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# Valorization of date palm sap into commercially viable products: a comprehensive account on its composition, nutritional profile, processing, value addition, and potential applications

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Date palm sap, obtained as an exudate from date palms, is a nutritionally rich substance with significant potential as a functional food ingredient and natural sweetener. Despite the growing interest in the nutritional, economic, and cultural significance of date palm sap, research on its comprehensive benefits and risks remains limited. This review aims to summarize the current knowledge on the physicochemical properties, microbiological composition, nutritional value, traditional uses, and health risks associated with date palm sap consumption. Sap composition, influenced by factors such as tapping period and palm variety, includes high levels of sugar, minerals, vitamins, amino acids, and bioactive compounds. It harbors a diverse microbial community that affects quality and fermentation outcomes. Traditional uses include fresh consumption, fermented beverages, and sugar production, which are of socioeconomic importance in several regions. However, raw sap consumption poses health risks, particularly involving Nipah virus transmission. Innovative approaches for processing and preservation are being explored to extend the shelf life while maintaining nutritional quality. The sap also shows promise as a feedstock for bio-based products. This review highlights research gaps and future directions, including the optimization of processing techniques, characterization of sap composition across cultivars, evaluation of long-term health effects, development of risk communication strategies, and exploration of novel applications. A multidisciplinary approach that integrates traditional knowledge with modern scientific methods is crucial for realizing the full potential of date palm sap, addressing safety concerns, and ensuring sustainable production.

## KEYWORDS

date palm sap, natural sweetener, microbial composition, Nipah virus transmission, fermentation, functional food

## 1 Introduction

Date palms have a long history of cultivation, dating back to 4,000 BC in Mesopotamia (Al-Karmadi and Okoh, 2024). Its ability to thrive in arid and semi-arid regions has made it central to the economy and cultural heritage of the Middle East and North Africa (MENA) (Gros-Balthazard et al., 2021). The global cultivation of date palms covers approximately 1.3 million hectares,

with significant concentrations in Asia, Africa, and, to a lesser extent, Europe and the Americas (Crops and Livestock products, 2025). Date palm sap, extracted from *Phoenix dactylifera* and *Phoenix sylvestris*, is a naturally sweet liquid often referred to as “tamarind nectar” with diverse applications in beverages, culinary preparations, and traditional medicine (Alotaibi et al., 2023; Bakshi et al., 2020). Its significance extends beyond its use as a raw material for various products, including traditional beverages (Djemal et al., 2025), sugar (Jagannadha Rao et al., 2009; Tuturoong et al., 2024), and molasses (Al-Safy and Ali, 2023; Ray and Faculty, 2017), and its potential in bioethanol production (Van Nguyen et al., 2016).

The global beverage industry has faced increasing scrutiny owing to the association between certain products and chronic diseases. Meta-analyses have shown that high consumption of sugar-sweetened beverages is associated with an increased risk of hypertension (12%), type 2 diabetes (26%), and cardiovascular disease (19%) (Zhang et al., 2024). Even fruit juices, which are often considered healthier alternatives, have shown mixed results in their correlation with the incidence of chronic diseases (Auerbach et al., 2018). Furthermore, sugar-sweetened beverages have been associated with hyperactivity disorders, and a meta-analysis has indicated a positive correlation between their consumption and the development of attention deficit hyperactivity disorder (Farsad-Naeimi et al., 2020). The adoption of artificial sweeteners as a mitigation strategy has not fully addressed these concerns. Epidemiological studies have suggested that they may promote cardiovascular complications and the development of type 2 diabetes (Schiano et al., 2021). This has led to increased interest in beverages derived from natural sources that are rich in bioactive compounds and potentially offer health benefits.

Palm saps, including those from date palms, have emerged as promising candidates for natural beverages because of their multifunctional composition (Sarma et al., 2022). Date palm sap is a rich reservoir of nutrients, including sugars, vitamins, minerals, amino acids, and polyphenols. Its potential as a low-glycemic index food further enhances its appeal in the alternative beverage market. Despite the potential benefits and widespread cultivation of date palms, several key research gaps need to be addressed, such as the comprehensive characterization of the physicochemical properties and microbiological composition of date palm sap across different cultivars and regions, and the evaluation of the nutritional value and potential health benefits of date palm sap compared to other beverages. In addition to its practical applications, date palm sap is associated with public health concerns owing to its association with Nipah virus transmission (Islam et al., 2023; Khan et al., 2012). Therefore, there is a need to explore innovative processing methods to enhance the shelf life and safety of date palm sap while preserving its nutritional qualities.

This review summarizes existing research and recent developments on date palm sap, including its physicochemical properties, microbiological composition, nutritional value, traditional uses, and associated health risks. By addressing these aspects, we aim to provide a comprehensive understanding of the potential of date palm sap as a sustainable and healthy alternative in the beverage industry.

## 2 Collection procedures for date palm sap

Palm sap collection is a traditional practice of significant cultural, economic, and nutritional importance in many regions of the world. The process involves extracting sugary fluid from various species of palm trees, which is then used for direct consumption, fermentation, or further processing into products such as palm sugar and bioethanol (Sarma et al., 2022). The sap collection process is intricate and requires precise timing, skill, and appropriate equipment to maximize the yield while minimizing harm to the trees. The collection period of date palm sap generally covers 3 to 4 months (March–June), and during this time, a total sap yield of up to 500 L can be obtained (Barreveld, 1993). The conventional approach is based on obtaining palm sap by cutting trees. Vessels such as bamboo tubes, plastic bottles, and mud pots are suspended from the tree trunk or placed near the base (Khan et al., 2012; Nahar P. P. et al., 2014). Under the gravitational pull, sap flows into the containers and is collected. This method does not require specialized equipment; however, it has certain drawbacks, such as contamination of sap and irreversible destruction of palm trees (de Wit et al., 2014; Nahar et al., 2010). In mechanical pressing, palm yield is increased by shedding palm trees to increase the surface area. Higher sap outputs have been reported using smaller shredding sizes and extended processing times; however, the question of sustainability remains, as the method is destructive (Ezzatzadegan et al., 2021).

A more common and widely practiced method of collecting sap involves tapping date palm trees, which has been practiced for thousands of years. This method is still prevalent in many regions, including India and Southeast Asia, where it is used to collect sap for direct consumption and fermentation into products such as bioethanol (Nahar et al., 2010; Van Nguyen et al., 2016). Sap collection begins with the selection of mature and healthy date palms, usually between 5 and 10 years old. An experienced sap collector, known locally as a “tapper,” makes a deliberate incision below the crown. The goal is to stimulate sap flow while avoiding excessive damage that could compromise the long-term health of trees (Makhlouf-Gafsi et al., 2016b). Compared with other methods, tapping is sustainable, as there is no irreversible destruction of the tree, and sap production can continue throughout the entire life cycle of the tree. However, the need for skilled labor and lower yields render this method inefficient.

Another method involves cutting a tree at the top and letting the sap flow into containers placed below. Higher yields were observed compared to conventional methods, and the plant was preserved. Various types of cuts, such as forehead- and tongue-shaped cuts, are employed to collect sap. Sap is collected over a period of 2–3 days after each scraping, followed by a period of rest for 3–5 days. As the cut portion of the tree regenerates, this method is relatively sustainable. Protection from the Nipah virus is assured by covering the collection area and assembly with polyethylene, jute sticks, and bamboo (Hai et al., 2024). In Bangladesh, skilled personnel known as *gachhis* are responsible for collecting date palm sap. The bark of the tree is shaved on one side near the top and then allowed to dry for 7–14 days (Nahar et al., 2010; Nahar N. et al., 2014). This is followed by scraping and cutting the shaved trunk

for sap drainage. A V-shaped cut, referred to as a forehead shape, is believed to resemble eyebrows. A small bamboo tube or piece of bark is sometimes used to direct sap into the collection vessel. Sap from approximately 10–15 trees is generally consolidated into larger containers to facilitate transportation (Nahar et al., 2010). A myriad of factors, including the tree's age, area of origin, variety, and tapping procedure, define the overall quality of the palm sap.

Sustainability is a major challenge in sap collection. Over-harvesting, improper cutting techniques, and tapping during unsuitable seasons can damage trees. In addition, pests, climate stress, and microbial contamination threaten both yield and quality. This is particularly concerning in regions such as Bangladesh, where traditional collection methods do not always prevent animal access (Ábrahám et al., 2024; Nahar et al., 2010). The lack of effective preservation techniques limits the marketability of palm sap, especially in urban areas where sap is often misconceived as an alcoholic drink. This challenge is compounded by the natural tendency of sap to ferment rapidly (Sarma et al., 2022). Promoting traditional knowledge alongside scientific innovation is essential for maintaining valuable cultural and economic resources (Ezzatzadegan et al., 2021).

### 3 Physicochemical composition and properties of date palm sap

Date palm sap is a complex natural exudate characterized by a rich composition of sugars, proteins, vitamins, minerals, and bioactive compounds. Its physicochemical profile varies depending on factors such as cultivar, geographical origin, tapping season, and palm sex, which in turn dictate its potential applications and nutritional value. The primary components of date sap are sugars, with sucrose being the most abundant. For instance, sap from the Gabes region of Tunisia contains very high sucrose (186.8 g/L), followed by lower levels of glucose (13.0 g/L) and fructose (1.2 g/L) (Ben Thabet et al., 2010), which is significantly greater than the levels reported for coconut and nipa palm saps (Asghar et al., 2020; Ben Atitallah et al., 2021; Manzano et al., 2024). This positions it as a premier raw material for syrup and sugar production in the food industry. Table 1 provides a consolidated summary of the comparison of date palm sap with other commercially relevant sap-based sweeteners, such as coconut, nipa, and maple saps, as well as other tree saps, such as birch.

