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Fermented traditional wine from palm trees: microbial, nutritional attributes and health impacts

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Fermented wine from palm trees is gaining more acceptance by consumers given its natural and health promoting attributes. The traditional wine is fermented from the extracted sap of palm trees by microbes, however, excessive contamination by spoilage microorganisms must be avoided, storage conditions must be ensured to foster its natural fermentation. The importance and quality of this locally produced fermented wine will benefit from a better understanding of the scientific knowledge on its micro and macro nutrients. In this review paper, we explore the science of the traditional fermentation process that leads to the sweet, effervescent, milky but alcoholic beverage known as palm wine or toddy. The microbes that are involved in its fermentation (especially yeasts and lactic acid bacteria) are of interest towards realising the potential economic benefits that will be gained from the standard production of palm wine. It is important to emphasize 'sustainability' in the entire value chain of palm wine as an industry starting from its cultivation, to its processing, side streams, storage and consumption. In addition, the packaging materials for the large-scale production of palm wine will need to be eco-friendly when sustainability is considered.

KEYWORDS

palm-sap, fermentation, alcohol, lactic acid bacteria, yeasts, toddy, tropical

1 Introduction

Traditional wine from palm trees is fermented from the sap of the following *Palmae* family plants: coconut palm (*Cocus nucifera*), oil palm (*Elaeis guineensis*), date palm (*Phoenix dactylifera*), kithul palm (*Caryota urens*), nipa palm (*Nypa fruticans*), ron palm (*Borassus aethiopum*) and raffia palm (*Raphia hookeri*) (Sambou et al., 2002; Dayo-Owoyemi et al., 2008). When unfermented, the sap is a clear, sweet and colorless syrup of 10%–12% (w/v) sugar (Ogbulie et al., 2007).

For several years, the utilisation of fermentation techniques has been an inexpensive prominent practise in food preservation especially during the times of food scarcity. A range of foods and beverages fermented locally exist worldwide especially in the developing countries (Anagnostopoulos and Tsaltas, 2019; Obafemi et al., 2022). They form an essential dietary component of the peoples' meal, refreshment and cultural heritage in these countries as cited by several authors such as: (Lamba et al., 2019; Mishra et al., 2021; Deka and Sit, 2023): - India, (Azam et al., 2017),—Pakistan, (Adebo, 2020; Pswarayi and Gänzle, 2022; Aworh, 2023), - Africa, (Elizaquível et al., 2015),—Argentina, (Bassi et al., 2020; Rebaza-Cardenas et al., 2021),—Peru, (Guerra et al., 2022), - Ecuador, (Pérez-Armendáriz and Cardoso-Ugarte, 2020; Ojeda-Linares et al., 2021), for Mexico. Evidence-based studies on the health benefits of fermented food and beverages are extremely important to enable this food category entry in dietary guidance (Marco et al., 2021; Diez-Ozaeta, and Astiazaran, 2022). Tamang *et al.* (2016) estimated that thousands of variations of fermented foods and drinks are consumed worldwide. According to Marco *et al.* (2021), fermented beverages are produced by controlled microbial growth that converts major and minor components by enzymatic actions.

Palm wine is common in tropical regions of Asia, Africa and South America where palm trees grow. In these locations, fermented drink from palm trees is of great significance to the people. Many African countries have their own palm wine variety, (Ukhun et al., 2005; Karamoko et al., 2012). However, similar to other traditional fermented foods in Africa, the production of palm wine occurs by chance inoculation with uncontrolled fermentation. Therefore, discrepancies in their stability and quality of the product are rampant. The process involves tapping the sap of a palm tree after which the liquid obtained undergoes spontaneous fermentation. The yeast species proliferation converts the substrate into alcoholic beverage that contain important nutritional components, such as sugars, proteins, amino acids, and vitamins (Okafor, 1972).

There were studies carried out in Nigeria and Ghana in the last 40 years on several production and composition aspects of palm wine. The studies carried out by Uzochukwu *et al.* (1994) and Amoa-Awua *et al.* (2007), reported variations in the quality of palm wine throughout tapping, while Ouoba et al. (2012) showed that the variety of oil palm tree also affects the quality of palm wine.

In this review, we emphasize the microbes that are associated with palm wine fermentation, their nutritional characteristics and reported health impacts and concerns. We highlight the various traditionally produced wine from palm trees in several countries in Section 2. Section 3 discusses the nutritional profile of palm wine, in particular its biochemical composition, the concentrations of its sugars, pH, organic acids, ethanol, flavour compounds, minerals and trace elements. In Section 4, the microbes that are associated with palm wine, their characteristics, its preservation and spoilage are discussed while section 5 highlights its health impacts, medicinal properties and concerns. Section 6 concludes and suggests the need for further research on palm wine.

2 Traditionally produced palm wine from several countries

Fermented wine from palm species is one type of fermented beverage. It is known as toddy palm nectar from *Borassus flabellifer* Linn. commonly known as Palmyra Palm (Pammi et al., 2021). This specie belongs to Arecaceae family, with a common name of "toddy" in India (Zeid and FarajAlla, 2019), ron (*Borassus aethiopum*) in Ivory Coast (Djeni et al., 2022), Bandji from *Borassus akeassii* in Burkina Faso (Ouoba et al., 2012), Taberna from *Acrocomia aculeata* (Jacq.) Lodd. ex Mart.) in Mexico (Santiago-Urbina et al., 2013), and from *Acrocomia mexicana* in Honduras (Balick, 1990). For example, in Nigeria, most palm wine is tapped from three types of palm trees, namely, *Elaeis guineensis* (the palm oil tree) *Raphia vinifera* and *Raphia hookeri* (raphia palms) (Nwaiwu et al., 2016). Table 1 shows the list of palm species, their traditional names and country of origin.

Santiago-Urbina and Ruíz-Terán (2014) compiled available research and knowledge on the biochemistry and microbiology of traditional fermented palm wine worldwide. Generally, there are two methods that are traditionally employed to collect the wine from palm trees: in the first method, the sap is obtained from a live standing tree, such as the Bandji and Toddy production, this process involves climbing very tall palm trees, and perforate the trunk in the top of the tree for Bandji production (Ouoba et al., 2012), or cutting into the end of spadix from the tender inflorescence of the palm tree (inflorescence tapping) for Toddy production (Mbuagbaw and Noorduyn, 2012). The second method involves felling the tree or cutting it down before tapping, such as palm wine from Ghana and Taberna production. Normally, palm wine is collected twice a day, in the morning and the evening, it can be either immediately consumed or stored for later sale (Santiago-Urbina and Ruiz-Terla, 2014). The knowledge associated with the applied method will influence the quality attributes of the collected palm wine.

