



***Balanites aegyptiaca* and *Adansonia digitata*: A Comprehensive Review of Ethnobotany, Phytochemistry, and Comparative Antioxidant Potential**

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Abstract

The global burden of chronic diseases linked to oxidative stress has intensified the search for safe and effective natural antioxidants. *Balanites aegyptiaca* (Desert Date) and *Adansonia digitata* (Baobab), two cornerstone species of the African flora, have been used for generations as food and medicine, suggesting a rich reservoir of bioactive compounds. This comprehensive review synthesizes existing scientific literature with new comparative research data to evaluate the ethnobotanical significance, phytochemical composition, and in-vitro antioxidant efficacy of these fruits. The analysis confirms that both fruits are nutritionally dense, containing valuable proximate components (crude fiber, protein, carbohydrates), essential antioxidant minerals (Cu, Fe, Zn, Se, Mn), vitamins (A, C, E), and a diverse profile of phytochemicals including flavonoids, saponins, and phenolic compounds. However, a direct, systematic comparison reveals that *Balanites aegyptiaca* fruit pulp possesses a consistently superior antioxidant profile. It demonstrates significantly higher concentrations of total phenolics (39.74 vs. 28.96 mg GAE/g) and flavonoids (27.14 vs. 19.75 mg QE/g), a richer mineral content (e.g., Se: 0.04 vs. 0.02 ppm; Fe: 0.05 vs. 0.03 ppm), and greater levels of vitamins C and E. Consequently, *B. aegyptiaca* exhibits a stronger dose-dependent free radical scavenging activity in the DPPH assay (38.19% vs. 34.53% at 100 mg/ml). These findings provide a scientific basis for the traditional uses of these plants and strongly position *Balanites aegyptiaca*, in particular, as a potent and sustainable source of natural antioxidants for developing functional foods, nutraceuticals, and therapeutic agents aimed at mitigating oxidative stress-related pathologies.

Keywords: *Balanites aegyptiaca*, *Adansonia digitata*, Antioxidants, Oxidative Stress, Phytochemicals, Proximate Analysis, DPPH, Indigenous Knowledge, Functional Foods.

1. Introduction

1.1 The Central Role of Oxidative Stress in Human Disease: Oxidative stress is defined as a pathological state arising from an imbalance between the production of reactive oxygen species (ROS) and the body's ability to detoxify these reactive intermediates or repair the resulting damage (Pisoschi & Pop, 2015). ROS, including free radicals like the superoxide anion ($O_2^{\bullet-}$) and hydroxyl radical ($\bullet OH$), are natural byproducts of cellular metabolism, particularly mitochondrial respiration. At low concentrations, they play roles in cellular signaling and immune function. However, their overproduction, driven by factors such as environmental pollutants, UV radiation, poor diet, and smoking, overwhelms the endogenous antioxidant defense system (Alkadi, 2020).

This imbalance leads to the oxidative modification of critical cellular macromolecules. Lipids undergo peroxidation, damaging cell membranes; proteins are denatured, impairing enzyme function; and DNA suffers strand breaks and mutations, initiating carcinogenesis (Halliwell, 2024). This molecular damage is a fundamental etiological factor in a wide spectrum of chronic diseases, including atherosclerosis, diabetes mellitus, cancer, neurodegenerative disorders like Alzheimer's and Parkinson's disease, and the aging process itself (Leyane et al., 2022). Consequently, strategies to bolster the body's antioxidant defenses have become a major focus of preventive medicine and nutritional science.

1.2 The Shift Towards Natural Antioxidants:

The body's defense against ROS comprises enzymatic antioxidants (e.g., superoxide dismutase-SOD, catalase-CAT, glutathione peroxidase-GPx) and non-enzymatic, dietary antioxidants. For decades, synthetic antioxidants like butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) were widely used in the food and pharmaceutical industries. However, growing concerns over their potential toxicity, carcinogenicity, and side effects with long-term consumption have prompted a global shift towards natural alternatives (Wang et al., 2021).