This sucrose-dominant profile is consistent across many studies (Ben Thabet et al., 2009a), although a striking seasonal variation exists; sucrose is the sole sugar detected in winter, whereas glucose and fructose appear in spring, coinciding with a period of higher total sugar content and lower acidity (Ziadi et al., 2014). This shift is attributed to increased invertase enzyme activity as the tapping period progresses, hydrolyzing sucrose into its monomeric units (Makhlouf-Gafsi et al., 2016b). The total soluble solids (TSS) typically range around 18.6% but are known to decrease over a prolonged tapping season because of plant stress (Ziadi et al., 2014). The pH is generally acidic, approximately 4.8, with stable titratable acidity (Ben Atitallah et al., 2021).

A critical and fascinating aspect of its composition is the divergence between male and female palms. Female cultivars generally yield more sap (190.31 L/plant vs. 140.42 L/plant for

males) with a higher sucrose content, whereas male sap contains higher protein (5%), ash, total phenolic content (TPC), and a distinct amino acid and protein profile, including a unique 30 kDa protein band (Makhlouf-Gafsi et al., 2016b; Swaraz et al., 2019). Its protein content, although modest (0.2 µg/µl in the Deglet Nour cultivar), is comparable to that of coconut palm sap (0.1 µg/µl) (Ben Thabet et al., 2010). In addition to sugars, date sap is a source of minerals, notably potassium (501.1 mg/100 g dry matter) and magnesium (298.1 mg/100 g dry matter), along with phosphorous, sodium, calcium, and iron (Ben Atitallah et al., 2021), offering a different nutritional advantage compared to the very high sodium content found in nipa sap or the balanced mineral cocktail of maple syrup (Phetrit et al., 2020; Zhang et al., 2014).

The functional food potential of date sap is underscored by its bioactivity. It exhibits significant antioxidant properties, with a DPPH radical inhibition of 47.64% and a TPC of 7.64 mg/100 ml (Ben Thabet et al., 2009a). This activity is cultivar-dependent, with the Thokar variety showing the highest capacity, followed by Khalet, Beser, and Ameri varieties (Abdennabi et al., 2017). While the antioxidant profile of date sap (e.g., ~47% DPPH inhibition) appears potent, direct quantitative comparison is challenging because of the varying methodologies across studies. However, its documented phenolic content and antimicrobial activity suggest a competitive bioactive profile against coconut and birch sap, although likely different from the well-characterized and unique polyphenol map of maple syrup (e.g., quebecol) (Borodušakis et al., 2017; González-Sarrías et al., 2012). These phenolic compounds are linked to potential health benefits, including antimicrobial (e.g., against *Staphylococcus aureus* and *Enterococcus faecalis*) and antidiabetic effects. Furthermore, date sap demonstrates promising functional properties for food processing, such as excellent foaming capacity and stability, particularly in its native state rather than when reconstituted from a lyophilized powder (Ben Thabet et al., 2009a; Ziadi et al., 2011).

### 4 Microbiological composition and fermentation

The microbial diversity of date palm sap is a critical factor influencing its quality, shelf life, and fermentation potential. Raw date palm sap provides a favorable environment for various bacterial species because of its high sugar content and slightly acidic pH (Makhlouf-Gafsi et al., 2016a,b). Culturomics and metagenomics have identified a rich microbial community in fresh, unfermented date palm sap (Djemaï et al., 2025). They identified 250 bacterial and nine fungal species, including key fermentation species such as *Zymomonas mobilis* and *Saccharomyces cerevisiae*. The study also revealed 28 previously unreported bacterial and eight fungal species, highlighting the unexplored microbial diversity of date palm sap (Djemaï et al., 2025).

Fermentation involves intricate interactions between lactic acid bacteria (LAB) and yeast. These organisms can exist symbiotically, where yeast fermentation provides ethanol, which LAB can tolerate, and they continue to ferment lactic acid. Such mixed cultures can be intentionally used to develop products with complex sensory profiles. Microbiological analysis of date palm sap from Southern Tunisia identified high loads of mesophilic aerobic

TABLE 1 Critical comparative analysis of compositional attributes across different tree saps.

| Parameter        | Date palm sap                                        | Coconut sap                      | Nipa palm sap          | Maple sap                                              | Birch sap                                                                |
|------------------|------------------------------------------------------|----------------------------------|------------------------|--------------------------------------------------------|--------------------------------------------------------------------------|
| Total sugars     | Very high (~20 g)                                    | Moderate (~13 g)                 | Moderate (12–16 g)     | Low (1–3 g)                                            | Very low (0.8–1.2 g)                                                     |
| Sucrose          | Dominant (≥90% of sugars)                            | Dominant (~6.91%)                | Variable (1.11–7.10%)  | Extremely High (≥98% in syrup)                         | Very low                                                                 |
| Glucose/Fructose | Low (Increases with tapping)                         | Present (~3.5%, ~2.5%)           | Main components (~5%)  | Trace                                                  | Main sugars                                                              |
| Key minerals     | K (High), Mg (High)                                  | K (Very High), Na, Mg            | Na (Extremely High), K | K, Ca, Zn (in syrup)                                   | Ca, Mg, K                                                                |
| Unique features  | Sex-based variation, High foaming capacity           | Rich in Vitamins (B1, B2, B3, C) | Very high Na content   | Unique polyphenols (Quebecol, Ginnalin)                | Diverse amino acids, Betulin Xylitol                                     |
| Key bioactives   | Cultivar-specific phenolics                          | Vitamins                         | Minerals               | Lignans, Phenolic acids                                | Flavonoids, Tannins (Betulin)                                            |
| Reference        | Ben Atitallah et al., 2021; Ben Thabet et al., 2009b | Asghar et al., 2020              | Manzano et al., 2024   | Ball, 2007; Li and Seeram, 2010; Nahar N. et al., 2014 | Boroduškis et al., 2017; Kallio and Ahtonen, 1987; Svanberg et al., 2012 |

K, Potassium; Na, Sodium; Mg, Magnesium; Ca, Calcium.

bacteria, coliforms, yeasts, and LAB (Ziadi et al., 2011). Ten LAB strains, including *Lactobacillus*, *Leuconostoc*, *Enterococcus*, and *Bifidobacterium*, have been isolated and characterized for their acidifying activity in palm sap, indicating their potential for use as starter cultures in fermentation processes (Ziadi et al., 2011). The presence of these microorganisms is crucial for the spontaneous fermentation of date palm sap, which leads to changes in pH and TSS (Ziadi et al., 2014), contributing to the sourness and preservation of traditional fermented products such as toddy (Aparnna et al., 2023).

A previous study also employed nanopore sequencing to identify bacterial species in raw date palm sap in Bangladesh. They observed two predominant fermentation pathways dominated by *Leuconostoc* or *Lactococcus* species alongside opportunistic human pathogens (Ábrahám et al., 2024). Species such as *Lactobacillus*, *Leuconostoc*, and *Pediococcus* metabolize sugars into lactic acid, which reduces the pH of the sap, suppresses pathogenic growth, and imparts a characteristic sour flavor to fermented products such as toddy (Hossain et al., 2023). Yeasts, particularly *Saccharomyces cerevisiae*, are vital for the alcoholic fermentation process. They metabolize sap sugars into ethanol and CO<sub>2</sub>, initiating the fermentation process. Dash et al. (2015) identified eight yeast strains, *Saccharomyces cerevisiae* and *Pichia bessae*, isolated from fermented date palm sap (toddy) in India, and evaluated their ethanol tolerance and bioethanol production capacity. *Pichia besseyi* showed the highest ethanol production capacity and tolerance, highlighting the potential of date palm sap as a source of natural yeasts for bioethanol production and contributing to sap fermentation, influencing flavor development through the production of volatile organic compounds (Dash et al., 2015). A study on the fermentation dynamics of naturally fermented palm beverages further supports this, showing that the fermentation process leads to changes in physicochemical properties, such as pH, sugar content, and bioactive compounds in khejur toddy (date palm sap beverage). The resulting toddy exhibited increased antioxidant activity and phenolic content compared to that of fresh sap (Das and Tamang, 2023).

Improper sap collection or storage may result in contamination with pathogenic bacteria, such as *Escherichia coli*, *Salmonella*, and

*Staphylococcus aureus*. These pathogens are typically introduced through contact with contaminated tools, containers, or water, posing a significant risk of foodborne illness (Ábrahám et al., 2024; Luby et al., 2009). Although less frequently reported, the potential for viral contamination through unsanitary handling, especially with viruses such as norovirus and rotavirus, exists and can contribute to gastrointestinal illnesses (Gurley et al., 2017).

## 5 Nutritional value and health benefits

Date palm sap possesses significant nutritional value, contributing to its use as a food and beverage source and offering potential health benefits. A comparative study of different palm saps revealed that fresh date sap contains the highest levels of total sugars, calcium, iron, zinc, copper, phosphorus, and niacin (Barh and Mazumdar, 2008). The amino acid profiles of date palm sap show variations in essential amino acids depending on collection time, further enhancing its nutritional value (Makhlouf-Gafsi et al., 2016b). Interestingly, fermentation increased thiamin, riboflavin, and niacin contents without significantly altering the micronutrient levels.