An example of an applied research knowledge is bottled indigenous palm wine in Nigeria shown in Figure 1.

When natural microflora fermentation occurs in palm wine, there is a reduction in the concentration of sugar. This is due to the conversion of sugar to alcohol giving a milky white fluid resulting from the prolific increase of organisms responsible for fermentation with an increase in the microbial load (Obire, 2005). The final outcome is an alcoholic beverage that has a milky white appearance and effervescent nature.

The packaging and distribution of palm wine to consumers is worth considering, especially in terms of its carbon footprint and sustainability when exported. The utilization of calabash (dried gourd), an old age packaging material for palm wine in many African countries is biodegradable, eco-friendly and light weight can be revisited (Umeh et al., 2021).

3 Nutritional profile of palm wine

The nutritional value of palm wine has to be taken in the context of a natural drink or beverage which is normally consumed after meals to refresh. The palm sap contains sugar, protein, fat and mineral matter (Ezeagu and Fafunso, 2003), it is generally regarded as safe (GRAS) with beneficial lactic acid bacteria and *Saccharomyces* yeast species that possess probiotic attributes.

Table 2 below shows the average value of some major constituents of palm wine sap as reported by several authors (Obahiagbon and Oviasogie, 2007; Ben Thabet et al., 2009; Ouoba et al., 2012; Santiago-Urbina et al., 2013).

Palm wine beverage is linked to a high content of amino acid, potassium, zinc and iron (Eze et al., 2019). Palm sap is a good source of vitamins B1, B2, B3 and B6. According to (Mbuagbaw and Noorduyn, 2012) it has been associated with increased sperm and breast milk. However, further studies on animal models will be required.

TABLE 1 Palm wine plant species with their traditional names and country of origin (Data sourced from Santiago-Urbina and Ruíz-Terán (2014) and Sarma et al. (2022)).

Palm scientific name	Traditional names	Country of origin	References
Acrocomia aculeata	Taberna	Mexico	Santiago-Urbina *et al.* (2013)
Acrocomia aculeata	Palm wine	Caribbean countries, Paraguay, Argentina	Francisco-Ortega and Zona (2013)
Acrocomia mexicana	Coyol Wine	Honduras	Balick (1990)
Arenga pinnata	palm toddy	Malaysia	Ho et al., 2007; Nur Aimi et al., 2013
Attalea butyracea	Palm wine	Colombia	Bernal *et al.* (2010)
Beccariophoenix madagascariensis	Palm wine	Madagascar	Van Nguyen et al. (2016)
Borassus aethiopum	Ron	Côte d'Ivoire	Djeni *et al.* (2020), Djeni *et al.* (2022)
Borassus aethiopum	Palm wine	Guinea	Sambou *et al.* (2002)
Borassus akeassii	Bandji	Burkina Faso	Ouoba *et al.* (2012)
Borassus flabellifer	Toddy	India	Zeid and FarajAlla, (2019); Pammi et al., 2021
Borassus flabellifer	Palmyrah toddy	Sri Lanka	Theivendirarajah and Chrystopher (1987)
Borassus madagascariensis	Palm wine	Madagascar	Decary (1964)
Cocos nucifera	Mnazi	Kenya	Kadere *et al.* (2008)
Cocos nucifera	Toddy	Sri Lanka	Atputharajah *et al.* (1986)
Cocos nucifera	Tuba	Philippines, Mexico	Atputharajah et al., 1986; de la Fuente-Salcido et al., 2015; Astudillo-Melgar et al., 2019
Cocos nucifera	Tuak	Indonesia	Atputharajah *et al.* (1986)
Cocos nucifera	palm toddy	Malaysia	Nur Aimi *et al.* (2013)
Corypha umbraculifera	Talipot palm	Sri Lanka, India, Myanmar, Thailand, and Cambodia	Irawanto (2014)
Elaeis guineensis	Palm wine	Nigeria	Ezeronye and Legras, (2009); Nwaiwu et al., 2016
Elaeis guineensis	Mimbo/Palm wine	Cameroon	Jespersen, (2003); Stringini et al., 2009
Elaeis guineensis	Akpeteshie	Ghana	Amoa-Awua *et al.* (2007)
Hyphaene petersiana	Omalunga	Namibia	Sullivan et al., 1995; Cheikhyoussef and Embashu, (2013)
Hyphaene coriacea	Palm wine	Mozambique	Martins and Shackleton (2018)
Hyphaene petersiana	Palm wine	Botswana, Zimbabwe	Babitseng and Teketay (2013)
Hyphaene thebaica	Doum Palm	Mauritania, Senegal, Egypt, Kenya, Tanzania, and Nile basin in Sudan	Van Nguyen et al., 2016; El-Beltagi et al., 2018
Jubaea chilensis	Chilean palm	Chile	González *et al.* (2009)
Mauritia flexuosa	Buriti palm	Trinidad, Colombia, Venezuela, Guyana, Suriname, French Guinea, Brazil, Ecuador, Peru, and Bolivia	Delgado et al., 2007; Francisco-Ortega and Zona, (2013)
Metroxylon sagu	Sago palm	Papua New Guinea, Indonesia, Malaysia, and Thailand	Corbishley and Miller (1984)
Nypa fruticans	Toddy	Malaysia	Nur Aimi *et al.* (2013)
Nypa fruticans	Toddy	Papua New Guinea	Päivokë (1985)
Orbignya martiana	Babassu Palm	Brazil	May *et al.* (1985)
Phloga polystachya	Palm wine	Madagascar	Decary, (1964)
Phoenix dactylifera	Legmi	Tunisia	Ziadi *et al.* (2011)
Phoenix dactylifera	Palm wine	Egypt, Iran, United Arab Emirates, Saudi Arabia, Pakistan, Algeria, Iraq, Sudan, Oman, and Libya	Makhlouf-Gafsi, et al., 2016; Al-Alawi et al., 2017
Phoenix reclinata	Palm wine	Mozambique	Martins and Shackleton (2018)

(Continued on following page)

TABLE 1 (*Continued*) Palm wine plant species with their traditional names and country of origin (Data sourced from Santiago-Urbina and Ruíz-Terán (2014) and Sarma et al. (2022)).

