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Comprehensive Nutritional Characterization and Functional Food Applications of Borassus flabellifer Inflorescence Sap

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ABSTRACT

Borassus flabellifer L., commonly known as the Palmyra palm, produces a sweet inflorescence sap traditionally consumed across tropical regions of South and Southeast Asia. This study presents a comprehensive nutritional and biochemical assessment of fresh Borassus flabellifer inflorescence sap, highlighting its potential as a natural functional beverage. The sap was analyzed for its macro- and micronutrient content, including essential carbohydrates, amino acids, vitamins (notably B-complex and vitamin C), minerals such as potassium, calcium, and magnesium, as well as the presence of antioxidant phenolic compounds and fermentable sugars. The findings reveal that the sap offers a balanced profile of energy-yielding nutrients and bioactive phytochemicals with potential health benefits such as antioxidative, antimicrobial, and anti-inflammatory effects. Traditional uses of the sap for hydration, digestive health, and seasonal wellness were further substantiated by preliminary phytochemical screening and comparative antioxidant activity. Given its natural origin, ease of availability, and historical use in indigenous diets, Borassus flabellifer sap emerges as a promising candidate for functional food and nutraceutical development. However, further studies on standardization, microbial stability, and controlled fermentation are necessary to support its commercial application...

Keywords: Borassus flabellifer; Inflorescence Sap; Antioxidants; Indigenous Knowledge; Nutraceuticals; Phytochemicals; Palmyra Palm..

INTRODUCTION

Borassus flabellifer, commonly known as doub palm, palmyra palm, tala or tal palm, toddy palm, lontar palm, wine palm, or ice appleis a fan palm native to South Asia (especially in Bangladesh and South India) and Southeast Asia. It is reportedly naturalized in Socotra and parts of China. Palms are largely widespread in several tropical areas of Asia, America and Africa (Miège 1985). The most important product from palms trees is palm wine which is an alcoholic drink obtained by the natural fermentation of the sap from various types of palm species. This beverage is produced and consumed by population in tropical regions of the world

The sap is mainly composed of approximately 80% water and 10–15% of total sugars with sucrose as the major constituent along with glucose, fructose, inositol and raffinose sugars at trifling levels The sap of the palm tree contains essentially sugar (10–12% of saccharose), soluble proteins, amino acids, amides, organic acids, phenolic compounds, flavonoids, minerals and vitamins (Bassir 1968)Palmyra palm (Borassusflabellifer) sap, an alcoholic beverage available along coastal Karnataka, India. Fresh palm sap tapped from the tip of the inflorescence of Palmyra palm tree is sweet, but gets contaminated by microor-ganisms by the sap collection vessel and the insects that are attracted towards it . Nutritionally rich palm sap is very good source of medium for the microorganisms to grow. Freshly tapped sweet palm sap contains 11.36% (w/v) of Total sugar, 0.96% (w/v) of reducing sugar, 0.35% (w/v) of protein, 0.056% (w/v) of nitrogen, 0.14% (w/v) of phosphorus, 0.54% (w/v) of mineral ash, 0.4% (w/v) of iron, 13.25% (w/v) of Vitamin C, 3.9 IU of Vitamin B1 and pH of 7.25.Since microorganism associated with palm sap is known to pay a major role in fermentation, identification and characterization of the palm sap could give crucial information to plan a strategy to intervene the fermentation of sweet palm sap to bitter palm “toddy”..:

Toddy is formed as a result of fermentation of neera/sap by wild yeasts and bacteria, which come into contact with the sap after tapping. This is an uncontrolled natural fermentation by number of different strains of yeast and bacteria. The alcohol content in naturally fermented toddy is reported to be 5%. But fermentation of palmyrah sap by using pure yeast culture gives about 7.8% alcohol content under laboratory conditions. The major sugars that are present in partly fermented toddy is sucrose, glucose and fructose but these will be gradually converted into ethyl alcohol during the process of fermentation.