The health benefits of date palm sap are largely attributed to its rich composition of bioactive compounds, particularly polyphenols (Al-Alawi et al., 2017; Kharal et al., 2023). Figure 1 illustrates some of the bioactive compounds and their associated health benefits. polyphenols commonly reported in date palms include gallic, sinapic, caffeic, and gallic acids, quercetin, catechin, and epicatechin. These compounds exhibit antidiabetic activity by inhibiting the formation of human Islet Amyloid Polypeptide (hIAPP), a potent causative factor for type-2 diabetes (Chaari et al., 2020). These polyphenols are also likely to be present in sap, conferring diverse health benefits to this natural drink. Table 2 provides an overview of the various bioactive compounds present in different types of palm sap.

Research studies have shown that date palm sap obtained from four Tunisian varieties inhibited the activity of amylase, which is responsible for carbohydrate digestion, suggesting its potential application in the management of diabetes

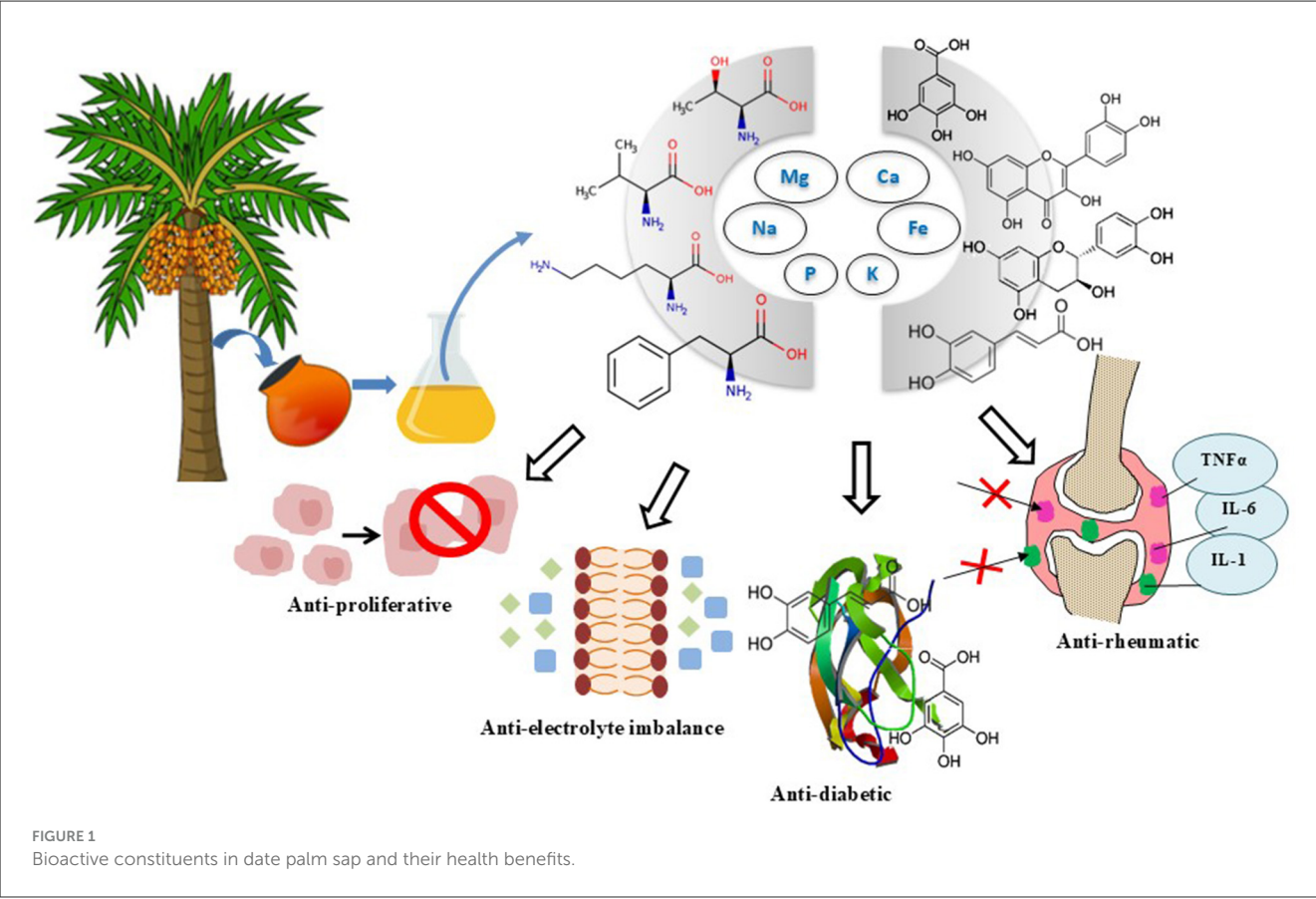


FIGURE 1 Bioactive constituents in date palm sap and their health benefits.

TABLE 2 Key bio-active and immune-modulatory primary and secondary (untargeted) metabolites identified in different varieties of palm sap.

| Class of bio-active compounds | Name of the compounds                                                                                                                                                            | Source                                                         | Metabolite classification | References                                                                   |
|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|---------------------------|------------------------------------------------------------------------------|
| Phenolics                     | Gallic acid, vanillylamine, myristicin, arbutin, caffeic acid, yatein, syringic acid, gentisic acid, saffrole, eugenol, chlorogenic acid, rutin, trans-cinnamic acid, kaempferol | Coconut palm, date palm, palmyra palm, areca palm, Raphia palm | Secondary metabolites     | Flores-Gallegos et al., 2019; Das and Tamang, 2024                           |
| Flavonoids                    | Artonin E, artonin J, nobiletin, quercetin                                                                                                                                       | Date palm                                                      | Secondary metabolites     | Alharbi et al., 2021; Das and Tamang, 2024                                   |
| Alkaloids                     | Arecoline, guvacoline, alpha-terpineol, incensole, limonene, arecaine, calystegine B2.                                                                                           | Palmyra palm, areca palm, doum palm, date palm                 | Secondary metabolites     | Arul Ananth et al., 2013; Das and Tamang, 2024                               |
| Terpenoids                    | Moronic acid, cinnamaldehyde, ferulic acid, piquerol A                                                                                                                           | Date palm                                                      | Secondary metabolites     | Das and Tamang, 2024                                                         |
| Carotenoids                   | Beta-carotene, cis-lycopene, alpha-carotene, campesterol, sitosterol                                                                                                             | Coconut palm, kittul palm, oil palm, Raphia palm, areca palm   | Secondary metabolites     | Alharbi et al., 2021; Arul Ananth et al., 2013; Flores-Gallegos et al., 2019 |
| Vitamins                      | Ascorbic acid, tocopherol (vitamin E), riboflavin (vitamin B2), folic acid, biotin, folinic acid                                                                                 | Oil palm, date palm, Raphia palm                               | Primary metabolites       | Alharbi et al., 2021; Das and Tamang, 2024; Obahiagbon, 2012                 |

mellitus (Abdennabi et al., 2017). Furthermore, date palm sap has been investigated for its ability to combat bleomycin-induced lung fibrosis in rats. The administration of date palm sap reversed the effects of bleomycin-induced lipid peroxidation and restored normal levels of superoxide dismutase (SOD), malondialdehyde (MAD), and catalase (CAT). Additionally, improvements in morphological lesions have been observed, indicating the potential application of date palm sap in lung cancer treatment (Bahri et al., 2019; Hai et al., 2024).

The nutritional and health benefits of date palm sap extend to its potential use during childbirth. Labor pain is often accompanied by anxiety and fear, which can stimulate the secretion of cortisol and catecholamines, leading to incomplete uterine contractions and prolonged labor. Prolonged labor can result in fatigue, maternal mortality, fetal complications, and, in some cases, labor hypoxia (Hekmatzadeh et al., 2014). Providing laboring mothers with food and energy can fulfill their immediate needs, with an energy requirement of 50–100 calories per hour (Aghdam et al., 2015). The administration of oral fluids during active labor can help relieve pain, reduce anxiety, and provide immediate energy to the mother. In a double-blind placebo-controlled randomized clinical trial, 15 ml of date palm sap (60 kcal) was administered to 60 low-risk primiparous women per hour of active labor, whereas the control group received 15 ml of sugar solution. The results revealed a reduction in the active phase of labor compared to the control state, with a significant difference observed in the mean values for active labor. However, no effects were observed on pain and anxiety levels (Rahmani et al., 2023). Similar results have been reported for honey-date syrup and saffron syrup with date sugar (Ghaderi et al., 2019; Mohammadierad et al., 2018). These studies collectively establish that palm sap is not only a sustainable alternative in the beverage market, but also a drink with significant functional and health benefits.

## 6 Traditional uses and socioeconomic significance

Date palm sap has traditionally been utilized in various ways across different cultures and communities in regions ranging from North Africa to the Middle East and Southeast Asia. The sap can be consumed fresh, fermented into an alcoholic beverage known as arrack or palm wine, or processed into a sweet syrup known as date palm syrup or jaggery. In Southern Tunisia, a fresh juice called “Legmi” is widely produced and consumed (Makhlouf-Gafsi et al., 2016b; Ziadi et al., 2011). In West Bengal, India, the tapping and processing of sap from silver date palm (*Phoenix sylvestris*) is an age-old practice with considerable economic importance (Bakshi et al., 2020). Date palm sap contributes significantly to family income, ranging from 9.4% to 28% among different categories of farmers (Bakshi et al., 2020). This study also highlighted gender roles in sap processing, with males primarily involved in tapping, whereas both sexes participated in processing and palm maintenance (Bakshi et al., 2020). In Bangladesh, date palm sap is widely consumed as a traditional drink (Chakraborty et al., 2016; Islam et al., 2016; Jackson et al., 2024), and its consumption habits are associated with knowledge of the Nipah virus infection. A study on the date palm molasses (Gur) industry in India further illustrated the socioeconomic importance of date palm sap as a raw material for traditional products (Ray and Faculty, 2017), which found that entrepreneurs in the industry reported sufficient profits, emphasizing the economic significance of traditional date palm processing.

