., 2007; Lamien-Meda et al., 2008; Blomhoff et al., 2010; Brady, 2011). Antioxidants could help prevent oxidative stress related diseases such as cancer, aging, inflammation and cardiovascular diseases as they may eliminate free radicals which contribute to these chronic diseases (Kaur and

Kapoor, 2001; Blomhoff et al., 2010). The antioxidant capacity of baobab fruit pulp was investigated using the Photochemiluminescence (PLC) assay, comparing the antioxidant properties of the fruit pulp to the antioxidant properties of several other fruits including kiwi, orange, apple and strawberry (Vertuani et al., 2002). The baobab fruit was found to have the highest content of vitamin C at 280 to 300 mg/100 g, out of all fruits investigated. This compared to a vitamin C content of 46 mg/100 g in oranges, a well-documented source of vitamin C (Vertuani et al., 2002). Baobab fruit pulp was found to have interesting antioxidant properties; in particular the Integral Antioxidant Capacity (IAC) value of baobab fruit pulp (11.1 mmol/g fresh weight) was higher than that of orange pulp (0.3 mmol/g fresh weight) (Vertuani et al., 2002). The high vitamin C and antioxidant content of the fruit pulp may have a role to play in the extension of shelf-life for foods and beverages, as well as cosmetics. The food/beverage industry could introduce baobab fruit pulp into foods in order to act as a preserving ingredient by preventing oxidation of lipids in the food (Afolabi and Popoola, 2005).

Anti-inflammatory properties

Ramadan et al. (1993) found that the fruit pulp of baobab has similar anti-inflammatory properties to phenylbutazone used as standard in rats. 800 mg/kg baobab pulp aqueous extract gives comparable and long

lasting effects with classical drugs - equivalent to 15 mg/kg phenylbutazone anti-inflammatory effect. This activity may be attributed to the presence of sterols, saponins and triterpenes in the aqueous extract (Ramadan et al., 1993; Brady, 2011).

Antipyretic activity (anti-fever effect)

Sufferers of malaria in Africa, India, Sri Lanka and the West Indies are said to consume a mash containing dried baobab bark as a febrifuge in order to treat the fever associated with this illness (Wickens and Lowe, 2008; Brady, 2011). Fruit pulp and seeds are also widely used for their anti-pyretic properties (Ramadan et al., 1993; Wickens and Lowe, 2008). Baobab fruit pulp has also been shown to lower elevated body temperature without affecting normal body temperature (Ramadan et al., 1993). In a study conducted by Ramadan et al. (1993), *A. digitata* was tested *in vivo* to determine the biological anti-pyretic activity of fruit pulp in rats. The results show that there was a marked reduction of 1.94°C in the temperature of the mice that had been provided with an aqueous baobab extract of 800 mg/mL, compared to 0.42°C reduction for the control group. The antipyretic activity of the extract resembles that normally induced by standard dose of administered acetylsalicylic acid (ASA) in hyperthermic rats (Ramadan et al., 1993).

Analgesic property

The analgesic effect of baobab pulp was also investigated by Ramadan et al. (1993). The results showed that 800 mg/kg baobab pulp aqueous extract gives comparable and long lasting effects with classical drugs - equivalent to 50 mg/kg acetylsalicylic acid analgesic effect. This activity may be attributed to the presence of sterols, saponins and triterpenes in the aqueous extract (Ramadan et al., 1993). The analgesic activities were also mentioned by Masola et al. (2009), probably due to the presence of sterols, saponins and triterpenes in the fruit pulp.

Hepatoprotective properties

The hepatoprotective influences of baobab fruit pulp were investigated by Al-Qarawi et al. (2003). When extracts of baobab pulp were assessed for their influence on the liver of Wistar male albino rats, it was found that significant hepatoprotection was achieved. The results showed that baobab fruit pulp extract had both protection and restoration effects of liver damage in the rats. The authors stated that this may have been as a result of the triterpenoids, β -sitosterol, β -amyirin palmitate, terpenoids

and ursolic acid present in the fruit. The authors also summarized that other bioactivities of baobab fruit including analgesic, anti-inflammatory and antimicrobial activities could be the factors influencing the hepatoprotective activity observed (Al-Qarawi et al., 2003).