Palm scientific name	Traditional names	Country of origin	References
Phoenix reclinata	Palm wine	Tropical Africa, the Arabian Peninsula, Madagascar and the Comoro Islands	Lim, (2012); Orwa et al., 2009
Phoenix sylvestris	Toddy	India	Shamala and Sreekantiah (1988)
Phoenix sylvestris	Palm wine	Arabian Peninsula, Iran, Pakistan, Bangladesh, and India	Namoff *et al.* (2011)
Pseudophoenix ekmanii	Palm wine	Dominican Republic	Namoff et al., 2011, Rodriguez, (2014)
Pseudophoenix vinifera (Cacheo)	Palm wine	Dominican Republic, Haiti	Rodriguez (2014)
Raphia hookeri	Emu/Palm wine	Nigeria	Jespersen, (2003); Ezeronye and Legras, (2009); Nwaiwu et al., 2016
Raphia farinifera	Palm wine	Madagascar	Dalibard, (1999)
Raphia hookeri	Raffia palm	South Africa	Erukainure *et al.* (2020)
Raphia hookeri	Raffia palm	Ghana, Cameroon, Nigeria, Madagascar Gabon, and Congo	Obahiagbon and Osagie, (2007); Francisco-Ortega and Zona, (2013)
Raphia vinifera	Palm wine	Nigeria	Ezeronye and Legras, (2009); Nwaiwu et al., 2016
Raphia vinifera	Mimbo	Cameroon	Francisco-Ortega and Zona, (2013); Van Nguyen et al., 2016

FIGURE 1
Nigerian Indigenous premium palm wine. Photo credit ©Sulaimon Kosoko.

The nutritional profile of palm wine makes it a good medium for microbial growth. Due to rapid fermentation by microbes, hydrolysis of sucrose to fructose and glucose occurs within 24 h. They are then converted to lactic acid at 0.05%–4.7% (w/v), acetic acid at 0.01%–0.24% (w/v) and ethanol at 0.21%–5.28% (w/v) (Ouoba et al., 2012; Santiago-Urbina et al., 2013). According to the authors, this action reduces the pH of palm sap to 5 making it unacceptable to consumers as a drink.

A better understanding of how the nutritional attributes of palm wine can be utilized warrants a brief overview of its biochemical components as highlighted in the following sub-sections.

3.1 Biochemical components in palm wine

Naturally, there are millions of biochemical compounds that can act synergistically and in the case of palm wine the observed biochemical compounds will depend on the state of fermentation (Santiago-Urbina and Ruíz-Terán, 2014).

The biochemical components described in this review includes sugars, organic acids, ethanol, polyphenols, short-chain fatty acids present in palm wine. For instance, 'Taberna' palm wine from Mexico contain bioactive substances, e.g., polyphenols including flavonoids, carotenoids, isoflavones, saponins, and lignans; they are known to have a protective effect on the cardiocirculatory system, they stimulate the immune system and regulate blood glucose (Robledo-Márquez et al., 2021).

The activity of microbes in palm wine produces phenolic compounds. Fresh sap contains around 0.33 g/L phenolic compounds, it rises during fermentation up to 1.24 g/L at 58 h, beyond which there is very little change (Sarkar et al., 2023). The authors also confirmed the presence of gallic acid, protocatechuic acid, galangin, caffeic acid and p-coumaric acid palm sap. One of the bioactive peptides produced by *Lactobacillus bulgaricus, L. acidophilus, L. casei, and L. plantarum* is melatonin, which acts

TABLE 2 Major constituents of the sap of palm wine.

Constituents	Palm sap	References
Total sugar	11.4%	Obahiagbon and Oviasogie, (2007); Ben Thabet et al., 2009 Ouoba et al., 2012; Santiago-Urbina et al., 2013
Reducing sugar	0.9%	
Sucrose	95.3%	
Phosphorous	0.1%	
Iron	0.4%	
Protein	0.4%	
Nitrogen	0.05%	
Mineral ash	0.5%	
Vitamin C	13.2%	
Vitamin B1	3.9IU	
pH	7.3	

on sleep and reproductive behavior and controls immunity, inflammation, and carcinogenesis in mammalian cells (Tan et al., 2014).

The beneficial effects of probiotic bacteria such as *Lacticaseibacillus. casei, Lactiplantibacillus plantarum*, *Bifidobacterium bifidum* and *Bacillus subtilis* were noted to be associated with several indigenous African fermented foods including palm wine (Mgbodile and Nwagu, 2023). The authors suggested further investigation on the use of these probiotic bacteria as a strategy against COVID-19 and other viral infections. Probiotic yeasts in palm wine were also reported to be effective in the treatment of acute diarrhea in children due to the release of polyamines that helps to repair mucous membranes (Ngongang et al., 2016). The released polyamines increase the activity of short chain fatty acids and disaccharide enzymes - lactase, maltase and sucrase (Ngongang et al., 2016). Raphia palm wine is evidenced to improve pancreatic β-cell function and stimulate insulin secretion with concomitant inhibition of glycolytic and carbohydrate-digesting enzymes, which leads to reduced blood glucose level while attenuating oxidative pancreatic injury and proinflammatory, dyslipidemia and Nrf2 expression (Erukainure et al., 2019a). The observed raphia palm wine reduction of serum, liver, cardiac, and kidney biomarkers suggests its safety on diabetic and healthy organs. The authors also emphasized that low dose of the wine was more effective than high dose suggesting toxicity at higher doses.

There is very little evidence on the pathways mechanism that are responsible for the production of bioactive compounds such as polyphenols during palm wine production in comparison to other wines from grapes. However, the work of Erukainure and colleagues shed some light on how bioactive compounds in Raphia palm wine improves antioxidative activities. The pathway enrichment of the identified metabolites in Raphia palm wine revealed an alteration of the glycine and serine metabolic pathway on the induction of oxidative stress, with concomitant activation of the malate-aspartate shuttle, citric acid cycle, transfer of acetyl groups into the mitochondria, and the alanine, tryptophan, tyrosine metabolic pathways (Erukainure et al., 2019a). Treatment with the palm wine were shown to deactivate the oxidative induced metabolic pathways, with concomitant activation of biotin, carnitine synthesis, sulfate/sulfite, androstenedione, estrone, lysine degradation, androgen and estrogen, nicotinate and nicotinamide, porphyrin, and sphingolipid metabolic pathways.