In Morocco, traditional knowledge of date juice processing, which is linked to date palm sap, is being studied to understand its cultural and medicinal significance (Houssni et al., 2024). This revealed the use of numerous aromatic and medicinal plants

in the preparation of date juices, highlighting the long-standing cultural practices associated with date palm products. Another study on the socioeconomic and traditional medicinal uses of wild date palms in India highlights the medicinal uses of both raw sap and tari (fermented sap), particularly in the Northeastern Plains Zone (Saran et al., 2018), which emphasizes the economic profitability of raw sap and tari production for small and marginal farmers.

## 7 Health risks and Nipah virus transmission

Raw date palm sap consumption has been strongly linked to Nipah virus infection, primarily in Bangladesh (Chakraborty et al., 2016; Islam et al., 2016). This association has raised significant concerns among public health officials and researchers, prompting extensive investigations into the pathology and transmission dynamics of this deadly virus. Fruit bats (*Pteropus giganteus*), which act as the natural reservoirs of the virus, play a crucial role in contaminating sap with saliva or urine (Epstein et al., 2020; Islam et al., 2023). This contamination pathway has been extensively studied, revealing a complex interplay between human behavior, ecological factors, and viral transmission.

The highly pathogenic nature of Nipah virus, which can cause severe respiratory and neurological diseases in both humans and animals, has intensified research efforts to understand its epidemiology and develop effective prevention strategies. Its ability to cross species barriers and cause devastating outbreaks has made it the subject of intense scientific scrutiny. Multiple studies have provided compelling evidence supporting the association between raw date palm sap consumption and Nipah virus infection (Ang et al., 2018; de Wit et al., 2014). A case-control study conducted during an encephalitis outbreak in Bangladesh reported a significant odds ratio of 7.9, strongly indicating the role of raw sap consumption in disease transmission (Epstein et al., 2020; Luby et al., 2009).

Further research has revealed that the epidemiology of Nipah virus in Bangladesh has revealed fermented date palm sap (tari) as another potential transmission route during outbreaks (Chakraborty et al., 2016). Researchers have identified 18 clusters of Nipah virus infections associated with tari consumption, indicating its potential to trigger localized outbreaks within communities (Islam et al., 2016; Parveen et al., 2016). The health risks associated with Nipah virus infection are severe and can be life-threatening. In some instances, people who handle date sap have developed symptoms of Nipah virus infection, including fever, headache, and encephalitis. These symptoms can progress rapidly and lead to death in severe cases. The presence of bat excreta in tari production pots further indicates a potential pathway for virus transmission, highlighting the need for improved hygiene practices during sap collection and processing (Epstein et al., 2020; Islam et al., 2016).

Experimental evidence has further solidified the link between date palm sap consumption and Nipah virus transmission. A study using Syrian hamsters demonstrated that drinking contaminated sap led to neurological disease,

mirroring the symptoms observed in human cases (de Wit et al., 2014). This animal model provides valuable insights into the pathogenesis of Nipah virus infection and confirms the potential of sap to serve as a vehicle for virus transmission.

Environmental factors play a significant role in the transmission dynamics of the Nipah virus. Studies have suggested that certain conditions, such as the proximity of bat roosts to sap collection sites, increase the likelihood of contamination. Additionally, warmer temperatures and increased humidity may facilitate the survival of the virus in the environment, thereby enhancing the risk of transmission during sap collection. Interestingly, weather patterns have been found to influence date palm sap consumption habits, potentially affecting the risk of Nipah virus transmission. Jackson et al. (2024) investigated the impact of weather patterns on household date palm sap consumption in Bangladesh, finding a significant association between lower minimum temperatures and precipitation with increased sap consumption during the harvesting season. This relationship highlights a potential risk of Nipah virus spillover during colder and drier winters, as increased consumption during these periods may lead to higher exposure rates.

Traditional sap collection and processing practices may inadvertently increase the risk of disease transmission. A study on raw sap consumption habits and their linkage with knowledge of Nipah virus in Bangladesh demonstrated low awareness among respondents regarding the risks associated with drinking raw date palm sap (Gurley et al., 2017; Nahar et al., 2015). This lack of awareness emphasizes the need for targeted education and outreach programs to inform communities about the dangers of consuming raw or fermented sap in Nipah virus-endemic areas. Addressing the threat of Nipah virus requires effective communication and preventive measures. The challenges of communicating prevention strategies for Nipah virus transmission during an outbreak in Bangladesh emphasized the need for culturally sensitive communication strategies (Parveen et al., 2016). Public health officials must tailor their messages to resonate with local communities, considering traditional practices and beliefs surrounding date palm sap consumption.

One promising intervention that has shown effectiveness in reducing the risk of Nipah virus transmission is the use of bamboo skirts by fruit collectors. These simple yet ingenious devices have been shown to effectively prevent bats from accessing date palm sap, thereby reducing the risk of contamination (Nahar N. et al., 2014). In a study conducted in Bangladesh, bamboo skirts, along with other materials such as dhoincha and polythene, significantly reduced bat contact with sap from 83% to 2% compared to control trees without any intervention (Khan et al., 2012). This dramatic reduction in bat access to sap demonstrates the potential of physical barriers as a practical and cost-effective preventive strategy. The promotion of bamboo skirts among sap harvesters (gachhis) yielded encouraging results. A high percentage of harvesters adopted the use of these barriers, with 83% in high-intensity intervention areas and 65% in low-intensity areas using skirts at least once during the sap collection season (Nahar N. et al., 2014). This finding highlights the importance of sustained and comprehensive outreach programs to achieve widespread

adoption of preventive measures. The complex interplay of ecological, behavioral, and environmental factors necessitates a multifaceted approach to prevention and control. By combining targeted interventions, such as the use of bamboo skirts, with comprehensive education and communication strategies, it may be possible to reduce the risk of Nipah virus transmission while preserving the important cultural practices surrounding palm sap consumption.

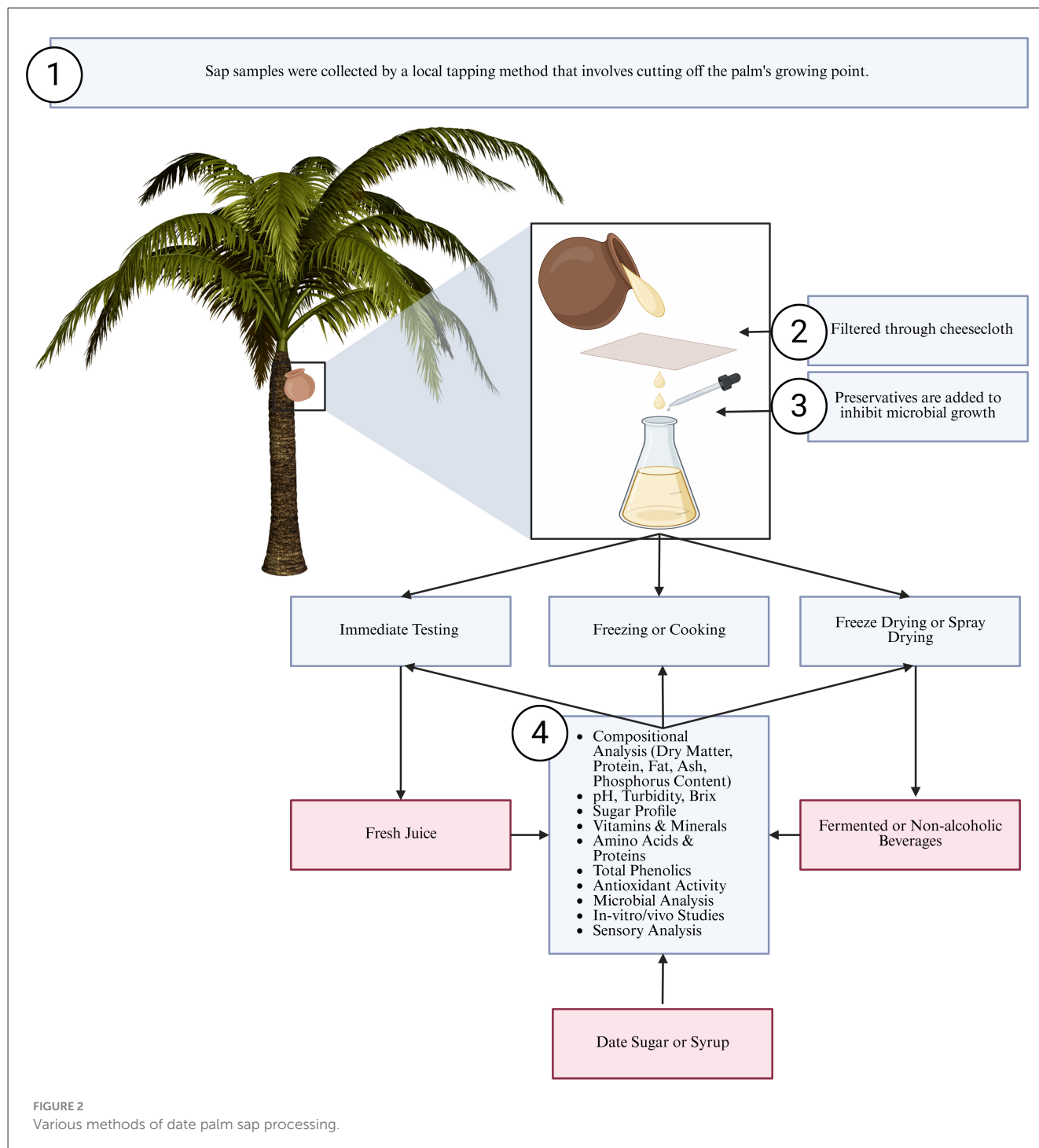
## 8 Innovative approaches for processing and preservation of date palm sap

The processing and preservation of date palm sap involves a variety of techniques aimed at maintaining its quality and extending its shelf life. Date palm sap, which is known for its nutritional value, is highly susceptible to fermentation, which poses a challenge for its preservation. Various chemical, biological, and mechanical preservation techniques have been explored to overcome these challenges. The effectiveness of these methods depends on an understanding of the biochemical composition and fermentation chemistry of the sap, as well as the specific requirements of the end product. In addition to novel products, innovative processing and preservation techniques are crucial. Figure 2 summarizes various potential processing methods of date palm sap.