Anti-microbial activity

An acid medium, as created by the addition of baobab pulp powder to *tempe* (fermented soybeans using the fungus *Rhizopus oligosporus*) fermentation could prevent the growth of pathogenic bacteria such as *Salmonella* sp., *Bacillus* sp. and *Streptococcus* sp. (Afolabi and Popoola, 2005). Moreover, increasing concentrations of baobab pulp powder led to an increase in the population of lactic acid bacteria. This is beneficial to consumers since most of the lactic acid bacteria species are nontoxic and have been reported to produce an enzyme that breaks the oligosaccharides in soybean down to their mono- and disaccharide constituents. The presence of lactic acid bacteria in *tempe* prepared as it is being done locally in Nigeria will not only improve the digestibility of *tempe*, but will also extend the shelf life of the product because of the preservative attributes of lactic acid bacteria (Afolabi and Popoola, 2005). According to Yagoub (2008) the petroleum ether, ethanol and aqueous extracts of baobab showed antimicrobial activity against *Escherichia coli*.

Anti-viral activity

A. digitata leaves, fruit-pulp and seeds have shown antiviral activity against influenza virus, herpes simplex virus and respiratory syncytial virus (Vimalanathan and Hudson, 2009) and polio (Anani et al., 2000). Chemical analyses have reported the presence of various potentially bioactive ingredients including triterpenoids, flavonoids and phenolic compounds (Chadare et al., 2009).

Anti-trypanosoma activity

Extracts of baobab roots eliminate the motility in *Trypanosoma congolense* within 60 min and drastically reduce motility in *Trypanosoma brucei brucei* (Manfredini, 2002).

Antidiarrhoea activity

In a study carried out by Tal-Dia et al. (1997), the efficacy of a traditional local solution made up of dried baobab

fruit with water and sugar was compared to the World Health Organisation (WHO) standard solution used to treat children with acute diarrhoea. The WHO standard solution is an oral rehydration salt (ORS) solution consisting of glucose, sodium, potassium and citrate dissolved in drinking water. Results obtained were based on the progression of diarrhoea and weight gain. Although, results obtained in this study revealed that the WHO solution was found to be superior to the baobab mixture, there was no statistical difference between the two solutions in terms of duration of diarrhoea and weight gain. It was also noted that the traditional local solution did possess the advantages of being an excellent nutrient source, more economical than the WHO solution and also easily available to African cultures compared to the WHO solution. Two main factors attributed to the anti-diarrhoeic action of baobab are thought to include the astringent action of the tannins causing an inhibition of osmotic secretions in addition to the anti-inflammatory action of the baobab mucilage on the intestinal mucous membrane (Wickens and Lowe, 2008). The presence of tannins, mucilage, cellulose and citric acid present in the baobab may also have a role to play in the effects of baobab fruit pulp against diarrhoea (Gruenwald and Galizia, 2005).

Source of fibers with prebiotic-like activity

Baobab fruit pulp supplies a quantity of soluble (22.54% dry weight) and insoluble (22.04% dry weight) fibres (Manfredini, 2002). Studies carried out highlight that the water-soluble fraction of the fruit pulp has stimulating effects on the growth of lactobacilli and bifidobacteria (Manfredini, 2002).

Vitamin C healing effect

Vitamin C is a powerful antioxidant and extremely important in human nutrition. Vitamin C has been shown to be related to low blood pressure, enhanced immunity against many tropical diseases, lower incidence of cataract development and lower incidence of coronary disease. The daily recommended intake for healthy adults is 65 mg (Chadare et al., 2009). Using the average vitamin C content of baobab fruit (2800 mg/kg dry weight), the recommendations can be converted into amounts of baobab powder. The daily recommended dose of vitamin C can be obtained from 23 g of baobab powder (Chadare et al., 2009).

