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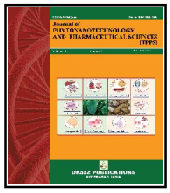

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Nutritional and immunological significance of *Adansonia digitata* L. fruit pulp

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Abstract

The increasing prevalence of immune-related disorders necessitates the exploration of natural functional foods with immunomodulatory potential. *Adansonia digitata* L. (baobab) fruit pulp, a nutrient-dense botanical, is rich in vitamin C, polyphenols, flavonoids, and dietary fiber; all of which contribute to its antioxidant, anti-inflammatory, and immune-enhancing properties. This study investigated the nutritional and immunological significance of baobab fruit pulp, emphasizing its bioactive components and their roles in metabolic and immune regulation. Phytochemical analysis confirmed the presence of flavonoids, tannins, saponins, and terpenoids, which contribute to its antimicrobial, antiviral, and anti-inflammatory effects. The high vitamin C content (213.18 ± 2.66 mg/100 g) enhances leukocyte function, modulates cytokine responses, and strengthens the epithelial barrier against pathogens. Additionally, its dietary fiber (5.28 ± 1.09%) promotes gut microbiota balance, supporting immune homeostasis. The hypoglycemic and hypolipidemic properties of baobab regulate glucose metabolism and reduce cardiovascular risk, further contributing to immune resilience. Despite its established pharmacological properties, few studies have explored its direct immunomodulatory mechanisms.This study aimed to bridge this gap by evaluating the immunonutritional effects of baobab pulp, providing scientific validation for its use as a functional food in immune enhancement. These findings underscore the potential of *A. digitata* as a natural dietary intervention for immune support and metabolic health, warranting further clinical investigation.

1. Introduction

Immunity is a highly coordinated defense mechanism that safeguards the body from pathogenic microbes, toxins, and abnormal cell proliferation (Asfaw *et al*., 2022). The immune system comprises innate and adaptive responses, each playing a distinct role in immune surveillance and protection (Jantan *et al*., 2015). While the innate immune system provides an immediate, non-specific defense through physical barriers, phagocytes, and inflammatory mediators, the adaptive immune system generates antigen-specific responses, mediated by B and T lymphocytes, resulting in immunological memory (Kumar *et al*., 2012a). However, immune dysfunction, characterized by hypo- or hyperactive responses, contributes to the development of infectious diseases, autoimmune disorders, and chronic inflammatory conditions. The increasing prevalence of immune-related diseases, including COVID-19, autoimmune disorders, and metabolic syndromes, highlights the necessity for effective and accessible therapeutic interventions (Qu *et al*., 2019; Banu *et al.,* 2024). Current therapeutic strategies, including vaccines, immuno-suppressants, and biologics, have significantly improved disease management. However, these approaches are often associated with high costs, limited availability in resource-poor settings, and potential side effects (Vesely *et al*., 2011). Consequently, there is a growing interest in alternative immunomodulatory approaches that are both safe and nutritionally beneficial. Among these, herbal medicine has emerged as a promising avenue, leveraging bioactive compounds with immunoregulatory properties (Wen *et al*., 2012). Functional foods rich in antioxidants, vitamins, and polyphenols have demonstrated the ability to enhance immune responses, mitigate oxidative stress, and regulate inflammatory pathways (Zebeaman *et al*., 2023).

Adansonia digitata L., commonly known as the baobab tree, is a multipurpose plant with exceptional nutritional and pharmacological properties (Dhlakama *et al*., 2022; Dare *et al*., 2022). Various parts of the tree, including the fruit pulp, leaves, seeds, and bark, have been traditionally utilized in African and tropical medicine to treat infections, inflammation, and metabolic disorders (Uhuo *et al*., 2022). The fruit pulp is a rich source of vitamin C, essential minerals, polyphenols, flavonoids, and tannins, all of which contribute to its potent antioxidant activity (El Yahyaoui *et al*., 2022). The leaves contain sterols, essential amino acids, and terpenoids, while the bark is a reservoir of alkaloids and cardiac glycosides. These phytochemicals collectively contribute to a range of pharmacological activities, including antimicrobial, antiviral, anti-inflammatory, and metabolic regulatory effects (Selvarani *et al*., 2020). Baobab fruit pulp has demonstrated significant antimicrobial activity against *Escherichia coli, Staphylococcus aureus,* and *Candida albicans*, primarily due to its high tannin and alkaloid content (Bashir *et al*., 2022). Additionally, it exhibits antiviral properties, particularly in respiratory infections such as influenza. The hypoglycemic effects of baobab are attributed to its ability to regulate glucose absorption and enhance insulin sensitivity, making it a promising dietary intervention for diabetes management (Rita *et al*., 2022). Furthermore, its hypolipidemic effects, largely mediated by phytosterols, contribute to reduced cholesterol and triglyceride levels (Yakubu *et al*., 2022). Traditionally,