### 8.1 Traditional and modern filtration strategies

Palm sap is widely consumed fresh or fermented and serves as a base for producing palm sugar, vinegar, and alcoholic beverages. However, the shelf life and quality of palm sap are heavily influenced by the cleanliness and efficiency of the filtration methods. Traditional methods of palm sap cleaning and filtering have been practiced for generations and rely on indigenous knowledge and the use of locally available materials. The palm sap cleaning process began at the time of collection. Traditionally, palm sap is collected in clay pots, bamboo containers, or plastic vessels tied to the inflorescence of palm trees (Nahar et al., 2010). To prevent contamination by insects, debris, and dust, collectors often cover the containers with fine mesh or cloth. This initial step acted as a primary filtration barrier for the removal of larger particulate matter. In some regions, leaves or fibers from palm trees are used as natural filters, showcasing the resourcefulness of traditional practices (Haryoso et al., 2020).

One of the most common traditional methods for cleaning palm sap involves the use of natural adsorbents such as charcoal, clay, or plant-based materials. Charcoal, derived from coconut shells or other plant sources, is widely used because of its porous structure, which effectively traps impurities and microorganisms (Rampe et al., 2025). The sap is passed through layers of charcoal or mixed with powdered charcoal, allowing it to absorb contaminants before being filtered again. Similarly, clay pots are often used



for storage because the microporous nature of clay helps to settle suspended particles and improve clarity. Sedimentation is a simple yet effective traditional method for cleaning palm sap. After collection, the sap was allowed to stand in containers for several hours, during which heavier particles settled at the bottom (Hebbar et al., 2018; Naknean and Meenune, 2015). The clear upper layer was then carefully decanted and siphoned off. This method relies on gravity and density differences between the sap and impurities, making it a low-cost and energy-efficient approach.

A widely used technique in palm sap processing involves straining the liquid through a fine mesh cloth or muslin to remove solid impurities such as dust, insect remains, and plant debris (Swain et al., 2016). Repeated filtration through fabric significantly reduces suspended particles but may not be sufficient for microbial decontamination (Naknean et al., 2010). Boiling or pasteurization is another traditional method employed to clean palm sap, particularly in palm sugar production (Naknean and Meenune, 2016; Saidi et al., 2018). Heating the sap not only concentrates

its sugars but also kills microbial contaminants, thereby extending its shelf-life. Studies have shown that heat treatment significantly reduces the microbial load in palm sap, making it safer for consumption (Das et al., 2024; Hebbar et al., 2018; Naknaen and Meenune, 2016). However, excessive boiling can lead to caramelization and loss of nutritional value, highlighting the need for careful temperature control (Hebbar et al., 2018; Ho et al., 2008). Table 3 presents a comparative evaluation of traditional palm sap filtration techniques.

Despite their effectiveness, traditional palm sap cleaning and filtering methods face challenges such as inconsistent results, labor-intensive processes, and limited scalability. However, traditional methods remain relevant, particularly in rural areas where access to modern technology is limited. Moreover, the increasing interest in natural and organic products has renewed interest in these age-old techniques. Modern adaptations, such as the use of mechanical filters (Tuturoong et al., 2024), UV treatment (Muttalib and Wartono, 2019), and biological and chemical preservatives (Kapilan et al., 2015; Naknean, 2013; Naknean and Meenune, 2015), have been introduced to address these limitations.

A more modern adaptation involves the use of a stainless-steel filtration device based on the Buchner method, which employs a vacuum mechanism to expedite the separation of solid impurities (Tuturoong et al., 2024). This method significantly increases sap clarity and reduces filtration time compared to traditional gravity-fed methods. The filtration process also increased sugar concentration without extensive cooking, benefiting farmers economically. Researchers have focused on the design and development of a stainless-steel fermentation tank for gravity purification of palm wine (Robot et al., 2024). The study aimed to optimize the fermentation process and improve the purification of palm sap, thereby leading to better-quality palm wine. The use of clarifying agents and deodorizing aids, such as chitosan, gelatin, bentonite, Hyflo-supercells, and activated granular carbon, can improve the clarity of palm sap (Baskaran and Radhakrishnan, 2024; Naknean and Meenune, 2015). These agents help coagulate and remove impurities, resulting in a clearer product with lower browning.

The addition of bio-preservatives, such as nisin, to pasteurized palm sap (*Borassus flabellifer* Linn.) has been shown to significantly improve the shelf life and safety. Nisin, a natural antimicrobial agent, is effective in inhibiting the growth of spoilage microorganisms, consequently extending the shelf life of pasteurized palm sap from approximately 2 to 10 weeks when used at a concentration of 30 IU/mL (Naknean, 2013). This enhancement was achieved without compromising the sensory qualities of the sap, making it a practical solution for producers seeking to improve the longevity and safety of their products. Incorporating natural preservatives, such as essential oils or extracts from medicinal plants, can enhance safety and extend shelf life while maintaining a natural product profile. Essential oils, such as those from *Ocimum basilicum* (Goudoum, 2017), *Mentha piperita* L., *Thymus vulgaris* L., *Cinnamomum zeylanicum* B. (Wilson et al., 2020), and Za'atar (*Thymbra spicata*) (Maskan and Horuz, 2017), as well as other natural preservatives such as mangosteen trunk bark (Lantemona et al., 2023), have shown potential for preserving palm sap. Chemical preservatives, such as sodium benzoate, citric acid, sorbic acid, diethylpyrocarbonate, and sodium metabisulfite, and anti-fermenting agents, such as

toluene and sulfanilamide, are used to improve the shelf life of inflorescence sap obtained from palm trees (Baskaran and Radhakrishnan, 2024). Therefore, research on the effectiveness and safety of these preservatives in date palm sap is crucial. This approach resonates with growing consumer preference for natural food products.

### 8.1.1 Microfiltration and ultrafiltration

Exploring advanced filtration techniques, such as microfiltration or ultrafiltration, could improve clarity, reduce microbial load, enhance product quality, and extend the shelf life of date palm sap (Kurniawan et al., 2018). Microfiltration of palm sap is used to clarify and sterilize the sap, enhancing its quality and stability for consumption or further processing purposes. This technique involves the use of membranes to remove suspended solids and microorganisms, thereby improving sap clarity and shelf life. This process is particularly relevant for producing syrups and other sap-derived products, where maintaining the natural properties of the sap is crucial. Microfiltration is employed to clarify palm sap by removing turbidity and microorganisms without significantly altering its TSS content. This is achieved using ceramic membranes with specific pore sizes, such as 0.1 and 0.2 microns, which effectively reduce turbidity and microbial load while maintaining the sap's natural composition (Ritthipairote et al., 2004). The choice of membrane material and pore size is critical. For instance, ceramic membranes made of ZrO<sub>2</sub>-TiO<sub>2</sub> have been used because of their durability and effectiveness in reducing turbidity and microbial content (Ritthipairote et al., 2004).

In contrast, ultrafiltration, a related technique, significantly affects the physicochemical properties of date palm sap syrup (Makhlouf-Gafsi et al., 2018). It alters the rheological behavior from pseudoplastic to Newtonian, which is attributed to changes in the chemical composition of the sap during filtration (Makhlouf-Gafsi et al., 2016a). This process also affects the thermal stability of the syrups, with the male sap permeate showing the highest stability among the studied samples (Makhlouf-Gafsi et al., 2016a). Microfiltration and ultrafiltration can influence the biological attributes of date palm sap syrups. For example, ultrafiltration does not significantly enhance antioxidant activity, unlike thermal concentration, which increases antioxidant activity and TPC (Makhlouf-Gafsi et al., 2018). The antimicrobial properties of sap syrups are also noteworthy, with significant activity against various pathogens, although this is more pronounced with thermal processing than with microfiltration (Makhlouf-Gafsi et al., 2018). A major challenge in microfiltration is membrane fouling, which leads to a decrease in permeate flux over time. This is primarily due to irreversible fouling, which is a significant concern for maintaining efficient filtration processes. The process parameters, such as transmembrane pressure and feed flow, require careful optimization to balance effective filtration and minimize fouling.

