

The Nutritional, Health Benefits and Possible Risks Factors of Locally Produced Palm Wine: A Review

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Abstract

Palm wine is a naturally fermented beverage produced from the sap of palm trees such as *Elaeis guineensis*, *Raphia hookeri*, and *Cocos nucifera*. It is widely consumed in many tropical regions, especially in West Africa, where it plays important cultural, social, and economic roles. This paper presents a comprehensive review of its nutritional composition, fermentation process, microbial activity, potential health benefits, associated risks, and factors influencing its quality and safety. Fresh palm wine contains carbohydrates, vitamins, minerals, organic acids, and various bioactive compounds that contribute to its nutritional value. However, it is highly unstable due to spontaneous fermentation initiated immediately after tapping. This process is driven by naturally occurring yeasts and bacteria, which convert sugars into ethanol and organic acids while continuously altering the beverage's chemical and sensory properties. As fermentation progresses, nutrient levels decline, acidity increases, and alcohol content rises, leading to rapid deterioration in quality. Palm wine has been linked to several potential health benefits when consumed fresh and in moderation, including quick energy supply, antioxidant activity, and possible probiotic effects due to the presence of beneficial microorganisms. It may also contribute modestly to vitamin and mineral intake. However, these advantages are inconsistent because of its uncontrolled production and rapid compositional changes. Again, palm wine consumption also poses health risks such as alcohol-related disorders, microbial contamination, exposure to chemical pollutants, and blood sugar fluctuations, particularly when over-fermented or poorly handled. In conclusion, palm wine is a dynamic and perishable biological product whose nutritional value and safety depend strongly on freshness, environmental conditions, and hygiene practices. Palm wine holds cultural and nutritional importance; careful handling, timely consumption, and moderation are essential to maximize its benefits and minimize potential health risks.

Keywords: Palm wine, fermentation, nutritional, microbial activity, *Elaeis guineensis*, *Raphia hookeri*, *Cocos nucifera*, health benefits.

Introduction

Palm wine is a traditional alcoholic drink produced through the natural fermentation of sap collected from different palm tree species such as *Elaeis guineensis* (oil palm), *Raphia hookeri* (raffia palm), and *Cocos nucifera* (coconut palm). The beverage is commonly consumed in many tropical parts of Africa, Asia, and South America. However, its social, cultural, and economic importance is particularly strong in West Africa, where it has remained part of community life for generations. In countries such as Nigeria, palm wine is often served during important cultural events, including weddings, festivals, burial ceremonies, and traditional religious practices [1][2]. In addition to its cultural value, studies in ethnobotany have shown that palm wine production and sales provide a source of livelihood and income for many rural households engaged in palm sap tapping and local distribution [3][4].

Palm wine is a naturally fermented alcoholic beverage obtained from the sap of various palm tree species, particularly *Elaeis guineensis* (oil palm) and *Raphia hookeri*.

It is widely consumed across tropical regions of Africa, Asia, and South America, but its cultural and economic significance is especially pronounced in West Africa, where it forms an important part of traditional ceremonies, social life, and rural livelihoods.

In Nigeria and surrounding countries, palm wine is deeply embedded in cultural identity and is commonly used in marriages, festivals, funerals, and religious rituals [1][2]. Ethno-botanical studies further confirm its continued relevance as both a cultural beverage and an income-generating commodity for rural communities involved in tapping and distribution [3][4]

Elaeis guineensis, commonly known as the oil palm, is a major tropical crop widely cultivated across West and Central Africa. It is economically important due to its role in palm oil and palm kernel oil production [5]. In addition to these uses, its inflorescence can be tapped to obtain sap used for palm wine production, a practice widely documented in traditional food systems of West Africa [1][2]. The sap from oil palm is typically rich in fermentable sugars and undergoes very rapid fermentation once exposed to air due to natural microbial activity [6].



***Elaeis guineensis* [5]**

Cocos nucifera (coconut palm) is widely distributed across coastal and tropical regions of Africa, Asia, and Latin America, and is another important source of palm wine, particularly in countries such as Ghana, India, Indonesia, and the Philippines. Coconut palm sap, often referred to as toddy, is obtained by tapping the inflorescence and is characterized by a high sucrose content and a relatively slower fermentation rate compared to oil palm sap. This results in a beverage that is often sweeter at the early stages of fermentation. Coconut palm wine is also noted for its relatively higher vitamin C content and distinct flavor profile, which differs from both oil palm and raffia palm wine [7][8]. The inclusion of coconut palm in palm wine production highlights the diversity of raw materials and fermentation characteristics across different geographical regions.