Antidote to poison

Bark, fruit pulp and seeds appear to contain an antidote

to poisoning by *Strophanthus* species (Sidibe and Williams, 2002). According to Wickens (1979) they contain the alkaloid "adansonin", which has a strophanthus-like action. The juice of these species has been used widely as an arrow poison especially in East Africa. In Malawi, a baobab extract is poured onto the wound of an animal killed in this way to neutralise the poison before the meat is eaten (Wickens, 1982).

Cosmetic treatments

An infusion of roots is used in Zimbabwe to bathe babies to promote smooth skin (Wickens, 1982). Seed oil is used to treat skin complaints (Sidibé and Williams, 2002).

Natural and interesting excipient

Baobab pulp fruit powder has good lubricating, binding-agent, diluting characteristics. In some studies it was used as hydrophilic excipient for the tablets preparation of paracetamol and theophylline with long lasting effect (Arama et al., 1988; Arama et al., 1989).

Uses in traditional medicine

Baobab leaves, bark, pulp and seeds are used as food and for multiple medicinal purposes in many parts of Africa (Diop et al., 2005). Baobab fruit and leaf are used in folk medicine as an antipyretic or febrifuge to overcome fevers. Fruit pulp and powdered seeds are used in cases of dysentery and to promote perspiration (Sidibe and Williams, 2002). Baobab fruit pulp has traditionally been used as an immunostimulant (Al-Qarawi et al., 2003), anti-inflammatory, analgesic, antipyretic, febrifuge and astringent in the treatment of diarrhoea and dysentery (Ramadan et al., 1993). The aqueous extract of baobab fruit pulp exhibited significant hepatoprotective activity and, as a consequence, the consumption of the pulp may play an important part in human resistance to liver damage in areas where baobab is consumed (Al-Qarawi et al., 2003). Medicinally, baobab fruit pulp is used as a febrifuge and as an anti-dysenteric and in the treatment of smallpox and measles as an eye instillation (Wickens, 1979). In Indian medicine, baobab pulp is used internally with buttermilk in cases of diarrhoea and dysentery. Externally, use is made of young baobab leaves (Figure 2) crushed into a poultice, for painful swellings (Sidibe and Williams, 2002). Seeds are used in cases of diarrhoea, and hiccough.

Oil extracted from seeds is used for inflamed gums and to ease diseased teeth (Sidibe and Williams, 2002). Since seed oil is used to also treat skin complaints, it can be considered to have cosmetic applications as well