## 8.2 Packaging innovations for extended shelf life

Effective packaging interventions are crucial for preventing contamination and extending the shelf life of sap, which is highly susceptible to microbial growth and fermentation. Various

TABLE 3 Comparative evaluation of traditional palm sap filtration techniques.

| Method                            | Effectiveness in particle removal | Microbial reduction | Impact on sap quality                 | References                               |
|-----------------------------------|-----------------------------------|---------------------|---------------------------------------|------------------------------------------|
| Sedimentation                     | Moderate                          | Low                 | Minimal impact                        | Naknean and Meenune, 2015                |
| Cloth/mesh filtration             | High                              | Low                 | No alteration                         | Das et al., 2024                         |
| Bamboo or nylon straining         | Moderate                          | Low                 | Enhances aroma                        | Islam et al., 2024                       |
| Charcoal or clay pot filtration   | High                              | Moderate            | Improves clarity, preserves freshness | Das et al., 2024                         |
| Boiling, skimming, pasteurization | High                              | High                | Alters taste                          | Hebbar et al., 2018; Saidi et al., 2018  |
| Coagulants or clarifying agents   | High                              | Moderate            | No alteration                         | Naknean, 2013; Naknean and Meenune, 2015 |

strategies have been explored to address these challenges, including the use of physical barriers to prevent contamination, preservatives, and eco-friendly packaging materials. These interventions aim to maintain the quality and safety of palm sap for consumption and commercial purposes. A study aimed to standardize packaging and storage technology for tender palmyra palm fruit endosperm and sap to extend their shelf life. Palmyra palm sap stored in high-density polyethylene 50  $\mu\text{m}$  at  $-4^\circ\text{C}$  maintained its quality for up to 8 months, with the highest sensory scores and beneficial chemical properties (Vagadia, 2016). The choice of packaging material significantly affects the retention of nutrients and the physical properties of sap.

Various natural preservatives, such as chitosan, have been used to extend the shelf life of palm sap. The experiment involved enriching fresh palm sap with chitosan at concentrations ranging from 0 to 2 g/L, followed by pasteurization at  $80^\circ\text{C}$  for 10 min (Naknean et al., 2015). Sensory evaluation determined that chitosan concentrations between 0 and 1.00 g/L were acceptable, leading to their selection for further study. During storage, samples were analyzed weekly, revealing that chitosan-treated samples exhibited increased lightness and transmittance, reduced polyphenol oxidase and invertase activity, and minimized sucrose loss while controlling glucose and fructose increases compared with the control (Naknean et al., 2015).

While limited research highlights several promising approaches to packaging date palm sap, it underscores the challenges associated with its preservation. A study evaluated different packaging materials for preserving date palm juice and Gur (Choudhury, 2023). They found that stainless steel jars with insulation provided the best shelf life and quality of preserved date palm juice compared to other materials. The study also highlighted differences in microbial activity in Gur collected from traditional markets vs. machine-produced Gur, which impacts preservation methods (Choudhury, 2023). When combined with other preservation methods, this technique offers substantial potential for extending the shelf life of date palm sap-based products. Date palm sap is rich in carbohydrates, proteins, and essential amino acids, and is highly valued in the functional food industry. Therefore, packaging solutions must ensure the retention of these nutritional properties during the storage period. The chemical composition of sap, including its sugar and acid content, varies with collection time and tree sex, which should be considered when designing packaging and preservation strategies for sap products.

### 8.3 Value-added products derived from date palm sap

#### 8.3.1 Functional and fermented beverages

Date palm sap is a nutrient-rich white liquid that is naturally sweet, initially alcohol-free, and a substantial source of sugars, vitamins, minerals, and antioxidants. Its high sugar content (92.29% w/w dry matter basis), primarily sucrose, along with proteins (5.14% w/w) and essential amino acids, makes it an excellent base for functional beverages (Ben Thabet et al., 2009b; Makhoul-Gafsi et al., 2016b; Ziadi et al., 2011). Traditionally, date palm sap is consumed fresh as “Lagmi” or fermented into alcoholic beverages in various cultures (Makhoul-Gafsi et al., 2016b; Ziadi et al., 2011). The inherent sweetness and nutritional properties of the sap have led to its exploration as a base for various food applications (Table 4). In India, fresh sap is used to prepare a sweet beverage known as Neera (Pareek, 2015). However, because of the presence of natural yeasts in the environment, the sap begins to ferment rapidly after collection. Within 2 h, it transforms into an aromatic wine containing up to 5% alcohol, commonly referred to as palm wine (Salomón-Torres et al., 2021). This fermented beverage can be further distilled to create stronger spirits, which are known by various names, depending on the region of production. It is important to note that excessive sap extraction from date palms can significantly reduce fruit yield and may even lead to tree death in the short term.

Date palm juice is prone to decay owing to its high sugar content, which affects its flavor, vitamins, color, and nutrients. A preservation technique for concentrated juice was developed, and ready-to-serve (RTS) drinks were formulated (Shanta et al., 2021). The date palm juice was heated at  $85^\circ\text{C}$  for 5 min, removed, and preserved in sterilized glass bottles. The juice was concentrated to TSS levels of 9, 12, 15, 18, and 21  $^\circ\text{Brix}$ , treated with 200 ppm of potassium metabisulfite, and stored at  $4^\circ\text{C}$ . RTS drinks were formulated with 10, 20, 30, and 40% date palm juice, preserved in sterilized bottles, and stored at  $30^\circ\text{C}$ . The 18 TSS concentrated juices showed the best sensory evaluation results for color, sweetness, flavor, acidity, and microbial load. RTS drinks with 30% date palm juice were found to be the most acceptable in terms of sensory attributes and stability (Shanta et al., 2021).

Ennouri (2023) demonstrated the potential of blending date palm sap with cactus juice (*Opuntia ficus indica*) at varying

TABLE 4 Diverse food and beverage products derived from date palm sap.

| Common name & source                                                                          | Food products                                | Collection of samples                                                                                                                                                                                                                            | Methods                                                                                                                                                                                                                                                             | Highlights                                                                                                                                                                                                                                                                                                                                                                                                             | References                   |
|-----------------------------------------------------------------------------------------------|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| Male palm date sap from a palm grove in Tozeur (Tunisia)                                      | Sap drink                                    | Sap samples were collected by a local tapping method that involves cutting off the palm's growing point. Sodium azide was added to inhibit microbial growth.                                                                                     | <ul style="list-style-type: none"> <li>Ash, protein, fat, dry matter</li> <li>Sugar composition</li> <li>Viscosity</li> <li>Surface properties</li> <li>Foaming properties</li> </ul>                                                                               | <ul style="list-style-type: none"> <li>The sap showed high sugar content, primarily sucrose, and significant protein and ash content.</li> <li>Increased dry matter content improved surface activity and foaming properties.</li> </ul>                                                                                                                                                                               | Ziadi et al., 2011           |
| Ripe cactus fruits ( <i>Opuntia ficus indica</i> ) + Exuded sap from a palm grove in Tunisia. | Beverage with cactus juice and date palm sap | Exuded sap was obtained by traditional tapping from palm grove and filtered through cheesecloth.                                                                                                                                                 | <ul style="list-style-type: none"> <li>pH, turbidity, TSS</li> <li>Sedimentation</li> <li>Serum separation</li> <li>Microbiological analysis</li> <li>Sensory analysis</li> </ul>                                                                                   | <ul style="list-style-type: none"> <li>The control sap was most appreciated for its aftertaste and overall acceptability.</li> <li>Among the formulated beverages cactus: date sap%, B3 (20:80%) was more appreciated than B2 (30:70%), followed by B1 (40:60%).</li> <li>The study highlighted the beverage mixture's potential to improve stability and sensory properties compared to individual juices.</li> </ul> | Ennouri, 2023                |
| Date palm cultivar, named Deglet Nour collected from a palm grove in Tunisia.                 | Fresh juice "lagmi" from date palm sap       | Sap was collected from three males and three females of the same date palm on the first day and seven days after using the traditional tapping method. Sodium azide was added immediately after collection to prevent microbial growth.          | <ul style="list-style-type: none"> <li>Dry mater, Protein, ash</li> <li>TPC</li> <li>Sugar profile</li> <li>°Brix</li> <li>Color</li> <li>Amino acid profile</li> <li>Protein profile by SDS</li> </ul>                                                             | <ul style="list-style-type: none"> <li>Male sap showed higher protein, total polyphenol, ash, and amino acid contents compared to female sap.</li> <li>A unique 30 kDa protein band was identified in male sap, suggesting potential biological functions.</li> </ul>                                                                                                                                                  | Makhlouf-Gafsi et al., 2016b |
| Date palm cultivar, named Deglet Nour from palms in Tozeur region (Tunisia).                  | Fresh juice "lagmi" from date palm sap       | The sap was collected by a traditional tapping method.                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>pH, dry matter, fat, protein, ash minerals, phosphorus content</li> <li>Color</li> <li>Sugar composition</li> <li>TPC</li> <li>AA</li> <li>Viscosity</li> <li>Dynamic surface tension</li> <li>Foaming properties</li> </ul> | <ul style="list-style-type: none"> <li>The sap showed high carbohydrate content, mainly sucrose, and significant antioxidant activity. It demonstrated good surface and foaming properties, although freeze-drying affected foam stability. The sap's viscosity increased with higher sugar concentrations.</li> </ul>                                                                                                 | Ben Thabet et al., 2009a     |
| Sap samples were collected from local farmers in Bangladesh                                   | Ready to serve drink from date palm sap      | Sap was collected in a clean jar and then sieved through a clean cloth before further treatment. The juice was pasteurized, concentrated to different TSS levels, treated with potassium metabisulfite, and stored at refrigerated temperatures. | <ul style="list-style-type: none"> <li>TSS</li> <li>Moisture</li> <li>Sugar</li> <li>Protein</li> <li>Crude fat</li> <li>Acidity</li> <li>pH</li> <li>Ascorbic acid</li> <li>Ash</li> <li>Standard plate count</li> <li>Storage study</li> <li>Sensory</li> </ul>   | <ul style="list-style-type: none"> <li>Drinks with 30% date palm juice were most acceptable in terms of sensory attributes and stability.</li> <li>No significant changes were observed in TSS, acidity, and microbial load for up to 3 months for concentrated juice and 6 months for drinks.</li> </ul>                                                                                                              | Shanta et al., 2021          |
| Sap samples were collected from male date palm trees in Tozeur region (Tunisia).              | Syrup from date palm sap                     | The initial TSS content of the juice was 11%. After filtering the sap through a fine cloth, boiling was conducted in an open pan on a hotplate at 100 °C, with continuous agitation. Date syrup was concentrated to 75 Brix.                     | <ul style="list-style-type: none"> <li>Water activity</li> <li>pH, TSS, protein, ash, minerals, phosphorous content</li> <li>Total sugars</li> <li>Reducing sugar</li> <li>TPC</li> <li>AA</li> <li>Rheological measurements</li> <li>DSC</li> </ul>                | <ul style="list-style-type: none"> <li>The syrup showed high TPC and AA.</li> <li>Rheological tests confirmed the syrup's Newtonian behavior, with viscosity decreasing as temperature increased.</li> <li>Sensory analysis revealed that while the color of maple syrup was preferred, the taste and viscosity of date palm syrup were well accepted</li> </ul>                                                       | Ben Thabet et al., 2009b     |