Carnitine has been reported for its free radical and antioxidative activities in cells (Kolodziejczyk et al., 2011; Ribas et al., 2014), thus activation of its synthesis in pancreatic tissues treated with Raphia palm wine samples may portray an increased antioxidative effective owing to concomitant increased level of cellular carnitine. The antioxidant protective effect of the palm wine samples against oxidative pancreatic tissues was observed by the activation of metabolism of sex hormones - androgen, and estrogen. The receptors of these hormones were reported in pancreatic tissues, and dysregulation of their metabolism were implicated in pancreatitis and pancreatic β-cell proliferation in diabetes (Li et al., 2008). These hormones have also been shown to modulate antioxidant enzyme activities (Bellanti et al., 2013). Similarly, the activation of B vitamins metabolism as well as that of sulfate/sulfite portrays increased antioxidant activities as well as generation of essential cofactors that are required for DNA repair and antioxidant enzyme activities (Kamat and Devasagayam, 1999; Mukwevho et al., 2014; Katsyuba et al., 2020).

As a result of increased superoxide dismutase (SOD), and catalase (CAT) activities, and decreased malondialdehyde (MDA) and nitric oxide (NO) levels, and myeloperoxidase activity in palm wine-treated tissues, it gives support to the antioxidative and anti-proinflammatory potentials of Raffia palm wine (Erukainure et al., 2019a).

Generally, the composition of palm wine depends on its state of fermentation when consumed. The main features of palm wine are its whitish color, effervescent, sweet and acidic taste. Palm wine is produced by natural lactic-alcoholic- acetic fermentation of the sugary sap of palm tree (Ouoba et al., 2012); its fermentation is in three stages, an initial lactic acid, a middle alcoholic and a final acetic acid (Amoa-Awua et al., 2007). At each stage, the microbial activity helps the microbial activity in the next stage (Atputharajah et al., 1986). The growth and activity of the associated yeasts results in higher total acidity and a lower pH due to organic acids production, which enhance the growth and invertase activity of yeasts (Naknean et al., 2010), consequently ethanol produced by the yeasts will serve as a substrate for the production of acetic acid (Amoa-Awua et al., 2007). The pH of palm sap is almost neutral (7-7.4), which is an indication that it is fresh (Santiago-Urbina et al., 2013).

Tryptophan, the least abundant in everyday food and precursor for serotonin, can support the claim of palm wine as a hypnotic and an antidepressant. A reduction of DL-Methionine present in ron palm wine and DL-Tryptophan present in oil palm wine during the later tapping stages (15–25 days) was observed by Djeni and co-workers (Djeni et al., 2022). In addition, the higher relative concentration of gevotroline (an antipsychotic agent and a dopamine receptor D2 antagonist) present in the early stages of oil palm wine tapping and a drastic decline during later stages of tapping support the difference in the health benefits of the palm wine obtained from different stages of tapping. This indicates early stages of tapping are more nutritional and healthier than the later stages.

TABLE 3 Sugar content in palm wine from different sources.

	Asian palmyra *Borassus flabellifer*	Oil palm *Elaeis guineensis*	Macaw palm *Acrocomia aculeate* (%)	Raffia palm *Raphia hookeri* (%)	Date palm *Phoenix dactylifera* (%)	References
Sucrose	9.3%–17.4%	9.6%–10.6%	11.4	9.5	95.3	Faparusi, 1981; Obahiagbon and Osagie, (2007); Naknean et al., 2010; Santiago-Urbina et al., 2013; Das and Tamang, (2021)
Glucose	0.5%	0.7%			2.5	
Fructose pH	1.8%	0.7%			1.6	
	7.4	6.6				

3.2 Concentrations of sugars, organic acids and ethanol in palm wine

During the natural fermentation in palm saps, the composition of microbiota tends to change in their dynamics, they are influenced by the fluctuation in micro-environments (pH, alcohol content, sugar profile and organic acids). Ultimately, this will affect the microbial community structures and metabolite profiles (Das and Tamang, 2021). Table 3.

It was reported that the total sugars in *Elaeis guineensis* palm wine samples dropped from an initial concentration of 14%–11% by the fourth day of tapping (Amoa-Awua et al., 2007). In raffia pam wine (*Raphia hookeri*), sucrose, glucose, maltose and fructose sugars were present in the 1st day of tapping; xylose and cellobiose were detected at middle tapping period; while galacturonic acid, arabinose and rhamnose were detected irregularly for a few days (Faparusi, 1981). The palm wine of Asian palmyra (*Borassus flabellifer)* contains 9.3%–17.4% of sucrose while the glucose and fructose ranges between 0.5% and 1.8% (Naknean et al., 2010) in the 1st samples of tapping. For oil palm (*Elaeis guineensis)* palm wine, the decrease in sugar content indicates that most of the sugars has fermented at the early stages of tapping. However, during the 15 days of tapping of macaw (*Acrocomia aculeate)* palm wine, it was discovered that there was an initial concentration of 11.4%, sucrose which dropped throughout the tapping process to 0.2%, due to the metabolic activities of microbes (Santiago-Urbina et al., 2013). Overall, the composition of sugar variation is as a result of multiple factors such as the tree species, when and how the palm wine was tapped.

3.3 Trace elements and minerals present in palm wine

There are several micro and macro elements reported in palm wine sap; sodium and magnesium were reported as the most abundant elements as shown in Table 4 below. The recommended daily intake (mg/day) of these elements are also indicated (Sarkar et al., 2023). In the palm wine of *Phoenix dactylifera,* phosphorus of 41.5 mg/100 g and magnesium 330 mg/100 g is present, potassium which is the most abundant element is 522.9 mg/100 g on a dry matter basis (Ben Thabet et al., 2009). Other reported mineral elements by the authors, in decreasing order were calcium, sodium, iron, copper, and zinc.

TABLE 4 Micro and macro elements in general sap of palm wine.