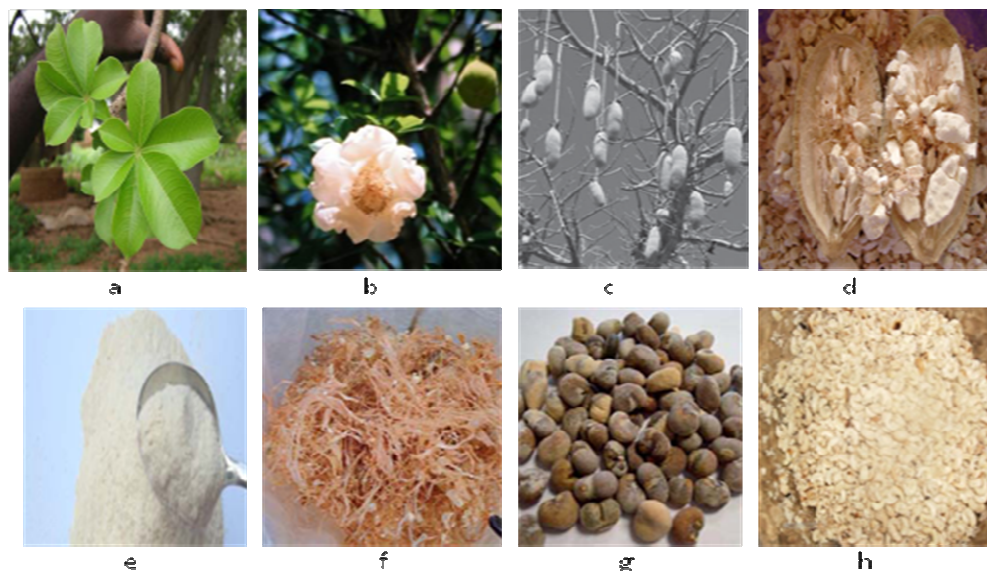


Figure 2. a- Baobab leaves; b- Baobab flower; c- Baobab fruits; d- Baobab pulp; e- Pulp powder; f- Baobab fibre; g- Baobab seeds; h- kernels.

(Sidibe and Williams, 2002). Powdered leaves are used as a tonic and an anti-asthmatic and known to have antihistamine and anti-tension properties. The leaves are also used to treat insect bites, Guinea worm and internal pains, dysentery, diseases of the urinary tract, ophthalmia and otitis (Sidibe and Williams, 2002). In Indian medicine, powdered leaves are similarly used to check excessive perspiration (Sidibe and Williams, 2002). Baobab leaves are used medicinally as a diaphoretic, an astringent, an expectorant and as a prophylactic against fever (Wickens, 1979). The leaves also have hyposensitive and antihistamine properties. Leaves are used to treat kidney and bladder diseases, asthma, general fatigue, diarrhoea, inflammations, insect bites and guinea worm (Wickens, 1979).

The widest use in tradition medicine comes from the baobab bark as a substitute for quinine in case of fever or as a prophylactic. A decoction of the bark deteriorates rapidly due to the mucilaginous substances present (Sidibe and Williams, 2002). Baobab bark is used in Europe as a febrifuge (antipyretic). In the Gold Coast (Ghana), the bark is used instead of quinine for curing fever (Shukla et al., 2001). In Indian medicine, baobab bark is used internally as a refrigerant, antipyretic and antiperiodic (Sidibe and Williams, 2002). The bark, however, is certainly used for the treatment of fever in Nigeria (Wickens, 1979). Moreover, the bark contains a white, semi-fluid gum that can be obtained from bark wounds and is used for cleansing sores (Wickens, 1979). According to the same authors, there are no alkaloids present in the bark. In Congo Brazzaville, a bark decoction is used to bathe rickety children and in

Tanzania as a mouthwash for toothache (Wickens, 1979). Baobab bark, fruit pulp and seeds appear to contain an antidote to poisoning by a number of *Strophanthus* species. The juice of these species has been widely used as an arrow poison especially in East Africa. In Malawi, a baobab extract is poured onto the wound of an animal killed in this way to neutralize the poison before the meat is eaten (Wickens, 1979). An infusion of roots is used in Zimbabwe to bathe babies to promote smooth skin (Wickens, 1982).

BAOBAB FOOD PRODUCTS: PROCESS AND TRADITIONAL USES

Food derived from baobab leaves

Dry leaf powder and dry leaves are also used to prepare sauces (Chadare et al., 2009). Young leaves are widely used, cooked as spinach, or frequently dried, often powdered and used for sauces, thick gruels of grains, or boiled rice (Sidibe and Williams, 2002).

Foods derived from baobab pulp

The pulp is a powdery product. The main foods from pulp are the gruel, the sour dough and the beverage. Gruel is made from cereal (maize or millet) flour and baobab pulp. There are two techniques: in the first case, water is boiled and cereal flour is mixed with cold water; this mixture is subsequently added to the boiling water to make cereal

gruel. This gruel is removed from the fire and diluted baobab pulp is added and mixed to obtain baobab gruel. For the second method, baobab pulp is diluted in water and boiled; diluted cereal flour is added to the boiling baobab juice to obtain the pulp gruel (Chadare et al., 2009). The sour dough is a fermented paste from baobab pulp. Diluted baobab pulp is required. This can be obtained by soaking the content of baobab fruit in water or by diluting baobab pulp in water. The second important ingredient for sour dough is cereal (maize, millet or sorghum) dough which is prepared with cereal flour and water.