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A. digitata has been used to manage gastrointestinal disorders such as diarrhea and dysentery. The fruit pulp, rich in dietary fiber, promotes gut microbiota balance and intestinal health (Sun *et al*., 2018). Baobab bark extracts have been utilized for fever management, while leaf poultices have been employed in wound healing. The cumulative pharmacological properties of baobab highlight its potential role in immune enhancement and disease prevention, particularly in mitigating oxidative stress-related disorders (Baky *et al*., 2021). Despite its well-documented nutritional and medicinal significance, limited research has explored the direct immunomodulatory effects of baobab fruit pulp.

This study aims to address this research gap by evaluating the immunological significance of *A. digitata* fruit pulp in relation to its nutritional profile. Investigating the interaction between its bioactive components and immune function will provide scientific validation for its application as a functional food for immune resilience and disease prevention. Given the increasing prevalence of immune dysfunction and metabolic disorders, understanding the immunonutritional properties of baobab pulp may contribute to the development of natural, food-based interventions for improved health outcomes.

2. Materials and Methods

2.1 Plant material

Adansonia digitata L. was collected from Nampally, Telangana, and its botanical identity was authenticated by the Botanical Survey of India, Deccan Regional Centre, Hyderabad. The authentication was confirmed under the reference number BSI/DRC/2023-24/Identification/52, ensuring the accuracy of species identification for further research and analysis.

2.2 Extraction

The fruits were collected and the pulp was separated manually. Phytochemicals from dried fruit pulp powder were extracted by Soxhlet extraction using ethanol at 60^0C for 24 h.The crude extract was collected, filtered, and the solvent was evaporated using a rotary evaporator at 40^0C (Dokuparthi *et al*., 2023; Naaz *et al.,* 2024).

2.3 Phytochemical study

Preliminary phytochemical analysis of the *A. digitata* extract was performed according to established protocols (Dokuparthi *et al*., 2014).

2.4 Nutritional profile

2.4.1 Moisture content determination (Oven-drying method)

To determine the moisture content, approximately 2-5 g of finely ground baobab fruit pulp was weighed and placed in a pre-weighed moisture dish.The sample was dried in a hot-air oven at 105°C for 12 h to ensure complete removal of water. After drying, the dish was transferred to a desiccator and cooled before being reweighed. Moisture content was calculated using the following formula (Oyeleke *et al*., 2012):

$$\% \text{ Moisture} = [(W_2 - W_3) / (W_2 - W_1)] \times 100$$

where,

W_1 = Weight of empty dish (g)

W_2 = Weight of dish + sample before drying (g)

W_3 = Weight of dish + sample after drying (g)

2.4.2 Crude protein determination (Macro-kjeldahl method)

The baobab pulp sample (0.5-1 g) was placedinto a Kjeldahl digestion flask. Potassium sulfate and 0.3 g of copper (II) oxide as the catalyst, followed by 25 ml of concentrated sulfuric acid.The mixture was heated gently until the solution became clear, indicating complete digestion of organic matter. After cooling, the digest was diluted with distilled water and transferred to the distillation apparatus. Added an excess of sodium hydroxide solution to make the solution alkaline and then distilled the liberated ammonia into a known volume of boric acid solution containing a mixed indicator. The collected solution was titrated with standard hydrochloric acid until the endpoint was reached. The nitrogen content was calculated and multiplied by a factor of 6.25 to obtain the crude protein percentage (Abdalla *et al*., 2010):

$$\% \text{ Nitrogen} = [(V - Vo) \times N \times 14.007] / (\text{Sample weight} \times 10)$$

$$\% \text{ Protein} = \% \text{ Nitrogen} \times 6.25$$

where,

V = Volume of HCl used for sample titration (ml)

V_o = Volume of HCl used for blank titration (ml)