Component	mg/100 mL	Recommended RDI[a] (mg/day)
Micronutrients		
Iron	0.04–1.58	8.7–14.8
Zinc	0.013–0.71	8–11
Copper	0.02–0.21	0.9–1.3
Manganese	0.009–2.23	1.8–2.3
Nickel	0.06	0.18–0.25
Macronutrients		
Potassium	65.28–1326.0	1600–2000
Sodium	2.85–117.5	<2300
Magnesium	0.54–31.00	310–420
Calcium	0.24–79.00	700

[a]RDI, recommended daily intake. Adapted from Sakar et al. (2023).

3.4 Flavor compounds of palm wine

The unique flavor of palm wine was attributed to the higher amount of volatile organic compounds produced by dominant yeast *Hanseniaspora guilliermondii* and *Hanseniaspora jakobsenii*, isolated from raffia palm wine and ron palm wine (Gamero et al., 2016; Lombardi et al., 2018; Amoikon et al., 2020).

The overall quality of palm wine is influenced by metabolites that are produced by microbes to give it a distinct taste and flavor. Lactic acid, acetic acid, amino acids, esters are compounds that influence the flavor of palm wine (Djeni et al., 2022).

These organic acids and alcohols contributing to the flavor of palm wine are produced during the fermentation process. The major flavors that were observed in fresh palm wine sap are ethyl lactate, 3-hydroxy-2-pentanone, farnesol, phenylethyl alcohol, tetradecanone and 2-methyl tetrahydrofuran were found (Hebbar et al., 2018). The major volatile components that are responsible for the aroma of palm wine are the higher alcohols and esters as well as acids, aldehydes and ketones (Uzochukwu et al., 1997).

Some species of lactic acid bacteria and fungi synthesise aromatic amino acids (Fairbairn et al., 2017; Sugiyama et al., 2022), leading to the distinct aroma of palm wine drink (Santiago-Urbina and Ruíz-Terán, 2014). For example, *Lactobacillus* contributes to the biosynthesis and metabolism of glutathione (GSH), an important

TABLE 5 Microorganisms isolated from palm wine and their identification methods.

Microbes	Category	Identification methods	References
Saccharomyces cerevisiae, Schizosaccharomyces pombe, Geotrichum lactis, Debaryomyces hansenii, and *Zygosaccharomyces rouxiii*	Yeast	Biochemical and morphological	Dayo-Owoyemi et al. (2008)
Saccharomyces cerevisiae S. globosus, and *Hanseniaspora uvarum*	Yeast	Morphological, biochemical, and physiological	Nwachukwu et al. (2006)
Leuconostoc palmae	LAB	Phylogenetic analysis	Ehrmann et al. (2009)
Lactobacillus plantarum, Leuconostoc mesenteroides and *L. mesenteroides* subsp. *dextranicum*	LAB	Biochemical and genetic	Amoa-Awua et al. (2007)
			Rakowska et al. (2017)
Saccharomyces cerevisiae, Arthroascus, Issatchenkia, Candida pararugosa, C. tropicalis, Trichosporon asahii, Hanseniaspora, Kodamaea, Schizosaccharomyces, Trigonopsis and *Galactomyces*	Yeast	26S rRNA gene sequencing	Ouoba et al. (2012)
Lactobacillus plantarum, L. Fermentum, Leuconostoc mesenteroides, Fructobacillus durionis and *Streptococcus mitis*	LAB	16S rRNA sequencing	Ouoba et al. (2012)
Acetobacter tropicalis, A. indonesiensis, Gluconacetobacter, Gluconobacter oxydans and *G. saccharivorans*	AAB	gyrB gene sequencing	Ouoba et al., 2012; Astudillo-Melgar et al., 2019
Lactobacillus acidophilus, L. plantarum, Lactobacillus brevis, Leuconostoc mesenteroides ssp. *Mesenteroides/ dextranicum*	LAB	Biochemical and morphological	Adamu-Governor et al. (2018)
Erwinia, Klebsiella, Serratia, and *Cronobacter*	Enterobacteriaceae	next-generation sequencing (NGS)	Astudillo-Melgar et al. (2019)
Sphingomonas sp. , *Vibrio* sp., *and Zymomonas mobilis*	Proteobacteria	next-generation sequencing (NGS)	Alcántara-Hernández et al., 2010; Astudillo-Melgar et al., 2019
Leuconostoc pseudomesenteroides, Lactobacillus paracasei, Lactobacillus fermentum Weissella cibaria, Enterococcus casseliflavus and *Lactococcus lactis*	LAB	16S rRNA gene sequencing	Kouamé et al. (2020)
Fructobacillus durionis, Fructobacillus ficulneus, Fructobacillus fructosus Lactobacillus diolivorans, Lactobacillus fermentum, Oenococcus kitaharae, Oenococcus oeni	LAB	next-generation sequencing (NGS)	Astudillo-Melgar et al., 2019; Djeni et al., 2022
Lactiplantibacillus paraplantarum, uncultured Leuconostoc sp., *Leuconostoc mesenteroides, Lactobacillus* sp., *Lactococcus lactis, Acetobacter* sp. *and Gluconobacter* sp.	LAB	NGS	Das and Tamang, (2021)
Saccharomyces cerevisiae, Starmerella meliponinorum, Torulaspora delbrueckii, Lachancea thermotolerans, Lachancea lanzarotensis, Lachancea kluyveri, and *Hanseniaspora uvurum*	Yeast	NGS	Das and Tamang, (2021)
Saccharomyces cerevisiae, Hanseniaspora guillermondii, Saccharomycodes sp. and *Schizosaccharomyces pombe*	Yeast	NGS	Satyalakshmi et al., 2018; Djeni et al., 2022
Acinetobacter xiamenens	Moraxellaceae	NGS	Djeni et al., 2022
Acetobacter tropicalis, Gluconobacter frateurii, and *Gluconobacter oxydans*	AAB	NGS	Djeni et al., 2022

antioxidant (Das and Tamang, 2021) with vital role for cells protection such as hepatocytes, erythrocytes, and other human body cells against toxic injury (Mazari et al., 2023; Tan et al., 2023) promotes health (Rakowska et al., 2017). Most of the microorganisms isolated from palm wine are mainly yeasts and bacteria shown in Table 5.