***Cocos nucifera* [7]**

Raphia hookeri, commonly referred to as raffia palm, is predominantly found in swampy and freshwater forest ecosystems, especially in southern Nigeria, where it thrives in wetland conditions [9]. Unlike oil palm, raffia palm is less significant for industrial oil production but is highly valued for its sap, fibers, and leaves. Its sap is widely used for palm wine production in rural communities due to its relatively high yield and milder taste compared to oil palm sap [10]. Both species therefore play essential but distinct roles in traditional palm wine production, differing in sap yield, sugar concentration, and fermentation behavior [2][11].



***Raphia hookeri* [9]**

The production of palm wine is entirely traditional and depends on tapping fresh sap from the palm tree using indigenous methods. Once the sap is exposed to air and collected in containers such as gourds or plastic vessels, fermentation begins almost immediately. This spontaneous fermentation is driven by naturally occurring microorganisms present in the environment, tapping tools, and the sap itself. These microorganisms include yeasts, lactic acid bacteria, and acetic acid bacteria, which together initiate a complex biochemical process that continuously alters the composition of the beverage [6][11].

Fresh palm sap is initially sweet due to its high concentration of fermentable sugars such as sucrose, glucose, and fructose. However, microbial activity begins immediately after tapping. Yeasts, particularly *Saccharomyces cerevisiae*, convert these sugars into ethanol and carbon dioxide, initiating alcoholic fermentation. As fermentation progresses, lactic acid bacteria contribute to acid production and pH reduction, while acetic acid bacteria may oxidize ethanol into acetic acid in later stages. This sequential microbial activity results in rapid changes in taste, aroma, and chemical composition, causing palm wine to transition from sweet sap to a mildly alcoholic beverage and eventually to a sour liquid if left for extended periods [10][2].

Modern research now describes palm wine fermentation as a dynamic microbial ecosystem rather than a simple natural process. Studies have shown that the microbial community is highly variable and influenced by palm species, environmental conditions, and hygiene practices during tapping and storage [12][11]. This variability explains why palm wine differs significantly in taste, alcohol content, and safety depending on location and handling.

One of the major characteristics of palm wine is its high perishability, unlike industrial alcoholic beverages that undergo controlled fermentation and preservation, palm wine begins to deteriorate immediately after tapping. Within a few hours, significant biochemical changes occur, and within 24 hours, it may become overly acidic and unsuitable for consumption [2]. This rapid deterioration creates challenges for storage, transportation, and commercialization, especially in rural areas where preservation technologies are limited.

From a nutritional perspective, palm wine has long been recognized as a source of energy and micronutrients. Early studies reported that fresh palm wine contains carbohydrates, amino acids, vitamins, and minerals such as potassium, calcium, magnesium, and iron [1]. Vitamins such as vitamin C and B-complex vitamins also contribute to its nutritional importance, particularly in communities with limited dietary diversity.

Recent scientific studies have further shown that palm wine contains bioactive compounds formed during fermentation, including phenolics, organic acids, and volatile metabolites. These compounds exhibit antioxidant properties and may help reduce oxidative stress in the body [13][14]. Fermentation has also been found to improve the bioavailability of certain nutrients, enhancing their absorption in the human body [10].

In addition to its nutritional value, palm wine has attracted attention for its potential functional and probiotic properties.

The presence of lactic acid bacteria suggests possible benefits for gut health, including improved digestion and inhibition of harmful microorganisms [15]. However, because palm wine is not standardized, its microbial composition varies widely, which limits consistent health effects.

Palm wine is also deeply rooted in traditional medicine and cultural practices. It is often used as a medium for herbal preparations and is believed in some communities to stimulate lactation, improve appetite, and promote general well-being. Again, these claims remain largely based on traditional knowledge and require further scientific validation [3].

Despite its benefits, palm wine consumption is associated with several health risks. As fermentation progresses, ethanol levels increase, and excessive intake can lead to liver damage, cardiovascular complications, and neurological impairment. The World Health Organization [16] identifies harmful alcohol use as a major global health risk factor contributing to disease burden and mortality.

Another concern is microbial contamination. Due to traditional production methods, palm wine is vulnerable to contamination by pathogenic microorganisms such as *Escherichia coli*, *Salmonella* spp., and *Staphylococcus aureus*, which may be introduced during tapping, handling, or storage [6][4].