N = Normality of HCl

14.007 = Atomic weight of nitrogen

6.25 = Protein conversion factor for plant material

2.4.3 Crude fat determination (Soxhlet extraction)

Dried baobab pulp (2-5 g) was placed into a thimble made of filter paper. The thimble was inserted into a Soxhlet extractor attached to a pre-weighed flask containing n-hexane as solvent. The assembly was heated to allow the solvent to reflux and extract the fat content for 6-8 h. After extraction, the solvent was removed by evaporation using a rotary evaporator. The flask containing the extracted fat was dried to a constant weight in an oven, cooled in a desiccator, and then weighed. The crude fat content was calculated as a percentage of the original sample weight (Murray *et al*., 2001):

$$\% \text{ Fat} = [(W_3 - W_1) / W_2] \times 100$$

where,

W_1 = Weight of empty flask (g)

W_2 = Weight of sample (g)

W_3 = Weight of flask + extracted fat (g)

2.4.4 Ash content determination (Muffle furnace method)

The baobab pulp sample (2-5 g) was into a pre-weighed crucible.The sample was heated over a Bunsen burner until it was charred and then transferred to a muffle furnace set at 550°C.The sample was incinerated for 6 h until white or light gray ash remained, indicating complete combustion of the organic material.The crucible was cooled in a desiccator before weighing. The ash content was calculated as a percentage of the original sample weight (Cisse *et al*., 2013).

$$\% \text{ Ash} = [(W_3 - W_1) / (W_2 - W_1)] \times 100$$

where,

W_1 = Weight of empty crucible (g)

W_2 = Weight of crucible + sample before ashing (g)

W_3 = Weight of crucible + ash (g)

2.4.5 Carbohydrate content determination (Difference method)

After determining the moisture, crude protein, crude fat, and ash content, the carbohydrate content was calculated by subtracting the sum of these components from 100%. This method assumes that the remaining portion of the sample primarily consists of carbohydrates (Obizoba *et al*., 1993). The formula is:

$$\% \text{ Total carbohydrates} = 100 - (\% \text{ Moisture} + \% \text{ Protein} + \% \text{ Fat} + \% \text{ Ash} + \% \text{ Fiber})$$

2.4.6 Crude fiber determination (Acid-alkaline digestion method)

2 g of the defatted baobab pulp sample was placed in a 500 ml beaker. Then, 200 ml of 1.25% sulfuric acid was added and the mixture was boiled for 30 min with constant stirring. The mixture was filtered through a muslin cloth and the residue was washed with hot distilled water.The residue was transferred back into the beaker, 200 ml of 1.25% sodium hydroxide solution was added, and the mixture was boiled for another 30 min.The residue was filtered, washed again, and dried in an oven at 105°C to a constant weight. After drying, the residue was incinerated in a muffle furnace at 550°C for 3 h. The remaining ash was weighed, and the crude fiber content was calculated as the weight loss upon ignition, expressed as a percentage of the original sample weight (Glew *et al*., 1997):

$$\text{Crude fiber (\%)} = \frac{\text{Weight loss on ignition}}{\text{Sample weight}} \times 100$$

2.4.7 Determination of vitamin C (UV spectrophotometry)

This method quantifies vitamin C in baobab pulp based on its characteristic ultraviolet (UV) absorption at 265 nm.Sample preparation involved extracting 5 g of homogenized pulp with 50 ml of cold 3% metaphosphoric acid while protecting from light and oxygen exposure. The mixture was vortexed (2 min), shaken (30 min at 4°C), centrifuged (5000 × g for 15 min), and filtered through Whatman No. 42 filter paper. Standards (0-150 mg/l) were prepared from l-ascorbic acid in the same extraction medium.The spectrophotometer was calibrated at 265 nm with a blank solution (3% metaphosphoric acid) and background correction was performed by subtracting the absorbance at 290 nm. Vitamin C concentration was calculated using the calibration curve equation, with the final results expressed as mg/100 g fresh weight. Method validation included recovery testing (95-105% acceptable range) and confirmation by DCPIP titration. Critical parameters include maintaining a cold temperature throughout the analysis, using fresh solutions, and analyzing samples within 2 h of extraction to prevent oxidative losses (Santos *et al*., 2016):

$$\text{Vitamin C content (mg/100 g)} = (C \times V \times D) / (W \times 10)$$

where,

C = Concentration from calibration curve (mg/L)

V = Volume of extraction solvent (ml)

D = Dilution factor (if any)

W = Weight of sample (g)

10 = Conversion factor to express result per 100g

3. Results

3.1 Phytochemical screening

The ethanolic extract of *A. digitata* fruit pulp was subjected to preliminary phytochemical analysis, which revealed several secondary metabolites, including alkaloids, saponins, flavonoids, and tannins (Table 1).