4 Microbes associated with palm wine

In palm wine, the microbes that are predominant are lactic acid bacteria, acetic acid bacteria, and yeasts. These microbes act as functional microbes since they can stimulate probiotic functions, and fortify food or beverage with bioactive compounds that

4.1 Characteristics of beneficial microbes in palm wine

There are several studies that demonstrates the benefits of yeasts as valuable source of peptides and amino acids (Marson et al., 2020), such that they can be incorporated in dietary supplements and functional foods. Since palm wine contains *S. cerevisiae* yeast at all stages of fermentation, there was extensive studies on the probiotic effects of *Saccharomyces boulardii* yeast strain with a strong suggestion that its clinical activity can be beneficial to diarrhoea caused by antibiotics ingestion and intestinal infections by *Clostridium difficile* (Nwaiwu et al., 2016). Other yeasts include *Candida and Pichia* (Ouoba et al., 2012). The sediments or dregs that are formed when palm wine is left standing over a period of time contain *S. cerevisiae* and *Schizosaccharomyces pombe* as dominant yeast species (Odunfa and Oyewole, 1998) with the later possessing a unique metabolism and capabilities such as wine acid regulation during malo-alcoholic fermentation (Loira et al., 2018).

The co-existence of bacteria and fungi, yeasts and moulds during changes in natural fermentation of fresh palm saps to toddy was observed in a study. The study validated the indigenous knowledge of ethnic people to preserve the essential microbial resources during natural fermentation of fresh saps to mild-alcoholic drink, they designed tapping, and created a 'conducive environment' for the growth of microbiota (Das and Tamang, 2021).

Lactobacillus strains such as *Limosilactobacillus fermentum* (Naghmouchi et al., 2020), *Lactiplantibacillus plantarum* L3 (Wang et al., 2023), *Lactiplantiblacillus plantarum* A3 and *Lacticaseibacillus rhamnosus* ATCC7469 (Li et al., 2023), *Lacticaseibacillus paracasei* (Bengoa et al., 2023), *Lactiplantibacillus paraplantarum* (Coimbra-Gomes et al., 2023), *Lactobacillus rhamnosus* B2-1 (Guo et al., 2023), and *Limosilactobacillus fermentum* (Paulino do Nascimento et al., 2022) are involved in the manufacture of several fermented foods for health-promoting effects (Nath et al., 2020; Widyastuti et al., 2021; Manzanarez-Quin et al., 2023) and acting as probiotics (Lynch et al., 2018; Lee et al., 2022; Coimbra-Gomes et al., 2023). Some strains of lactobacilli were reported to have probiotic activities that are useful in the prevention and treatment of gastro-intestinal disorders, such as rotavirus diarrhoea, antibiotic-associated diarrhoea, and travellers' diarrhoea, they can act as potential therapeutic agents to treat inflammatory bowel disease and irritable bowel syndrome (Kim et al., 2017; Levit et al., 2019; Krammer et al., 2021). In Cameroonian raphia palm wine, three strains of *Lactobacillus* spp. with probiotic properties were isolated and identified as *Lactobacillus delbrueckii* subsp. *lactis* SA, *Lactiplantibacillus plantarum* SF and *Levilactobacillus brevis* SI (Tongwa et al., 2019). *Levilactobacillus brevis and Enterococcus faeccium* were reported by Fossi and colleagues as the two best cholesterol lowering LAB isolated from Cameroonian palm wine (Fossi et al., 2022). *Limosilactobacillus fermentum* strain BB101 and *Lactobacillus casei* 02 were also identified as sources of potential probiotic lactic acid bacteria in palm wine (Ngwa et al., 2022).

Acetic acid bacteria play an important role in the fermentation of food and beverages by oxidizing ethanol to vinegar or acetic acid. Acetic acid bacteria are normally produced towards the end of fermentation process in palm wine, thus enabling sufficient ethanol to oxidize (De Roos and De Vuyst, 2018; Gomes et al., 2018).

Humans have discovered the relationship between diet, lifestyle and good health and are looking into buying and consuming products that can extend benefits beyond providing adequate nutrients but also promote good health and wellbeing. Lactic acid bacteria (LAB) and foods fermented by it have proven to benefit the immune system and promote good health such as, increased resistance to malignancy, and infectious illnesses (Şanlier et al., 2019). LAB can improve lactose utilization, promote anti-cholesterol effect, and the production of bacteriocin, an effective antimicrobial compound which is beneficial to humans (Wang et al., 2021; Zhao et al., 2021; Darbandi et al., 2022). Lactic acid bacteria have been exploited in its co-administration with antibiotics, as they can help antibiotic therapy by reducing microbial adhesion and the growth of other inhibitory compounds or bacteriocins, they also have immunomodulatory properties, and can promote the integrity of intestinal barrier (Ibrahim et al., 2021; Mokoena et al., 2021). LAB promotes the recovery of commensal microbiota and the treatment tolerability in patients that are receiving antibiotic therapy (Wuethrich et al., 2021). It is now clearer that additional intervention in the application of antibiotics cannot be underestimated owing to the fact that the effectiveness of antibiotic administration is losing its effectiveness as a result of abuse, over administration and the increase in development of resistance to antibiotics (Rawson et al., 2021; Shah et al., 2021).

4.2 Preservation and spoilage of palm wine

Palm wine is culturally and socially significant in many societies. Attempts were made in the past to preserve palm wine by employing traditional methods as practiced in the Southern part of Nigeria, the indigenes or natives attempted to preserve palm wine by adding (*Sacoglottis gabonensis*) bitter bark tree (Nwaiwu et al., 2016). Ogbulie et al. (2007) described the use of refrigeration, which only delayed fermentation but could not preserve it and suggested the use of chemical preservatives as an alternative; Akujiobi et al. (2004) suggested the addition of burnt lime and sodium metabisulphite; Eapen (1982) recommended a method of preservation by heat treatment or pasteurizations (at 70 °C for 30 min) and the addition of sodium metabisulphite as a preservative. The method recommended by Eapen (1982), was adopted by most processors when the bottled palm wine was introduced into the Nigerian market.

Following the U.S. Food and Drugs Administration Act on the use of chemical preservatives in foods, and reactions from consumers who often had stomach ache, running stomach, *etc*., when the product was drunk, research was conducted to study the possibility of eliminating the chemical preservative, sodium metabisulphite, which most people were reacting to (Foulke, 1993). Attempts were made in a study that presents a new method of preserving the exudates of *Raphia vinifera* in its natural form by the application of heat only as most consumers are becoming scared about chemical preservatives in foods, due to their carcinogenic properties (Obahiagbon and Oviasogie, 2007).