Diversity of *Borassus flabellifer* Inflorescence Sap

One such species is Palmyra palm (*Borassus flabellifer*L.). It is a promising species in the trumpet vine family,Arecaceae that is native to Indian subcontinent and also found naturalized inSouth-East Asian countries (Mohan *etal.,* 2016). It is known by various names such as Palmyra palm, toddy palm or wine palm (Gummadi*et al.,* 2016). In Hindi and its subsidiary dialects it is known as *taad* while the extracted sapfrom inflorescence is called *Taadi*.Palmyra palm is referred to as tree of life with severaluses including food, beverage, fibre, medicine and timber (Arulraj and Augustine, 2008). It is a multipurpose tree ofgreat utility which plays an important role in the day-todaylife of rural poor of India. The Palmyra palm isdescribed as one of the most useful plant in the peninsularIndia as the Palmyra palm based processing industriesengage a significant chunk of human labour. It is easilycultivated and can be spotted growing in wild, in agriculturalfields and sporadically even on wastelands.For centuries, Palmyra palm has been tapped in orderto produce fresh juice (sweet toddy), fermented drinks(toddy, wine, and arak), syrup (honey), brown sugar(jaggery) or refined sugar. Most tapped palm trees do notonly produce sap but are multipurpose (edible fruits,building materials, fuel, fibres, wax, etc.) and their socioeconomicimportance is immense for the rural poor.Mahatma Gandhi, the father of the nation, reportedly calledPalmyra palm, a remedy against poverty (Dalibard,1999). Palmyra palm is considered as a total palm as eachand every part of the tree has economic use. In manyparts of the country, Palmyra palm is the main source oflivelihood for the poor people as they derive a substantialpart of their income from this plant. The different productsobtained from different parts of Palmyra palm aredescribed as under.– *Toddy (Neera)*: The sap extracted frominflorescence of Palmyra palm is called 'Neera'. Neera is typically the most economic produce of Palmyra palm.It is good source of minerals like calcium, phosphorus andiron and vitamins like vitamin A, niacin, thiamine and riboflavin. Neera acts as laxative and diuretic. Alcoholbuilds up naturally in neera when left undisturbed for afew hours.

***Toddy* :**

Toddy is obtained by tapping the tip ofthe inflorescence and collecting the dripping juice inhanging earthen pots. The juice so collected beforemorning is refreshing and the light drink is called *Neera*which is cool in nature. It has a sugary sweet taste. Thetoddy ferments naturally within a few hours after sunrise.It is locally popular as a beverage called *Tadi*. It is distilledto produce the alcoholic liquor called palm wine, arrack,or arak.

Availability of *Borassus flabellifer* inflorescence Sap

Palmyra palm trees are widely grows naturally throughout the semi arid to sub humid regions of Africa, South Asia, South America, Australia and inother tropical countries (7) and in Diu Island. Thesugar palm tree (*Borassus flabellifer*) is a source ofmaterial for producing a variety of product among that, most important product of sugar palm is the sap or juice. The drink is a rich nutrient medium containingsugars, protein, amino acids, alcohol and minerals palm jaggery is made from the extract of palm trees in southern india .these tress are also known as toddy palm trees or plalmyra trees the jaggery is processed from the unfermented Palmyra tree sap called neera. Palm jaggery is quite popular in southern states of tamilnadu (called karupattivellam or panavellam) ,Karnataka, kerala and Andhra Pradesh. In the south indian families of the coastal region of mangalore and also the keralites of the Malabar coast palm sap has a big role.

Biochemical Contents of *Borassus flabellifer* Inflorescence Sap

The inflorescence sap of *Borassus flabellifer* L., commonly known as Palmyra palm, is a biochemically rich plant fluid tapped from the unopened male or female spadices of the tree. Traditionally consumed fresh or fermented, this sap contains a variety of macro- and micronutrients**,** enzymes**,** and bioactive compounds, contributing to its nutritional and therapeutic value.

1. Carbohydrates and Sugars

The most abundant biochemical constituents of the sap are natural sugars, which can account for 10–15% of the sap's fresh weight. These include sucrose**,** glucose**,** and fructose, with sucrose being predominant in fresh, unfermented sap (Miller, 1958; Rao &Sastry, 2012). These carbohydrates provide immediate caloric energy and serve as substrates for natural fermentation, leading to toddy or vinegar production (Dalibard, 1999).