(Continued)

TABLE 4 (Continued)

| Common name & source                                                                                                                                         | Food products                              | Collection of samples                                                                                                                                                                                                                                                                             | Methods                                                                                                                                                                                                                                                                       | Highlights                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | References                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| Exuding saps were collected by traditional tapping from male and female date palms in a Tunisian palm grove.                                                 | Syrup from date palm sap                   | After filtration through fine cloth, the sap was divided into two quantities. One was split: the first concentrated at 100 °C using a hotplate to 74 °Brix and the second concentrated with a rotary vacuum evaporator at 60 °C to 70 °Brix. The other quantity was clarified by ultrafiltration. | <ul style="list-style-type: none"> <li>• Total sugar</li> <li>• Reducing sugar</li> <li>• Protein</li> <li>• TPC</li> <li>• HMF</li> <li>• 2-furaldehyde</li> <li>• Browning index</li> <li>• AA</li> <li>• Antimicrobial activity</li> <li>• Cytotoxic properties</li> </ul> | <ul style="list-style-type: none"> <li>• Ultrafiltration produced syrups with varying AA, influenced by phenolic content and Maillard reaction products. A positive correlation existed between DPPH scavenging activity and phenolic content in both male and female syrups.</li> <li>• Ultrafiltration retains high molecular weight proteins, resulting in syrups with smaller peptides exhibiting different antioxidant properties.</li> <li>• Ultrafiltration reduced pectin in permeate syrups compared to sap syrups. Female syrups had more reducing sugar and pectin but less ash than male syrups.</li> </ul> | Makhlouf-Gafsi et al., 2018, 2016a |
| Sap samples were collected from Khajura, Jashore and Sher-e-Bangla Nagor, Dhaka, Bangladesh                                                                  | Juice and Gur from date palm sap           | 20 date palm plants of identical ages were used with various protections to collect sap by tapping. Gur was made traditionally and by machine, also collected from local market.                                                                                                                  | <ul style="list-style-type: none"> <li>• TSS</li> <li>• pH, Titratable Acidity</li> <li>• Vit. C</li> <li>• Total sugar</li> <li>• Reducing sugar</li> <li>• Minerals</li> <li>• Bacterial count</li> </ul>                                                                   | <ul style="list-style-type: none"> <li>• Juice from bamboo &amp; nylon net protection had the highest TSS and vitamin C.</li> <li>• Gur from machines had higher mineral content and lower bacterial contamination than market samples</li> </ul>                                                                                                                                                                                                                                                                                                                                                                       | Islam et al., 2024                 |
| Kefir grains + Cheese whey + date palm sap (palm trees in the Tozeur region, located in the Sahara Desert, the largest of the five oases that make up Jerid) | Kefir beverage with whey-milk and palm sap | The sap was extracted using traditional tapping. To prevent fermentation, samples were quickly transported to the lab in an ice box. Juice samples were filtered through cloth and pasteurized.                                                                                                   | <ul style="list-style-type: none"> <li>• Microbial analysis</li> <li>• AA</li> <li>• pH</li> <li>• Sensory analysis</li> </ul>                                                                                                                                                | <ul style="list-style-type: none"> <li>• The optimized kefir formulation showed significant antioxidant activity, with palm sap contributing most.</li> <li>• The mixture of cheese whey, palm sap, and milk showed the highest DPPH scavenging activity, indicating a strong synergistic effect.</li> </ul>                                                                                                                                                                                                                                                                                                            | M'hir et al., 2023                 |

SDS, Sodium dodecyl sulfate polyacrilamide gel; DSC, Differential scanning calorimeter; TPC, total phenolic content; AA, antioxidant activity; TSS, Total Soluble Solids; HMF, Hydroxymethylfurfural.

ratios (40:60%, 30:70%, and 20:80%), indicating the feasibility of formulating new beverage types that combine the nutritional benefits of both components (Ennouri, 2023). The sensory evaluation indicated that the control beverage made from date palm sap (DPS) was the most appreciated in terms of aftertaste and overall acceptability, whereas among the formulated beverages, B3 (20:80% OFIJ:DPS) was preferred over B2 (30:70% OFIJ:DPS) and B1 (40:60% OFIJ:DPS). However, physicochemical analysis revealed that sedimentation and serum separation increased significantly after 28 d of cold storage, indicating beverage instability. Microbial analysis confirmed the absence of harmful bacteria, such as total coliforms, *Staphylococcus*, and *Escherichia coli*, but indicated that the beverages should not be consumed after 28 d of storage (Ennouri, 2023).

The high microbial load in date palm sap and the presence of beneficial microorganisms suggest the potential of fermented products (Djemal et al., 2025; Ziadi et al., 2011). Studies have isolated LAB strains, indicating the potential of fermented beverages to resemble traditional palm wine (Ziadi et al., 2011). The development of a novel kefir beverage using a mixture of whey milk and palm sap was explored using a simplex-centroid mixture design (M'hir et al., 2023). The study identified an optimal formulation consisting of 16.6% cheese whey, 78.6% palm sap, and 4.8% milk, which exhibited high antioxidant activity and acceptable

sensory properties. The presence of probiotics was confirmed, and the beverage demonstrated significant antioxidant activity, as measured by DPPH radical scavenging activity (M'hir et al., 2023). Future research could explore the use of selected starter cultures to control fermentation, investigate the impact of different fermentation parameters on product quality, and develop value-added fermented products with enhanced nutritional and health benefits (Das and Tamang, 2023; Djemal et al., 2025; Ziadi et al., 2011). However, the risk of Nipah virus transmission through raw sap highlights the need for effective preservation methods.

Advanced non-thermal processing methods, such as high-pressure processing or cold plasma, may offer solutions for extending the shelf life of sap while preserving its nutritional integrity. Future research should focus on optimizing formulations, enhancing sensory appeal, and incorporating functional ingredients such as probiotics (Sornsene et al., 2024) or antioxidants (Ben Thabet et al., 2009a). Kefir-like beverages containing date palm sap and probiotics are a promising area of research (Sornsene et al., 2024). However, the potential of these products for producing vinegar or sauces requires further investigation. The addition of spices, herbs, or flavorings can also improve sensory characteristics.

Carbonation is another preservation technique that can be used to prolong the shelf life of food products. Carbonating sap

involves pasteurizing the sap to eliminate bacteria, cooling it, and infusing it with carbon dioxide. This method is similar to the carbonation of coconut sap, which results in a refreshing beverage with a specific sugar content (Gunawardhana et al., 2018). Similarly, a study on palm (*Raphia hookeri*) sap explored the creation of a non-alcoholic “malt-like” drink, which was carbonated to produce a beverage named Palm Malt (Mintah et al., 2011). This product was evaluated for consumer acceptability and was found to be comparable to commercially available malt drinks, indicating a potential market for carbonated palm sap beverage. Date palm sap has the potential to be used as a carbonated beverage or blended with other functional juices for health benefits.

### 8.3.2 Sugar, syrup, and sweeteners

The transformation of date palm sap into syrup and sugar involves several critical steps, including collection, filtration, and concentration. Initially, sap was collected using traditional or improved methods to ensure minimal microbial contamination (Nahar et al., 2010). Subsequently, filtration techniques, such as the use of cloth filters or more advanced methods, such as stainless-steel filtration devices, are employed to remove particulate matter (Swain et al., 2016; Tuturoong et al., 2024). The concentration process, typically achieved by heating in open pans or using vacuum evaporators, is pivotal for syrup formation. This stage not only concentrates sugars but also initiates Maillard reactions, conferring a unique flavor and color to the syrup (Makhlouf-Gafsi et al., 2016b). Optimal processing conditions, including temperature control and duration, require careful management to preserve the nutritional quality of sap while ensuring microbial safety. Processing methods, such as evaporation and crystallization, can produce date palm sugar and syrup (Tuturoong et al., 2024). This aligns with the growing demand for natural alternatives to refined sugars.

One study investigated the nutritional and biochemical attributes of date palm juice and Gur or jaggery, revealing that controlled protection methods and machine-produced jaggery have higher quality and mineral content, including potassium, phosphorus, and calcium (Islam et al., 2024). The study concluded that the use of protective measures, such as bamboo and nylon nets, during date palm juice collection significantly enhanced its quality and quantity, resulting in higher levels of TSS, potassium, phosphorus, pH, and phenol, while also reducing bacterial contamination. Jaggery produced using machines demonstrated significantly higher TSS, vitamin C, titratable acidity, and TPC than Gur collected from local markets in Jashore and Khulna, which had higher sugar content and bacterial contamination (Islam et al., 2024).