Natural antioxidants, derived primarily from plants, are perceived as safer, more biocompatible, and often exhibit multifunctional health benefits beyond mere free radical scavenging (Budzianowska et al., 2025). These compounds, which include vitamins (A, C, E), minerals (Se, Zn, Cu, Mn), and a vast array of phytochemicals (flavonoids, phenolics, saponins), can chelate pro-oxidant metals, modulate antioxidant enzyme activity, and reduce inflammation (Kumar et al., 2022). The consumption of a diet rich in these compounds is consistently associated with a reduced risk of chronic diseases.

1.3 Indigenous Fruits as Untapped Reservoirs of Bioactivity: In many parts of Africa, a rich heritage of indigenous knowledge surrounds the use of local flora for food and medicine. Fruits from trees like *Balanites aegyptiaca* and *Adansonia digitata* are not only dietary staples but also form the backbone of traditional pharmacopoeias for treating various ailments, many of which are now understood to be linked to oxidative stress. Despite their cultural and nutritional importance, these species often remain underutilized from a scientific and commercial perspective. A systematic, comparative investigation of their antioxidant composition is crucial to validate traditional claims, unlock their economic potential, and integrate them into evidence-based health strategies. This review aims to fill this gap by providing a consolidated and comparative analysis of the ethnobotany, phytochemistry, and antioxidant power of these two remarkable African fruit species.

2. Botanical and Ethnobotanical Profiles

2.1 *Balanites aegyptiaca* (L.) Del. - The Desert Date: *Balanites aegyptiaca*, a member of the Zygophyllaceae family, is a resilient xerophytic tree native to the arid and semi-arid regions of Africa and South Asia. It is known by various vernacular names, such as 'Aduwa' in Hausa (Nigeria) and 'Tanni' in Fulfulde, reflecting its wide distribution (Chothani & Vaghasiya, 2011).

- **Botanical Description:** The tree is deep-rooted, evergreen or semi-deciduous, and can grow up to 12 meters in height. It is characterized by its multi-branched, spiny nature, with a bark that ranges from brownish to greyish in older plants. The leaves are dark green, fleshy, and bifoliate. The fruit is a drupe, typically ovoid, about 2.5-7 cm long. When unripe, it is green and tormentose, maturing to a yellow or brownish color with a sticky, bitter-sweet pulp surrounding a hard, stone-like seed (Liu & Nakanishi, 2022).
- **Ethnobotanical Uses:** Virtually every part of the *B. aegyptiaca* tree has a use. The fruit pulp is edible and is commonly used as a laxative or purgative for treating constipation, colic, and stomach aches. The leaves are used as a vegetable in soups. The stem bark and roots are renowned for their medicinal properties, used as a fish poison (non-toxic to humans), an abortifacient, and for treating malaria, jaundice, and viral infections (Kokwano, 2021). Its widespread use in traditional medicine points to a complex and potent phytochemical profile.

2.2 *Adansonia digitata* L. - The Baobab: *Adansonia digitata*, belonging to the Malvaceae family, is an iconic tree of the African savanna, easily recognized by its massive, bottle-shaped trunk which can reach up to 10 meters in diameter. It is a symbol of life and resilience in harsh environments, known as 'Kuka' in Hausa.

- **Botanical Description:** This long-lived tree can grow up to 25 meters tall and live for hundreds of years. Its branches are thick and gnarled, often appearing root-like, leading to the myth that the tree was planted upside down. The leaves are digitate, with 5-7 leaflets. The fruit is a large, ovoid to round capsule (15-20 cm long) with a hard, woody shell covered by a greenish-yellow, fuzzy exterior. Inside, the dry, white pulp envelops numerous oil-rich seeds (Vertuani et al., 2020).
- **Ethnobotanical Uses:** The baobab is a classic example of a multi-purpose tree. The fruit pulp is rich in vitamin C and is either sucked directly or dissolved in water or milk to make a refreshing and nutritious drink. The young leaves are used as a spinach-like vegetable in soups. The seeds can be roasted and eaten as a snack or ground into a flour. The bark is used for making ropes, cloth, and mats. Medicinally, the pulp is used to treat fever, diarrhea, and dysentery, while the leaves are used for kidney and bladder diseases, asthma, and as a general tonic (Gebauer et al., 2018). Its value extends beyond nutrition to providing shelter, clothing, and income.