The cereal dough is mixed with diluted baobab pulp, or alternatively the diluted pulp is boiled and used to make dough with cereal flour. The mixture is put in a jar, covered and fermented for at least 24 h. This dough keeps on fermenting up to seven days without any deterioration. After five to seven days, part of this dough can be used as starter in the preparation of sour dough. In this case, the starter will be mixed with the freshly prepared cereal dough and will be left again for one to seven days to ferment like the previous one. This “back-slopping” technique is used mainly during periods of pulp shortage (Chadare et al., 2009). Pulp beverage is obtained either by soaking the whole contents of the fruit in water to extract the drink from it or by diluting baobab pulp in water. The consistency is adjusted according to consumer preference (Chadare et al., 2009). Baobab pulp can be used to produce jam and jelly or nectar (Cissé et al., 2009; Ndabikunze et al., 2011).

Foods from the whole seeds

Baobab seeds can be eaten fresh or may be dried and ground into flour which can either be added to soups and stews as a thickener, or roasted and ground into a paste, or boiled for a long time, fermented and then dried for use (FAO, 1988; Nnam and Obiakor, 2003; De Galuwé et al., 2010). Figure 3 illustrates the production process of *maari*, a traditional fermented condiment produced from *A. digitata* seeds in Burkina Faso (Parkouda et al., 2010). For traditional fermentation, baobab seeds are boiled and kept in dark room at $28\pm 2^\circ\text{C}$ to ferment by the microflora present in the seeds for 96 h. The resulting product is air-dried. The condiment is used as a flavor intensifier for soups and stews and also added to protein-poor diet in certain home of Northern of Burkina (Compaoré, 2009; Parkouda et al., 2010).

Foods from the kernels

Kernels are obtained by dehulling the seed. Baobab kernels are used for kernel sauce. Other foods from kernels are roasted kernels. Kernel sauce is prepared by optional roasting of the kernels followed by grinding; the

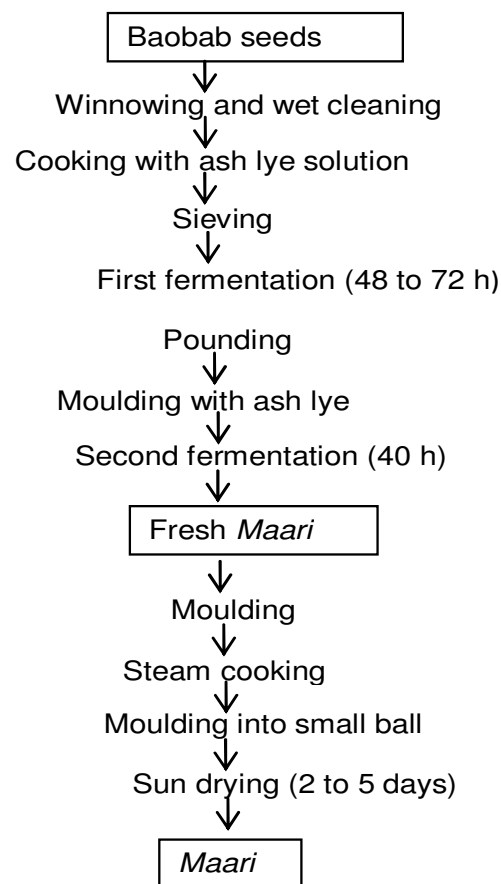


Figure 3. Diagram of traditional processing of baobab seeds into *maari* (Parkouda et al., 2010).

resulting product is used as protein concentrates in tomato or spiced sauce (Chadare et al., 2009).

Foods from baobab roots

Potash is the only food ingredient made from baobab roots. Potash solution is made with the ash from incineration of the roots (Chadare et al., 2009).