Date palm syrup, characterized by its high sucrose content and minerals and phenolic compounds, is notable for its nutritional and functional properties (Ben Thabet et al., 2009b). The presence of antioxidants and essential minerals, such as potassium, calcium, and magnesium, enriches its health profile, offering more than just sweetness alone. Comparative studies have highlighted the higher antioxidant capacity of syrup compared to other natural sweeteners, which is attributed to its phenolic content (Ben Thabet et al., 2009a). Moreover, sensory evaluation indicated that the acceptability of date palm syrup, particularly the more concentrated

versions (68 Bx and 74 Bx), was comparable to that of maple syrup, with a hedonic scale mean value of 6.39 for the most concentrated syrup, suggesting a preference for viscous syrups among Tunisian consumers.

The versatility of date palm syrup as a natural sweetener extends beyond traditional uses and has applications in modern food products and industries (Ben Thabet et al., 2009a; Makhlouf-Gafsi et al., 2016b). Its integration into baked goods, confectioneries, and beverages as a healthier alternative to refined sugars exemplifies its functional and sensory attributes. Its unique flavor profile, coupled with its nutritional benefits, makes it an attractive ingredient for the food industry, aiming to meet consumer demand for natural and health-promoting products (Ben Thabet et al., 2009b). Furthermore, the potential for developing novel food products, such as functional beverages enriched with date palm syrup, underscores the need for innovation in the utilization of this traditional sweetener in contemporary food applications.

Although the current understanding of date palm sap processing in syrup and its applications is extensive, several research gaps remain in this field. Future studies should focus on optimizing processing techniques to enhance the nutritional and sensory properties of syrup and explore the effects of different filtration and concentration methods on the final product quality. Additionally, the potential health benefits of the regular consumption of date palm syrup warrant further clinical and epidemiological research. Investigating the role of syrup in chronic disease prevention and management could provide a scientific basis for its traditional use and promote its integration into health-focused diet.

### 8.3.3 Bio-based product potential and sustainability

The high carbohydrate content and diverse microbial communities in date palm sap make it a promising feedstock for various bio-based products. The success of bioethanol production from other palm saps, such as oil and coconut palms, provides a strong precedent for exploring applications similar to those of date palm sap (Anwar et al., 2023; Dash et al., 2015). The fermentation process can be further enhanced by integrating solar energy, which would not only improve efficiency but also contribute to the overall sustainability of the production process (Ahmed et al., 2016).

Beyond bioethanol, the presence of organic acids in date palm sap or syrup opens new possibilities for producing bioplastics and other value-added bio-based products. These materials could potentially serve as alternatives to petroleum-based plastics, address environmental concerns, and meet the growing demand for sustainable materials. However, further research is necessary to fully realize the potential of date palm sap as a bio-based feedstock. This includes optimizing bioconversion processes to maximize yield and efficiency, conducting comprehensive economic feasibility studies to ensure commercial viability, and evaluating the environmental impact of large-scale production to ensure sustainability throughout the value chain (Shalsh et al., 2024).

The nutritional profile of the subject is remarkably rich, with significant levels of essential minerals and vitamins, as reported in

multiple studies (Barh and Mazumdar, 2008). This nutrient density not only contributes to overall health but also positions the subject as a valuable ingredient in the development of nutraceuticals and functional foods. Date sap has a slight stimulatory effect on gastrointestinal transit activity in rats, as observed in an *in vivo* study (Souli et al., 2014). This suggests its potential use in aiding digestion and treating constipation. In traditional Tunisian medicine, date sap is used for its potential benefits in treating digestive issues, although its effects are less pronounced than those of the date pulp extract. The potential health benefits extend beyond basic nutrition, with research indicating promising antioxidant and antimicrobial properties (Ben Thabet et al., 2009a). These characteristics suggest that products derived from or incorporating this subject could be particularly beneficial for individuals with specific health conditions, such as anemia, diabetes, or cardiovascular disease.

Recent studies have explored the incorporation of probiotics to further enhance the health-promoting potential of date palm sap (Sornsenee et al., 2024). This addition could synergistically boost overall health benefits, potentially improving gut health, immune function, and nutrient absorption. The combination of inherent nutritional value, bioactive compounds with antioxidant and antimicrobial properties, and potential for probiotic enhancement presents a compelling case for developing innovative functional foods and nutraceuticals (Barh and Mazumdar, 2008). These products could offer targeted health benefits while meeting the growing consumer demand for natural, nutrient-dense food options that contribute to overall wellness and disease prevention.

## 9 Other applications of date palm sap

Date palm sap has demonstrated potential for various applications beyond its traditional use as a beverage and raw material for sugar and molasses production. These applications span across agriculture, aquaculture, bioplastics, and biofuel industries. Researchers have isolated yeast strains (*Saccharomyces cerevisiae*) from date palm sap to create bioinoculants for wheat crops. These bioinoculants significantly improved crop quality by increasing chlorophyll, protein, and indole acetic acid content in wheat, as well as enhancing soil humus content (Ambawade et al., 2023). Palm sap sugar has shown positive effects on feed efficiency and growth indices when used in aquafeeds for giant gouramis (Azrita et al., 2023). Date palm sap is a biorenewable source of succinic acid, a precursor of various commodities and chemicals. A study investigating the production of succinic acid from date palm syrup (derived from sap) and palm fronds found that date juice produced 20.6 g/L succinic acid, highlighting its potential for bioplastic production (Shalsh et al., 2024).

Date palm sap has emerged as a potential feedstock for bioethanol production because of its high sugar content and widespread availability. For instance, fed-batch fermentation of date palm sap using *S. cerevisiae* X19G2 yielded an ethanol concentration of  $86.8 \pm 0.35$  g/L, corresponding to  $0.48 \pm 0.03$  g/g sugar and a productivity of  $1.49 \pm 0.11$  g/L/h. The minimum bioethanol production potential was estimated to be 11,000 L per hectare of trees (Ben Atitallah et al., 2021). Whereas, an earlier study using *Wickerhamomyces anomalus* X19 achieved ethanol production of 61.51 g/L and 73.12 g/L in batch and fed-batch mode

fermentations, respectively, which corresponds to ethanol yields of 0.41 g/g and 0.46 g/g sugar consumed (Ben Atitallah et al., 2020). Furthermore, wild date palm (*Phoenix sylvestris* Roxb.) The sap fermentation by *S. cerevisiae* yielded 0.323 g/g ethanol with 63.40% ethanol conversion efficiency after 60 h. In this study, an estimated potential yield of 7,774 L/ha was reported, surpassing the yields from nipa palm sap, sugarcane juice, and sugar beet (Swaraz et al., 2019).

## 10 Challenges and prospects in modernization

Despite the existing research on date palm sap, several knowledge gaps persist. Further research is needed to fully elucidate the complex microbial communities and their roles in date palm sap fermentation (Djemal et al., 2025). Further studies are needed to determine the long-term effects of date palm sap consumption, particularly its potential health benefits and risks (Khan et al., 2012; Nahar et al., 2015). Additional research is required to develop efficient and cost-effective methods for processing and preserving date palm sap to extend its shelf life and maintain its quality (Choudhury, 2023; Tuturoong et al., 2024). The development of culturally appropriate and effective communication strategies to address the health risks associated with raw date palm sap consumption is essential (Parveen et al., 2016). Further research should focus on developing sustainable agricultural practices to enhance date palm productivity and reduce the environmental impact of its cultivation (Alotaibi et al., 2023). Advanced non-thermal technologies, such as pulsed electric fields, high-pressure processing, cold plasma, and ultrasound, can be explored to inactivate spoilage microorganisms while maintaining product quality. These methods offer advantages over traditional heat treatments by preserving sensory attributes and nutritional value (Roobab et al., 2018). However, no research has been conducted on the emerging technologies utilized for date palm processing. Finally, more studies are needed to explore the potential of date palm sap for various applications, such as bioethanol production and bioplastic manufacturing (Ahmad et al., 2021; Shalsh et al., 2024). A deeper understanding of the genetic diversity within date palm cultivars and their relationship with pest resistance can inform sustainable agricultural practices.

## 11 Conclusion

Date palm sap is a nutritionally rich substance with significant potential as a functional food ingredient and natural sweetener. Its composition, influenced by factors such as tapping period and palm variety, includes high levels of sugars, minerals, vitamins, amino acids, and bioactive compounds. Sap harbors a diverse microbial community that impacts its quality and fermentation outcomes. Traditional uses include fresh consumption, fermented beverages, and sugar production, which are of socioeconomic importance in many regions. However, raw sap consumption poses health risks, particularly Nipah virus transmission from fruit bats. Innovative approaches for processing and preservation are being explored to extend the shelf life while maintaining nutritional quality. The sap also shows promise as a feedstock for bio-based products. Further

research is needed to optimize processing techniques, characterize sap composition, evaluate long-term health effects, develop risk communication strategies, and explore novel applications. A multidisciplinary approach integrating traditional knowledge with modern scientific methods is crucial for realizing the full potential of date palm sap, while addressing safety concerns and ensuring sustainable production.

## Author contributions

UR: Visualization, Conceptualization, Writing – review & editing, Writing – original draft. FN: Conceptualization, Writing – review & editing, Visualization, Writing – original draft. SK: Funding acquisition, Writing – review & editing, Conceptualization, Supervision. SM: Conceptualization, Supervision, Funding acquisition, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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