2. Proteins and Amino Acids

Although present in lower concentrations than sugars, the sap contains crude protein (approximately 0.2–0.5%) and essential amino acids such as lysine, methionine, and tryptophan, which are important for human metabolism and immunity (Sudhakar et al., 2010; Bhagya et al., 2016). These proteins may be more bioavailable in their unfermented form.

3. Vitamins

Fresh sap is a source of Vitamin C (ascorbic acid), which contributes to its antioxidant properties. It also contains B-complex vitamins, notably thiamine (B1), riboflavin (B2), and niacin (B3), which play roles in energy metabolism and nervous system function (Naknaen&Meenune, 2020; Ayyappan et al., 2021).

4. Minerals and Electrolytes

The sap is particularly rich in potassium, followed by calcium, magnesium, sodium, iron, and trace elements such as zinc. These minerals help regulate fluid balance, support nerve transmission, and contribute to cardiovascular health (Obahiagbon &Osagie, 2007; Gummadi et al., 2016). The high potassium content makes it an effective natural rehydration drink, comparable to tender coconut water.

5. Enzymes and Organic Acids

Fresh Palmyra sap contains natural enzymes like invertase, amylase, and alcohol dehydrogenase, which initiate breakdown of sugars and fermentation processes (ChayanikaSarma et al., 2022). The sap also has low concentrations of organic acids such as acetic acid, lactic acid, and oxalic acid, especially in the early stages of fermentation.

6. Phenolic Compounds and Antioxidants

Phytochemical analyses have shown that *Borassus flabellifer* sap contains total phenols, flavonoids, and tannins, which exhibit antioxidant activity by scavenging free radicals (Jerry, 2022; Shanmugalingam et al., 2022). These compounds also contribute to its antimicrobial, anti-inflammatory, and anticancer potentials, making the sap a source of nutraceutical interest.

7. Microbial and Fermentative Biochemistry

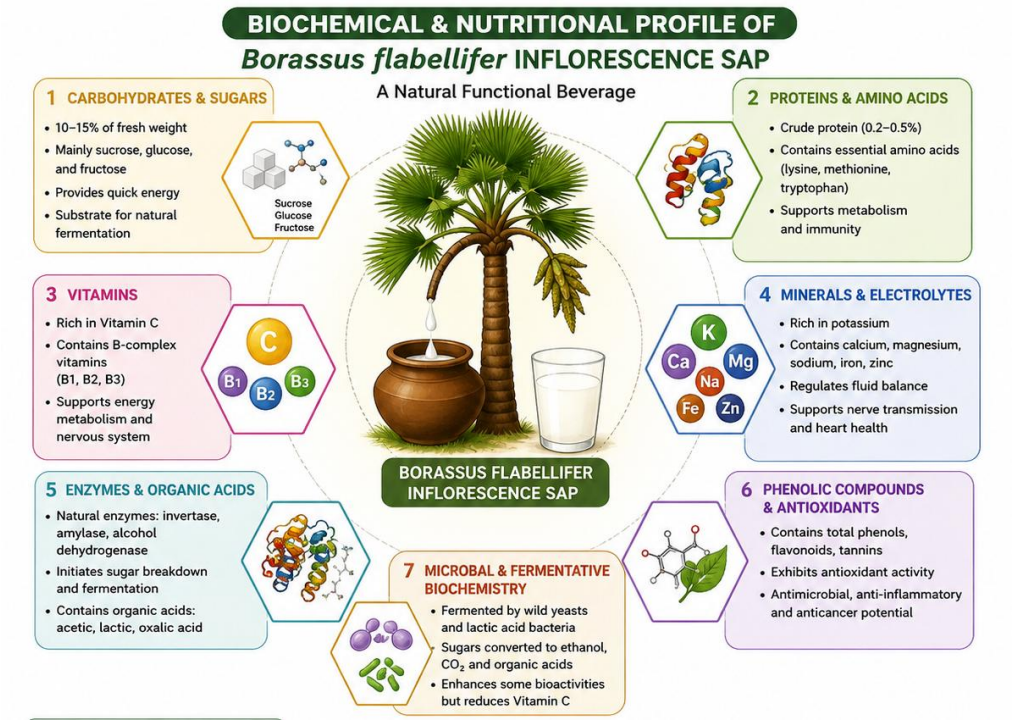
Upon natural fermentation, the biochemical profile shifts due to the action of wild yeasts and lactic acid bacteria, which convert sugars into ethanol, carbon dioxide, and acids (Fox &Robyt, 1991; Kotiya et al., 2022). The fermentative transformation also enhances some bioactivities but reduces others, such as Vitamin C content.