EFFECTS OF PROCESSING TECHNIQUES ON BAOBAB FOOD PRODUCTS

The acceptability and optimal utilization of baobab part are limited by the presence of antinutrients such as tannins, phytic acid, amylase inhibitors and trypsin inhibitors. It is known that processing techniques may rob a food item of some nutrients. On the other hand, processing may enhance food nutritional quality by reducing or destroying the antinutrients present in it.

Some of the commonly used processing techniques

Table 2. Effects of the processing techniques on nutrient composition and antinutritional factors in baobab seeds.

References	Nnam and Obiakor, 2003		Addy et al., 1995				Igboeli et al., 1997					
	Unfermented seeds	Fermented seeds (72 h)	Hot-water	Hot-acid	Hot-alkali	Fermented (36 h)	Whole seeds	Dehulled	Cold water	Hot-water	Hot-acid	Hot-alkali
Protein	25.45	22.2	34.40	35.50	32.40	31.20	NM	NM	NM	NM	NM	NM
Protein digestibility	NM	NM	85.30	48.20	88.30	90.10	NM	NM	NM	NM	NM	NM
Carbohydrate	48.07	42.62	26.30	21.80	22.40	24.40	NM	NM	NM	NM	NM	NM
Fat	18.87	30.55	35.10	38.80	41.40	40.60	NM	NM	NM	NM	NM	NM
Ash	7.61	4.63	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Ca (mg)	0.50	0.57	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
P (mg)	326.33	303.00	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
K (mg)	0.60	0.77	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Fe (mg)	0.63	0.55	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Zn (mg)	1.29	1.80	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Cu (mg)	0.02	0.02	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
I (mg)	0.04	trace	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Amylase inhibitor activity ($\mu\text{g}/100\text{ g}$)	NM	NM	NM	NM	NM	NM	35	10	0.0	159	94	17
Trypsin inhibition activity (TIA/g)	NM	NM	18.7	4.8	2.7	3.6	NM	NM	NM	NM	NM	NM
Tannin (mg/100 g)	0.25	0.18	2.7	2.3	2.2	6.4	40	39	25	27	23	22
Phytate	0.18	0.16	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM

NM: Not mentioned.

include soaking in water, sprouting, boiling in alkaline or acidic solutions. The review on the effects of different processing techniques on nutrient composition and antinutritional factors in baobab seeds is presented in Table 2.

The effects of fermentation

Addy et al. (1995) and Nnam and Obiakor (2003) found that fermentation decreased the protein level of the seeds (Table 2). The decrease could

be attributed to possible increase in the number of microflora, which uses protein for metabolism (Nnam and Obiakor, 2003). Odunfa (1985) reported predominantly high numbers of proteolytic bacteria during the fermentation of a similar oil seed, the castor oil seed. However, the activities of the proteolytic bacteria could result in improved digestibility and availability of protein because of the breakdown by the proteases of the protein-tannin, tannin-enzyme and protein-phytate complexes to make the nutrient more available for digestion and utilization (Kazanas and Fields,

1981). Fermentation decreased the carbohydrate level of the seeds (Addy et al., 1995; Nnam and Obiakor, 2003). The decrease was likely due to the use of the nutrient especially its metabolite, the simple sugar, as a source of energy (Achinewhu, 1986), and the use of the carbohydrate to provide carbon skeleton for the synthesis of other compounds (Kazanas and Fields, 1981). It is known that amylolytic enzymes hydrolyze starch and oligosaccharides to simpler free soluble sugars during fermentation. The activities of the amylolytic enzymes to break down

the complex carbohydrates to simple and more absorbable sugars are likely to increase the availability of the nutrient in the fermented samples (Nnam and Obiakor, 2003). Unlike carbohydrates and proteins, the fat levels of the seeds increased during the fermentation period. The increase likely may be due to the increased activities of the lipases which hydrolyze fat to glycerol and fatty acids (Odunfa, 1983). The fatty acids could have been used for synthesis of new lipids. The increase in fat would increase the energy density of the seeds. Nnam and Obiakor (2003) reported that fermentation had varied effects on the mineral concentrations of the seeds. There was increase in calcium (Ca), potassium (K) and zinc (Zn) levels of the seeds due to fermentation. Phosphorus (P), iron (Fe) and copper (Cu) levels increased only in the 24 h fermented seeds. Fermentation did not improve iodine level. Fermentation decreased the tannin levels in baobab seed (Nnam and Obiakor, 2003).