As palm wine ferments further, its acidity increases due to the high production of acetic acid, which is one of the main causes of degradation in palm wine. In *Borassus akeassii* (Bandji) palm wine from Burkina Faso, species of *Bacillus cereus*, *Corynebacterium sp*., *Streptococcus mutans* and *Bacillus thuringiensis* were detected as well as *Acetobacter pasteurianus* in the second fermentation stage (Tapsoba et al., 2016). It was also reported that the spoilage of bottled Raphia palm wine could be from Byssochlamys spp. that produce ascospores which are heat resistant and are able to survive heat above 85°C (Eziashi et al., 2010). In addition to their heat resistance, Byssochlamys species can grow under very low oxygen tensions and can form pectinolytic enzymes (Houbraken et al., 2006). *Byssochlamys zollerniae* and *Byssochlamys nivae* were implicated in the spoilage associated with bottled Raphia palm wine.

This indicates that the solution to palm wine preservation might be protection against oxygen and the limit of bacterial growth through the use of preservatives (Tapsoba et al., 2016).

In another study on raffia palm wine using liquid chromatography—mass spectrophotometer (LC–MS), several metabolites, mainly polyphenols and their glycosides, vitamins, and amino acids were identified (Erukainure et al., 2019). These metabolites affect the quality of palm wine and they will contribute to set up the characteristics of the palm wine produced during the tapping days.

5 Health impacts and concerns of palm wine

5.1 Health impacts

Globally, wines are the second most drunk alcoholic beverage or drink whose popularity have continued to grow because of their numerous health benefits (Adakaren et al., 2017). Fresh palm wine, has no or very low alcoholic content but offer socioeconomic, nutritional, health and medicinal benefits to humans (Uzogara et al., 1990; Olasupo and Obayori, 2003; Chandrasekhar et al., 2012). Some of the health benefits attributed to palm wine apart from the low alcoholic content are from yeasts, lactic acid, and acetic acid bacteria which confer probiotic qualities to the wine and several antioxidants. It was observed in a study that at early stages of tapping they are healthier and more nutritious when compared to later stages, tryptophan, a precursor for serotonin, can support the health claim of palm wine as a hypnotic and an antidepressant (Djeni et al., 2022).

Fresh palm wine has been used traditionally to cure children with measles. It is administered to children suspected of having measles, by giving them a portion of the fresh drink and this has been known to cut down drastically the temperature associated with measles (Eze et al., 2019).

It is customary for locals to give fresh palm wine to women who just gave birth to babies as lactation enhancer. Some evidence suggests that prolactin, the hormone originally identified as a neuroendocrine hormone of pituitary origin can enhance lactation (Harvey et al., 2012).

All the enumerated traditional health benefits are attributed to moderate intake of sweet non-fermented/slightly fermented *E. guinneesis* sap (Palm wine) due to the fact that fermentation of alcohol is dependent on time during which beverages rich in sugar are converted by the useful bacteria to alcohol and ethanoic acid.

Steinkraus (1997) and Ibegbulem et al. (2013) reported on the rich content of palm wine including vitamins C, B1, B6, B12 and other B vitamins. which are reported to be good for eyesight and energy. According to Ukhun et al. (2005), vitamin B and C from palm wine helps to build the connective tissues of the blood vessels in the eye thus helping to prevent cataracts, macular degeneration and similar problems in the eyes. The consumption of palm wine seems to have some action on the pupil, which regulates the amount of light allowed into the eyes and consequently dilates or constricts as light in the environment changes (Claisse et al., 2016; Kvamme et al., 2019).

Due to the abundance of nutrients such as water-soluble vitamins and essential amino acids in palm sap, they are well-known for their health effect in promoting the regeneration of brain cells and exhibiting potent antioxidant properties (Hebbar et al., 2018; Sarma et al., 2022). The sap from *Borassus flabellifer* is reported to possess antifungal activity (Singh et al., 2017). Ramya (2018) reported that a traditional drink called "Legen" is prepared from the sap of Palmyra tree has been used to heal kidney stones if taken for 30 days Zongo et al. (2020) appraised the fresh sap from *B. aethiopum* for its good nutritional value and indicated that the consumption of fresh sap can help to improve the intake of dairy foods of rural communities in Burkina Faso. Other reports valued palm wine for its nutritional value as a drink to promote lactation, conjunctivitis treatment, eyesight improvement, and its sedative effects (Obahiagbon and Osagie, 2007; Mbuagbaw and Noorduyn, 2012). Osim et al. (1991) reported on the effect of fresh palm wine on gastric acid secretion.

Erukainure et al. (2020) reported the therapeutic potential of raffia palm (*Raphia hookeri*) wine (RPW) on hyperglycemia-mediated lipid metabolites and pathways, its functional chemistry and ultrastructural morphology of cerebellums in type 2 diabetes. They reported significant changes in cerebellar lipid metabolites depicted through the observed changes in unsaturated and saturated fatty acids, fatty - esters, alcohols, and amides, glycols and steroids on induction of type 2 diabetes. Furthermore, Fourier Transform Infrared Spectroscopy (FTIR) analysis confirmed that RPW is capable to maintain cerebellar functional chemistry, meanwhile, Transmission electron microscopy (TEM) analysis confirmed an improvement in RPW-treated rats' ultrastructural morphologies showing RPW potential in the management of neurodegenerative complications in type 2 -diabetes.

Previous studies by the same team reported the protective effect of RPW against oxidative testicular injury and neuronal integrity in type 2 -diabetic rats (Erukainure et al., 2019a). They linked the protective effects to the presence of sugar alcohol and phytochemical constituents (allose, galactitol, rhamnose, d-tagatose, cymarin, and quinic acid) of RPW (Erukainure et al., 2019b; Erukainure et al., 2019c).

Meng et al. (2021) optimized the extraction of folate from date palm (*Phoenix dactilyfera* L.) fruits and reported their characteristics during fruits wine fermentation using response surface methodology (RSM). They reported a maximum level for the total folate in the date palm wine of 700 μg/L after fermentation, and the sugar content and calories were drastically decreased.