Table 1: Phytochemical profile of *A. digitata*

Phytochemicals	Ethanol extract
Alkaloids	-
Glycosides	+
Saponins	+
Flavonoids	+
Steroids	+
Tannins	+

Present (+)/absent (-)

3.2 Nutritional Profile of *A. digitata*fruit pulp

The nutritional profile of *A. digitata* fruit pulp was mentioned in Table 2 and Figure 1.

3.2.1 Moisture content and its functional role in baobab pulp

The moisture content of *A. digitata* fruit pulp was relatively low, measured at 7.16 ± 1.02%. This low moisture level contributes to the extended shelf life of the dried pulp and inhibits microbial spoilage, making it a stable food product for prolonged storage. From a biochemical perspective, moisture plays a crucial role in enzymatic and metabolic processes. Although the moisture content is relatively low, reconstitution of baobab pulp in water facilitates nutrient bioavailability and enhances its functional properties when consumed in the form of beverages or porridges.

3.2.2 Crude protein and its immunological significance

The crude protein content of baobab fruit pulp was at 2.11 ± 0.53%, which, although lower than that of leguminous plants, still provides essential amino acids required for physiological processes.Proteins play a vital role in immune system modulation by facilitating the production of immunoglobulins, cytokines, and acute-phase proteins, which are necessary for an effective immune response.Amino acids, such as arginine and glutamine, are particularly important in maintaining immune function, as they contribute to the proliferation and activation of lymphocytes, macrophages, and natural killer (NK) cells.Despite its relatively modest protein content, baobab pulp can serve as a supplementary protein source in regions where protein malnutrition is prevalent, particularly when consumed along with protein-rich legumes and grains.

3.2.3 Crude fat and its role in nutrient absorption and inflammation

The crude fat content in baobab fruit pulp was 0.41 ± 0.11%, indicating that it is a low-fat food. Dietary fats are essential for the absorption of fat-soluble vitamins (A, D, E, and K), and the synthesis of cell membranes, and excessive fat intake is associated with inflammatory responses and metabolic disorders. The low lipid content in baobab pulp suggests that it is beneficial for individuals requiring a diet low in fat, such as those with cardiovascular diseases or obesity-related inflammation. Additionally, essential fatty acids, although present in minimal amounts, contribute to the synthesis of eicosanoids, which are lipid mediators involved in immune regulation and inflammatory responses. Given its low-fat content, baobab pulp is best consumed alongside lipid-containing foods to optimize fat-soluble vitamin absorption.

3.2.4 Ash content and its implications on mineral composition

The ash content of *A. digitata* fruit pulp was 6.17 ± 0.45%, which is a direct indicator of its mineral richness.Minerals are essential cofactors for enzymatic reactions and play pivotal roles in immune function, bone development, and cellular signaling. Baobab pulp is an excellent source of essential minerals such as calcium, potassium, magnesium, and iron. Calcium is critical for immune cell activation and signal transduction, while potassium maintains the electrolyte balance and contributes to neuromuscular function. Magnesium is vital for DNA replication, protein synthesis, and cytokine production, all of which are essential for adaptive immunity. The presence of iron in the baobab pulp supports haemoglobin synthesis and oxygen transport, which are crucial for immune cell metabolism. Iron deficiency is known to impair immune responses, making baobab fruit pulp a valuable dietary component for individuals at risk of anaemia and immunosuppression.

3.2.5 Carbohydrate content and its role in energy metabolism and immune function

The carbohydrate content of baobab pulp is 78.77 ± 1.25%, making it a rich source of energy. Carbohydrates serve as the primary energy substrate for immune cells, particularly activated lymphocytes and macrophages, which require high metabolic rates to function effectively. The presence of complex carbohydrates and natural sugars in baobab pulp ensures sustained energy release, which is beneficial for individuals with increased metabolic demands, such as pregnant women, lactating mothers, and individuals recovering from infection. Furthermore, dietary carbohydrates influence the gut microbiota composition, which in turn affects immune homeostasis. Prebiotic fibers found in baobab pulp promote the growth of beneficial gut bacteria such as *Lactobacillus* and *Bifidobacterium*, which enhance gut-associated immune function and reduce systemic inflammation.