The decrease in tannin likely may be due to hydrolysis of the polyphenolic compound to simpler substances by the enzyme polyphenol oxidase or the breakdown of the tannin complexes (tannin-protein, tannic acid-starch and tannin-iron complexes) to release free nutrients (Obizoba and Atti, 1991). The tannins leached into the fermentation medium. Tannins are known to reduce the availability of proteins, carbohydrates and minerals by forming indigestible complexes with the nutrients. The reduced tannin level due to fermentation could improve the availability of nutrients in the seed (Nnam and Obiakor, 2003). However, the decreases in tannin are not in line with the findings of Addy et al. (1995) who reported increased tannin level due to fermentation of baobab seeds. Nnam and Obiakor (2003) reported that the phytate levels were reduced during fermentation. This could be attributed to increased activities of phytase during fermentation (Fardiaz and Markakis, 1981). The enzyme dephosphorylates phytate on successive steps terminating with the formation of inositol and phosphoric acid. The process releases certain metals to increase their availability and cause subsequent decrease in phytate (Nnam and Obiakor, 2003).

Effects of dehulling, cold-water, hot-water, hot-alkali and acid treatments of baobab seeds

Addy et al. (1995) reported that acid and alkali treatments caused a decrease in protein and carbohydrate contents of baobab seeds. This may be attributed to the leaching of soluble sugar and proteins. Unlike carbohydrates and proteins, the acid and alkali treatments increased the oil contents because of the cleavage of the protein-lipid or carbohydrate-lipid linkages thereby facilitating the easy extraction of the oil (Addy et al., 1995). The alkali treatment enhanced protein digestibility of baobab seeds

while the acid treatment decreased the digestibility indices. The treatments might have denatured the protein and rendered it more susceptible to proteolytic degradation (Addy et al., 1995). The levels of reduction in trypsin inhibitor activity values varied between 74 to 86% for the baobab (Addy et al., 1995). It would appear that the additional heat treatment used in acid, alkali were responsible for the denaturation of the trypsin inhibitors. It has been suggested that trypsin inhibitors exist in bound forms which may be released after fermentation (Kakade et al., 1974). However, it would be difficult to postulate the existence of bound trypsin inhibitors in baobab seeds. According to Addy et al. (1995) and Igboeli et al. (1997), dehulling, cold-water, hot-water, hot-alkali and acid treatments caused a decrease in tannin contents of baobab seeds. Addy et al. (1995) also reported the decrease of tannins level when the seeds were subjected to alkali and acid treatments.

The reduction in the tannin level of cold-water treated seeds could be due to leaching of the tannins since these tannins are water soluble. A reduction in tannins observed when hot water was applied to seed processing may have been due to heat degradation of the tannin molecules or to the formation of water-soluble complexes with other macromolecules of the seeds. Such water-soluble complexes could leach out into the cooking liquor (Uzogara et al., 1990). It is suggested that the decrease in tannin level when hot-alkali treatment is used might be due to a possible reaction between tannic acid and the base or to alterations in the chemical structure of the tannins that rendered them incapable of giving the colour reaction (Babar et al., 1988). The activity of the amylase inhibitors in the seeds was also reduced significantly by dehulling, cold-water and hot-alkali treatments while the hot-water and hot-acid treatments increased the activity of the amylase inhibitors that could be due to the presence of some unidentified factors in the seeds which enhanced amylase inhibitor activity by modifying the enzyme active sites. It may also be possible that the inhibitors diffused into the seed matrix (Igboeli et al., 1997).