3. Classification and Mechanisms of Antioxidants

To appreciate the antioxidant potential of these fruits, a clear understanding of antioxidant types and their mechanisms is essential. Antioxidants can be broadly classified into two categories: enzymatic and non-enzymatic (Fig. 1.5).

3.1 Enzymatic Antioxidants: These are endogenous enzymes produced by the body that form the first line of defense against ROS.

- **Superoxide Dismutase (SOD):** Catalyzes the dismutation of superoxide radicals ($O_2^{\bullet-}$) into hydrogen peroxide (H_2O_2) and oxygen. It exists in forms dependent on copper-zinc (Cu/Zn-SOD) or manganese (Mn-SOD) (Ighodaro & Akinloye, 2018).
- **Catalase (CAT):** Located primarily in peroxisomes, it rapidly decomposes H_2O_2 into water and oxygen.
- **Glutathione Peroxidase (GPx):** A selenium-dependent enzyme that reduces H_2O_2 and lipid hydroperoxides to water and alcohols, respectively, using glutathione (GSH) as a substrate.

3.2 Non-Enzymatic Antioxidants: This category includes compounds obtained from the diet, which are the primary focus of this review.

- Minerals: Act as essential cofactors for enzymatic antioxidants.
 - Selenium (Se): A central component of GPx.
 - Copper (Cu), Zinc (Zn), Manganese (Mn): Serve as cofactors for SOD.
 - Iron (Fe): Essential for catalase and cytochrome enzymes, though free iron can be pro-oxidant.
- Vitamins:
 - Vitamin C (Ascorbic Acid): A powerful water-soluble antioxidant that directly scavenges a wide range of ROS and regenerates Vitamin E from its oxidized form (Agwu et al., 2023).
 - Vitamin E (Tocopherols): The major fat-soluble antioxidant that protects cell membranes from lipid peroxidation by donating a hydrogen atom to peroxyl radicals (Niki & Abe, 2019).
- Phytochemicals:
 - Phenolic Compounds: Characterized by aromatic rings with hydroxyl groups. They exert antioxidant activity through Hydrogen Atom Transfer (HAT) or Single Electron Transfer (SET) mechanisms, effectively neutralizing free radicals. They also chelate metal ions (e.g., Fe^{2+} , Cu^{2+}), preventing Fenton reactions that generate highly reactive $\bullet\text{OH}$ radicals (Vuolo et al., 2019).
 - Flavonoids: A large subclass of polyphenols with a C6-C3-C6 structure. They are potent free radical scavengers, metal chelators, and can also upregulate endogenous antioxidant enzymes (Saleem et al., 2022).
 - Saponins: Glycosides with amphiphilic properties. Their antioxidant activity is linked to their ability to scavenge radicals and interact with cell membranes, protecting them from oxidative damage (Mustafa et al., 2022).

The synergy between these different classes of antioxidants creates a robust and efficient defense network, which is precisely what makes plant-based foods so effective.

4. Comparative Phytochemical and Nutritional Composition

A comparative analysis of the biochemical constituents of *B. aegyptiaca* and *A. digitata* provides the foundation for understanding their differential antioxidant capacities.

4.1 Proximate Composition: Proximate analysis reveals the basic nutritional matrix of the fruit pulps. The results, summarized in Table 4.1, show significant differences.

- Moisture Content: Both fruits have very low moisture content (*B. aegyptiaca*: 1.20%; *A. digitata*: 0.80%), which is advantageous for stability, shelf-life, and resistance to microbial spoilage, making them ideal for storage and use in dry formulations (WHO/FAO, 2004).
- Ash Content: The ash content, an indicator of total mineral matter, is significantly higher in *B. aegyptiaca* (6.00%) compared to *A. digitata* (2.50%). This directly suggests a greater overall mineral density in the Desert Date, which is corroborated by the mineral analysis discussed later.