Nutritional Analysis

The inflorescence sap of *Borassus flabellifer* (Palmyra palm) is a nutrient-rich natural drink, traditionally consumed for its refreshing and therapeutic benefits. Nutritional studies have revealed that the sap contains significant amounts of reducing sugars (mainly sucrose, glucose, and fructose), making it a natural source of quick energy (Rao et al., 2012). In addition to carbohydrates, the sap possesses moderate levels of crude proteins and traces of essential amino acids, contributing to its nutritional value, particularly during the early hours of tapping when the sap is most biochemically active (Sudhakar et al., 2010).

Mineral profiling through atomic absorption spectroscopy (AAS) and flame photometry has identified potassium, calcium, magnesium, sodium, and iron as predominant micronutrients, highlighting its potential as an electrolyte-replenishing drink (Ayyappan et al., 2021). The sap also contains small quantities of Vitamin C and B-complex vitamins, especially thiamine and riboflavin, which contribute to its antioxidant potential and aid in metabolic functions (Bhagya et al., 2016).

Moreover, its low fat contentandnatural sugar composition make it suitable for occasional consumption by individuals managing cardiovascular or diabetic risks, though fermentation can alter its glycemic impact. Given its naturally occurring bioavailable nutrients and ease of digestion, *Borassus flabellifer* sap holds promise as a sustainable and affordable functional beverage, deserving wider recognition and nutritional promotion.

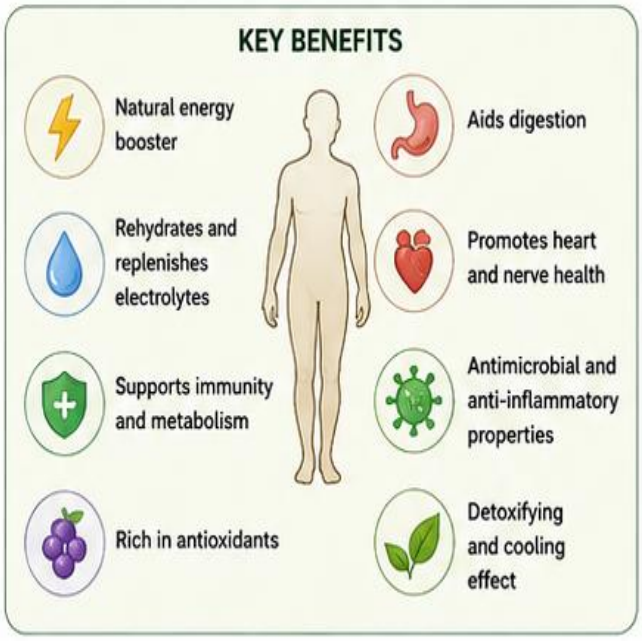


Applications of *Borassus flabellifer* Inflorescence Sap

NUTRITIONAL COMPOSITION

(Approx. values per 100 ml fresh sap)

Nutrient	Amount
Energy	60–70 kcal
Carbohydrates	14–16 g
Sugars (Sucrose, Glucose, Fructose)	10–15 g
Protein	0.2–0.5 g
Fat	<0.1 g
Fiber	<0.1 g
Vitamin C	5–10 mg
Thiamine (B1)	0.01–0.02 mg
Riboflavin (B2)	0.01–0.02 mg
Niacin (B3)	0.2–0.5 mg
Potassium	150–250 mg
Calcium	30–50 mg
Magnesium	20–30 mg
Sodium	20–40 mg
Iron	1–2 mg



The inflorescence sap of *Borassus flabellifer* L., commonly known as the Palmyra palm, has long held significant socio-economic and medicinal value in South and Southeast Asia. Traditionally tapped from the unopened male or female inflorescences, the sweet sap—locally called "padaneer" in Tamil—is used across several domains, including nutrition, medicine, fermentation industries, agriculture, and increasingly, biotechnology.