Sarma et al. (2022) reported that toddy shows antibacterial activity against two pathogenic bacteria of *Staphylococcus aureus* and *Pseudomonas aeruginosa.* Another study by Djeni et al. (2020) attributed the therapeutic benefits of palm wine to its content of antipsychotic agent, gevotroline and anti-carcinogenic agent of mitoxantrone.

5.2 Concerns

There are concerns on the processing and storage conditions for palm sap. Palm wine can ferment quickly beyond the desired alcohol content and acceptable taste; therefore, its market value will be lost

(Mbuagbaw and Noorduyn, 2012). This warrants the need for legislation and collaboration with traditional and public health authorities that offer a framework for change in current practices by palm wine tappers.

Ogunro and Ologunagba (2011), evaluated the activities of lipid peroxidation and antioxidants in the blood of humans that regularly consume palm wine by measuring their plasma enzymatic activities and reported that the consumption of palm wine may diminish human body's levels of antioxidants against free radical attacks and lead the body into oxidative stress based on the reduction of plasma selenium and erythrocytes glutathione peroxidase activity with increased level of plasma malonyl dialdehyde. Ogunro and Ologunagba (2012) also evaluated the effect of the level of palm wine consumption on atherogenic and anti-atherogenic factors in the plasma of the humans recruited in their study. Furthermore, they revealed that if palm wine was consumed heavily, it promotes atherogenic factors, and recommended that the recorded benefits of moderate consumption of palm wine should be further investigated.

Obesity and Diabetes: People that are obese or those living with diabetes may need to drink palm wine less frequently due to its sugary nature. When palm wine is harvested fresh, it is still very sweet but as it is allowed to ferment, it gets less sweet. A useful suggestion to the commercial producers of palm wine is for them to specify the type and quantity of sugar on the label of the package product, this will encourage consumers to decide on the quantity they can drink.

Alcohol: Palm wine varies in its ethanol content, it has been reported that it is <2% in the sap when fresh but with fermentation it increases to 5%. Palm wine cannot be regarded as a functional beverage in the European Union (EU), since according to EU regulations, beverages with over 1.2% alcohol content cannot claim nutritional or health benefits (EC, 2006). The consumption of ethanol in large quantity can harm the liver and cause other complications.

In Nigeria, palm wine is consumed by millions of people, and there are concerns that it may harm neonates due to the practice that sometimes when mothers consume it postpartum it helps the flow of breast milk (Osarolube and Nwaiwu, 2016). Some lactating mothers that consume this drink to aid their lactation are unaware of the harm associated with this, as they believe since the ethanol content of the wine they consume is low, it has no effect and that is a myth.

Extraneous contaminants: A major health concern in the consumption of palm wine can result from extraneous materials, which may either be intentional or unintentional contamination of the drink. There are some societies where palm trees are ever green and ever present, henceforth, there is scarcely the need for adulteration as they have abundant resources. However, there are some communities with just a few palm trees and they need to generate income, some do this by adulterating the drink with water and artificial sweeteners which compromises the drink. Unintentional contamination during palm wine processing was summarized in an article by (Nwaiwu and Itumoh, 2017), and they emphasized that food safety hazards are from chemicals that contaminate palm wine. By recommendation, there should be a detailed HACCP on palm wine processing supply chain made public to manufacturers. Since regulation for private consumption may be difficult to enforce, hence it would be better to enforce food safety standards on entrepreneurs that sell palm wine in shacks, hawkers, retailers and in kiosks to the public.

Infestation by insects and contamination with Nipah virus: When palm wine is harvested, a usual sight on the receptacle hung to collect the sap is dead insects like flies and bees. Cross contamination might occur especially from the pathogens from the dead insects and this is definitely harmful to humans. Apart from insects, during tapping, aerial animals might contaminate the product. Nipah viral disease, is one prominent case that was reported in 1998 in Malaysia. The disease occurs as a result of zoonotic infection caused by Nipah virus, a paramyxovirus, that belongs to the genus Henipavirus of the family Paramyxoviridae which has been associated with palm wine and bats (Luby, 2013; Islam et al., 2016; Sharma et al., 2018). It was discovered that bats, usually during the tapping of palm wine, try to drink as well and in the process contaminate the drink with saliva and excreta. This can be prevented by utilizing coverage in form of a mesh or any suitable one to prevent any form of invasion during all processes in the production chain.

Alcohol as a low molecular substance, can cross the barrier of the placenta and enter the foetus, resulting in a similar level of alcohol in the foetus and its mother (Streissguth et al., 2004). Alcohol exposed pregnancies can cause adverse health effects including miscarriage, premature delivery, sudden infant syndrome, low birth weight, and other prenatal conditions such as foetal alcohol syndrome. Foetal alcohol syndrome is regarded as a leading cause of mental retardation, attributed to alcohol consumption by pregnant mothers. It can result in growth retardation, facial dysfunction, learning abnormalities, lower intelligent quotient (IQ) and behavioural problems (Popova et al., 2023).

6 Concluding remarks

Traditional wine from palm trees is a fermented alcoholic drink, produced in several countries of the world and has been ascribed as a functional drink. This is due to the fact that it contains a high level of macro and micronutrients; and most especially beneficial microbes known to promote certain health benefits. Nonetheless, there is a lack of standardization of its production processes thereby resulting in variations in taste, colour and aroma due to differences in sugar and ethanol content across different production countries and sites. Research into the biochemical and microbial properties of the drink during and after production will be useful in determining the level and method of production for obtaining optimum benefits for consumption as well as helping in elongating its shelf life. Additionally, safe practices during the process flow and packaging will eliminate the risk of contamination by extrinsic factors. Future research on integrating an eco-friendlier packaging material such as the round bottomed calabashes (*Lagenaria siceraria*) should be investigated.

Also, it is noteworthy to emphasize the need for adequate labelling of the packaged drink to include the sugar and alcohol content, *etc.*, as this would assist with making the product consistent in quality. Furthermore, this will provide useful information to those that require it for medicinal and health purposes, thus helping to promote the international market for palm wine thereby boosting the socio-economic development of the producers.

Author contributions

DR, OO, and AR contributed to conception and design of the study. DR wrote the first draft of the manuscript. OO, SK, OF, OI, AC, AS, and AR wrote sections 2–6 of the manuscript. All authors contributed to the article and approved the submitted version.

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.

The authors DR, OO, and AC declared that they were editorial board members of Frontiers at the time of submission. This had no impact on the peer review process and the final decision.

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