- Crude Lipid and Fiber: *B. aegyptiaca* also contains significantly higher crude lipid (3.50% vs. 2.50%) and crude fiber (30.50% vs. 26.50%). The high fiber content is beneficial for digestive health, glycemic control, and cardiovascular health (Giuntini et al., 2022). The lipids may carry fat-soluble vitamins and essential fatty acids.
- Crude Protein: The crude protein content is comparable and notably high for fruits (*B. aegyptiaca*: 15.76%; *A. digitata*: 17.07%). This highlights their potential as valuable protein sources in vegetarian diets and for addressing protein-energy malnutrition.
- Carbohydrates: *B. aegyptiaca* has a significantly higher carbohydrate content (50.54% vs. 43.13%), positioning it as a better source of dietary energy.

4.2 Qualitative and Quantitative Phytochemical Screening: Qualitative Analysis (Table 4.2): Preliminary screening confirms the presence of a broad spectrum of phytochemicals in both fruits, including flavonoids, saponins, phenolic compounds, alkaloids, tannins, steroids, and terpenoids. *B. aegyptiaca* consistently shows a higher abundance (✓✓✓) of key antioxidant compounds like flavonoids, saponins, and phenolics compared to *A. digitata*.

Quantitative Analysis (Table 4.3): This provides a more precise measure of key antioxidant phytochemicals.

- Total Phenolic Content (TPC): Phenolic compounds are often the most significant contributors to antioxidant activity in plants. *B. aegyptiaca* demonstrated a significantly higher TPC (39.74 mg GAE/g) than *A. digitata* (28.96 mg GAE/g). This ~37% higher concentration is a major factor in its superior antioxidant performance.
- Total Flavonoid Content (TFC): Similarly, the TFC was significantly greater in *B. aegyptiaca* (27.14 mg QE/g) than in *A. digitata* (19.75 mg QE/g).
- Total Saponin Content: While the difference was not statistically significant in this study, *B. aegyptiaca* showed a higher mean value (17.06 mg DE/g vs. 12.36 mg DE/g), consistent with its traditional use as a soap substitute and its known saponin-rich profile.

4.3 Antioxidant Micronutrients: Mineral Elements (Table 4.4): Analysis via Atomic Absorption Spectroscopy (AAS) quantified essential trace minerals that act as cofactors for antioxidant enzymes.

- Copper (Cu) and Manganese (Mn): *B. aegyptiaca* contained significantly higher levels of both (Cu: 0.02 ppm; Mn: 0.03 ppm) compared to *A. digitata* (Cu: 0.01 ppm; Mn: 0.01 ppm). These are critical for the activity of Cu/Zn-SOD and Mn-SOD, respectively.
- Iron (Fe): *B. aegyptiaca* had a higher iron content (0.05 ppm vs. 0.03 ppm), which is vital for oxygen transport and enzyme function.
- Selenium (Se): This was a key differentiator. *B. aegyptiaca* contained 0.04 ppm of Se, double the amount found in *A. digitata* (0.02 ppm). Selenium is an integral part of the active site of GPx, making this a significant finding.
- Zinc (Zn): Levels were comparable and sufficient in both fruits (~0.05-0.06 ppm).

Antioxidant Vitamins (Table 4.5):

- Vitamin C: *B. aegyptiaca* possessed a significantly higher concentration (2.05 mg/L) than *A. digitata* (1.89 mg/L). As a primary water-soluble antioxidant and regenerator of Vitamin E, this difference is critically important.

- Vitamin E: The fat-soluble antioxidant Vitamin E was also present in significantly higher amounts in *B. aegyptiaca* (0.62 mg/L vs. 0.57 mg/L).
- Vitamin A: Levels were statistically similar, though slightly higher in *B. aegyptiaca*.

5. Comparative Analysis of Antioxidant Efficacy: The DPPH Assay

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay is a widely used, standard method to evaluate the free radical scavenging ability of compounds. The stable DPPH radical is purple in color, and when it accepts an electron from an antioxidant, it decolorizes to a yellow hue. The extent of decolorization indicates the scavenging potential.