1. Nutritional and Functional Beverage

Fresh Palmyra sap is widely consumed as a natural health drink owing to its high content of natural sugars, essential minerals (potassium, calcium, magnesium), and vitamins (notably thiamine and ascorbic acid) (Bhagya et al., 2016; Ayyappan et al.,

2021). Its low fat content and presence of bioactive phytochemicals such as phenols and flavonoids contribute to its classification as a functional beverage (Naknaen&Meenune, 2020). Because of its natural electrolyte composition, it is recommended as a rehydrating drink in hot climates and during mild gastrointestinal discomfort (Sarma et al., 2022).

2. Fermented Products and Traditional Industries

One of the most common applications of *B. flabellifer* sap is in the preparation of fermented beverages**,** such as toddy (neera)andpalm wine**,** which are culturally significant in many parts of India and Sri Lanka (Rao &Sastry, 2012; Dalibard, 1999). Through spontaneous or controlled fermentation, the sap develops mild alcoholic content and probiotic potential, and can also be converted into vinegar or bioethanol (Fox &Robyt, 1991). This has implications for rural employment and value addition in small-scale industries.

3. Sweeteners and Traditional Foods

Boiled sap, known as "karuppatti" or palm jaggery, is widely used as a natural sweetener in traditional Indian sweets and Ayurvedic preparations. It is often considered a healthier alternative to refined sugar, rich in iron and antioxidants, and recommended for conditions like anemia, fatigue, and seasonal ailments (Sudhakar et al., 2010; Gummadi et al., 2016). The sap is also used in the preparation of palm sugar candies, toffees, and fermented desserts.

4. Medicinal and Therapeutic Uses

In traditional systems like Siddha and Ayurveda**,** Palmyra sap is believed to possess cooling, diuretic, and digestive properties. It is often used in remedies forconstipation, urinary tract infections, and skin conditions (Vivekanandarajah et al., 2018; Shanmugalingam et al., 2022). The sap's bioactive compounds—such as polyphenols, saponins, and natural antioxidants—exhibitantimicrobial, anti-inflammatory, and hypoglycemic effects, which are currently being validated through pharmacological studies (Jerry, 2022; Ida Leida et al., 2018).

5. Environmental and Agricultural Applications

The fermented residues and byproducts of Palmyra sap extraction have utility in agriculture**.** Spent sap and fibrous materials can be used asorganic compost, biofertilizer**,** or substrate for biogas production, contributing to waste reduction and circular economy practices (Srivastava et al., 2022). Moreover, recent research has explored the sap's application in aquaculture for managing plankton blooms in shrimp culture ponds, due to its ability to naturally reduce pH and nutrient overload (Kotiya et al., 2022).

6. Emerging Uses in Biotechnology and Food Innovation

There is growing interest in using Palmyra sap as a fermentation substrate for developing functional fermented beverages, probiotics, and even bioplastics**.** The sap's natural sugars and microbial load make it suitable for biotechnological applications, especially in sustainable food systems and green chemistry (ChayanikaSarma et al., 2022; Gummadi et al., 2016). With proper standardization and quality control, it could be used in nutraceutical formulations**,** beverages, and pharmaceutical excipients.

Conclusion

The inflorescence sap of *Borassus flabellifer* represents a nutritionally rich and biochemically diverse plant resource with immense traditional, dietary, and industrial significance. Its composition—rich in natural sugars, essential minerals, vitamins, amino acids, and bioactive phytochemicals makes it not only a sustainable source of energy and hydration but also a potential functional beverage with therapeutic value. Traditional knowledge, supported by modern scientific validation, highlights its antioxidant, antimicrobial, and antidiabetic properties, further establishing its role in health promotion.

The versatility of Palmyra sap, from fresh consumption to value-added products like jaggery, fermented drinks, and nutraceuticals, supports rural livelihoods and offers scalable economic opportunities. However, the sap's high perishability, variability in composition, and lack of standardized preservation techniques remain challenges that require systematic research and innovation. With increasing global interest in plant-based, functional, and sustainable foods, *Borassus flabellifer* sap has strong potential to emerge as a culturally rooted, scientifically validated, and commercially viable product. Integrating traditional knowledge systems with modern food science and biotechnology will be key to unlocking its full potential...

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