Effect of cooking

Chadare et al. (2009) investigated the effect of cooking on *in vitro* solubility of calcium, iron and carotenoids in baobab leaf. Cooking increase calcium content, caused by loss of other leaf components such as volatile ones. After *in vitro* digestion, 10 to 30% of Ca was available, probably resulting from the degradation of fibrous components (Chadare et al., 2009). The iron content after cooking slightly increased; this might be related to stable chemical binding to compounds that probably inhibit iron release such as phytates, calcium and polyphenols. For both raw and cooked leaves, the levels of dissolved iron

in *in vitro* prepared digests were below the detection limit. The very low solubility is probably caused by the retention of iron in the undigested pellet because of chemical complexation (Chadare et al., 2009). The zinc content after cooking slightly increased. After *in vitro* digestion, the levels of dissolved Zn of both raw and cooked leaves were below the detection level, probably caused by a strong complexation with the pellet of undigested leaf material (Chadare et al., 2009). The main carotenoids detected in baobab leaves were lutein, trans-betacarotene, betacarotene cis 1 and betacarotene cis 2 (Chadare et al., 2009). Cooking induced a decrease in lutein content while the trend for betacarotene varied according to the type of the leaves. Cooking decreased trans betacarotene content in sweet leaves and increased in bitter leaves. Cooking decreased betacarotene cis 1 content in leaves but no clear trend was observed for betacarotene cis 2 (Chadare et al., 2009).

OTHER USES OF BAOBAB

Fibre

Fibre from the inner bark is strong and widely used for making rope, basket nets, snares, fishing lines and is even used for weaving. Fibres are also available from disintegrated wood and have been used for packing. Other fibres used for rope are obtained from root bark (Sidibé and Williams, 2002).

Dye

In East Africa, roots are used to make a soluble red dye. The green bark is also used as a dye and for decoration (Sidibé and Williams, 2002).

Seed shell

The hard fruit shells are used in the manufacture of pots for food and drink (Sidibé and Williams, 2002).

Fuel

The wood is a poor source of fuel; however, fruit shells are used as fuel in Tanzania. Fruit shells are also used as water dippers (Sidibé and Williams, 2002).

Animal browse and feed

Leaves of baobab are routinely browsed especially in the agrosylvipastoral systems in the Sahel. The high tannin

content of the leaves has a significant effect on *in vivo* dry matter digestibility. Optimal dry matter degradation in sheep feed was at a level less than 30% of the browse, and browse digestibility of the leaves was 47% (Touré et al., 1998). Since the tannin level is more than twice the critical level, the amount of baobab leaf in the browse has to be kept to a reasonable level. However, an emollient is present in the leaves which may cause acceleration in the ruminant digestive tract. Shells from the fruits and the seedcake, left after pounding to extract seed oil, are usually fed to animal stock (Sidibé and Williams, 2002).

CONCLUSION

The baobab is a multipurpose tree species widely used for food, non-food products and medicine. Every part of the baobab tree is reported to be useful. Baobab's edible parts (leaves, seeds and pulp) are rich in nutrients. The acceptability and optimal utilization of baobab parts as nutrient source is limited by the presence of antinutrients such as protease inhibitors, tannins, phytates but the processing techniques may reduce or destroy the antinutrients present in it. Baobab leaves, bark, roots, pulp and seeds are used for multiple medicinal purposes in many parts of Africa and were found to show interesting pharmacological properties including antioxidant, prebiotic-like activity, anti-inflammatory, analgesic, antipyretic activity, anti-diarrhoea, anti-dysentery activity and excipient. Now, bioavailability and pharmacokinetics study of the plant need to be carried out for the assurance of safety reasons. It is hoped that this review will be a strong stimulus for research and development efforts towards better understanding and utilization of the baobab tree.

ACKNOWLEDGEMENTS

This work was supported by Département Technologie Alimentaire (DTA/IRSAT/CNRST in Ouagadougou, Burkina Faso) and Department of Food Science (Faculty of Life Sciences, University of Copenhagen, Denmark) are acknowledged for their assistance.

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