3.2.6 Crude fiber and its prebiotic and immunomodulatory effects

The crude fiber content of *A. digitata* pulp is 5.28 ± 1.09%, which plays a crucial role in digestive health and immune modulation. Dietary fiber consists of both soluble and insoluble components that contribute to gut motility, microbial balance, and metabolic health. Soluble fiber in baobab pulp forms gel-like structures in the digestive tract, slowing glucose absorption and improving glycemic control. Insoluble fiber facilitates intestinal peristalsis and reduces the risk of constipation and colonic disorders. More importantly, fiber functions as a prebiotic by serving as a substrate for colonic fermentation, producing short-chain fatty acids (SCFAs), such as butyrate, acetate, and propionate. SCFAs modulate immune responses by regulating the activities of macrophages, dendritic cells, and regulatory T cells, thereby reducing chronic inflammation and enhancing mucosal immunity. Given the role of dietary fiber in maintaining gut health, the consumption of baobab pulp may contribute to improved immune surveillance and resistance against infections.

3.2.7 Vitamin C and its immunoprotective properties

Baobab fruit pulp is exceptionally rich in vitamin C, containing 213.18 ± 2.66 mg per 100 g), making it a potent natural source of this essential nutrient. Vitamin C, or ascorbic acid, is a crucial antioxidant and a cofactor in enzymatic reactions involved in collagen synthesis, neurotransmitter function, and immune modulation. One of its primary roles in immunity is enhancement of leukocyte function, particularly neutrophil chemotaxis, phagocytosis, and oxidative burst activity.Vitamin C also plays a role in modulating inflammatory responses by reducing the levels of pro-inflammatory cytokines and suppressing excessive oxidative stress.

Furthermore, ascorbic acid enhances the production of interferons, which are critical for antiviral defenses.Regular consumption of vitamin C-rich foods, such as baobab pulp, strengthens the immune barrier by maintaining epithelial integrity, particularly in the respiratory and gastrointestinal tracts.Vitamin C deficiency is associated with impaired immune function, increased susceptibility to infection, and delayed wound healing.The high vitamin C content in baobab pulp makes it an excellent dietary supplement for immune resilience, especially in populations at risk of scurvy, common cold, and viral infections.

Table 2: Nutritional profile of *A. digitata*

Nutrient	Content per 100 g
Moisture	7.16 ± 1.02%
Crude protein	2.11 ± 0.53%
Crude fat	0.41 ± 0.11%
Ash	6.17 ± 0.45%
Crude fiber	5.28 ± 1.09%
Carbohydrates	78.77 ± 1.25%
Vitamin C	213.18 ± 2.66 mg

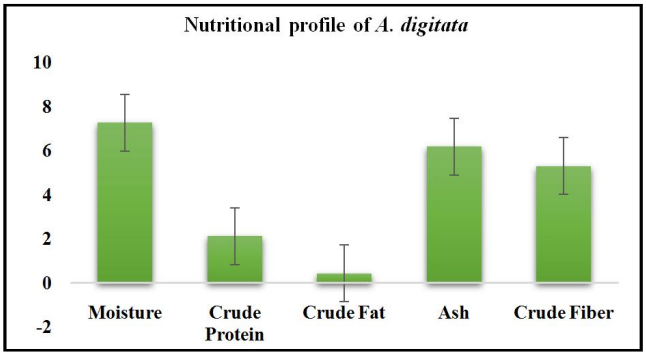

Figure 1: Nutritional profile of *A. digitata*.

4. Conclusion

The diverse nutritional composition of the *A. digitata* fruit pulp highlights its importance as a functional food with significant immunological benefits. The synergy between macronutrients, micronutrients, and bioactive compounds in baobab pulp contributes to immune cell function, antioxidant defence, and gut microbiota balance. High vitamin C content strengthens innate and adaptive immunity, while dietary fiber supports gut-associated lymphoid tissue (GALT) activity, reducing systemic inflammation.The presence of essential minerals enhances enzymatic reactions and cellular communication, further reinforcing the immune resilience. Incorporating baobab pulp into the diet can provide holistic health benefits, particularly for populations prone to malnutrition, infections, and inflammatory diseases. The bioavailability of these nutrients makes baobab a valuable dietary adjunct to enhance immune function and overall well-being. Future research should focus on the synergistic effects of baobab phytochemicals and their role in immune cell signaling pathways, further elucidating their potential as natural immunomodulatory agents.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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