5.1 Results and Interpretation: The results of the DPPH assay are presented in Table 4.6 and graphically in Fig. 4.1. The key findings are:

1. Dose-Dependent Response: Both fruit extracts showed a clear, concentration-dependent increase in radical scavenging activity. This is a classic characteristic of phytochemical antioxidants, where a higher concentration provides more electron-donating molecules to neutralize the DPPH radicals.
2. Consistent Superiority of *B. aegyptiaca*: At every concentration tested (20, 40, 60, 80, and 100 mg/ml), the scavenging activity of *B. aegyptiaca* was markedly higher than that of *A. digitata*. For instance, at the highest concentration (100 mg/ml), *B. aegyptiaca* achieved 38.19% scavenging, compared to 34.53% for *A. digitata*.
3. Comparison with Standard: As expected, pure ascorbic acid (Vitamin C) exhibited the highest activity (57.48% at 100 mg/ml), serving as a positive control. However, the fact that a crude extract of *B. aegyptiaca* approached this level of activity underscores its remarkable potency.

5.2 Correlation with Composition: The superior performance of *B. aegyptiaca* in the DPPH assay is not surprising given its compositional advantage. Its significantly higher levels of total phenolics and flavonoids—the primary contributors to antioxidant activity in plant extracts—directly account for its enhanced radical scavenging capacity. Furthermore, the synergistic presence of higher levels of antioxidant vitamins (C and E) and essential mineral cofactors (Se, Cu, Mn) creates a more comprehensive and efficient antioxidant system within its matrix. This synergistic effect likely amplifies its activity beyond what would be expected from the phenolics and flavonoids alone.

Conclusion and Future Perspectives

This comprehensive review, reinforced by new comparative data, unequivocally demonstrates that both *Balanites aegyptiaca* and *Adansonia digitata* are nutritional powerhouses with significant antioxidant properties. They represent a successful adaptation of traditional knowledge to address modern health challenges, particularly oxidative stress.

However, the evidence consistently positions *Balanites aegyptiaca* as the more potent of the two. Its significantly richer profile of phenolic and flavonoid antioxidants, its superior concentration of key mineral cofactors like selenium, and its higher levels of vitamins C and E collectively translate into a demonstrably stronger free radical scavenging capacity. This validates its extensive use in traditional medicine and suggests that it may offer greater health benefits when incorporated into the diet or used in therapeutic formulations.

While *Adansonia digitata* remains a valuable and nutritious fruit, especially noted for its vitamin C content and cultural significance, *Balanites aegyptiaca* emerges as a superior, yet relatively under-exploited, source of natural antioxidants.

Future research and development should focus on the following avenues to fully harness the potential of these fruits, particularly *B. aegyptiaca*:

1. **Bioactive Compound Isolation:** Employ advanced chromatographic techniques (HPLC, GC-MS) to isolate, identify, and characterize the specific phenolic acids, flavonoids, and saponins responsible for the observed activity.
2. **In-vivo and Clinical Studies:** Conduct animal and human intervention trials to confirm the bioavailability of these antioxidants and their efficacy in reducing biomarkers of oxidative stress *in vivo*.
3. **Mechanistic Elucidation:** Investigate the precise molecular mechanisms beyond radical scavenging, such as their effects on the Nrf2-ARE pathway, which regulates the expression of endogenous antioxidant enzymes.
4. **Synergistic Formulations:** Explore the development of functional foods, nutraceuticals, and cosmetic products by blending these fruit powders with other complementary ingredients to create synergistic antioxidant blends.
5. **Sustainable Valorization:** Promote the cultivation, sustainable harvesting, and commercial processing of these trees to create economic opportunities for rural communities while ensuring conservation of these valuable genetic resources.

In conclusion, the scientific validation of *Balanites aegyptiaca* and *Adansonia digitata* moves them from the realm of traditional folklore to the forefront of natural product research. Their integration into modern health and wellness paradigms offers a promising, sustainable, and culturally relevant strategy to combat the global rise of oxidative stress-related diseases.

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