In addition, chemical contaminants such as benzene and styrene have been reported in some palm wine samples, likely originating from environmental pollution or the use of non-food-grade storage containers [17][14]. These compounds pose potential long-term health risks if consumed regularly.

The quality and safety of palm wine depend on several factors, including palm species, environmental conditions, tapping methods, hygiene practices, and fermentation duration. Fresh palm wine is generally more nutritious and safer, while aged palm wine tends to be more acidic, unstable, and higher in alcohol content [2][15].

In recent years, scientific interest in palm wine has increased significantly, particularly in food microbiology and functional food research. Researchers are exploring controlled fermentation using selected starter cultures, as well as preservation techniques such as refrigeration and pasteurization, to improve safety, shelf life, and quality consistency [18][11].

Given the increasing interest in traditional fermented foods and their role in nutrition and health, there is a need to critically evaluate palm wine using both traditional knowledge and contemporary scientific evidence. This review, therefore, aims to provide a comprehensive analysis of the nutritional composition, microbial dynamics, health benefits, and potential risks associated with locally produced palm wine. It also seeks to highlight existing research gaps and suggest directions for improving its safety, quality, and utilization in modern food systems.

NUTRITIONAL COMPOSITION OF PALM WINE

Palm wine is a naturally fermented beverage obtained from the sap of various palm tree species such as *Elaeis guineensis* (oil palm), *Raphia hookeri* (raffia palm), and *Cocos nucifera* (coconut palm).

It is widely consumed across many tropical regions, particularly in West and Central Africa, as well as parts of Asia and Latin America, where it serves both cultural and nutritional purposes [1][10][2]. Recent studies have further emphasized its global relevance and complex biochemical nature, describing palm wine as a spontaneously fermented product shaped by diverse microbial communities and regional production practices [19][20][21]. Looking at processed drinks with standardized composition, palm wine is a biologically active liquid that undergoes continuous chemical transformation immediately after tapping due to spontaneous fermentation [6].

The inclusion of *Cocos nucifera* further broadens the diversity of palm wine sources. The coconut palm is widely distributed in coastal and tropical regions and is an important source of palm sap in countries such as India, the Philippines, and parts of East Africa. The sap obtained from the coconut palm, often referred to as coconut toddy, is rich in sugars and nutrients similar to oil palm and raffia palm sap, although it may differ slightly in composition, taste, and fermentation characteristics. Studies have shown that coconut palm sap typically contains high levels of sucrose, along with glucose and fructose, making it highly susceptible to rapid fermentation once tapped [10]. Its inclusion highlights the broader global relevance of palm wine beyond African species.

Because of this ongoing microbial activity, the nutritional composition of palm wine is highly unstable and changes rapidly with time. Factors such as the freshness of the sap, environmental temperature, hygiene during collection, palm species (including oil palm, raffia palm, and coconut palm), and the types of microorganisms present all influence its final composition. As a result, palm wine can vary significantly in taste, alcohol content, and nutritional value even within a few hours of tapping [10][2].

1. Carbohydrates

Carbohydrates are the most abundant nutrients in fresh palm wine, they occur mainly as simple sugars such as glucose, fructose, and sucrose, which are naturally present in the palm sap. These sugars are responsible for the sweet taste of freshly collected palm wine and provide a quick source of energy when consumed [10][20].

However, these sugars are rapidly metabolized after tapping, naturally occurring yeasts begin fermentation almost immediately, breaking down sugars into ethanol and carbon dioxide. This process causes a steady decline in sweetness and a corresponding increase in alcohol content [6][21].

The speed of sugar breakdown depends on environmental conditions such as temperature, palm species, and microbial load, but in most cases, significant biochemical changes begin within a few hours of collection [19][22][15].

2. Proteins and Amino Acids

Palm wine contains small amounts of proteins and free amino acids derived from the plant sap and microbial enzymatic activity during fermentation. These components are present in palm wine obtained from species such as *Elaeis guineensis*, *Raphia hookeri*, and *Cocos nucifera*. Although the protein content is relatively low, they contribute to the overall biochemical and nutritional profile of the beverage [10].

In palm wine tapped from *Cocos nucifera*, similar nitrogenous compounds have been reported, although slight variations may occur due to differences in sap composition and environmental conditions. Amino acids such as alanine, glutamic acid, and aspartic acid have been identified in fermented palm wine. While they do not make palm wine a major protein source, they contribute to flavor complexity and mild sensory depth [2].

During fermentation, microbial activity, particularly from yeasts and lactic acid bacteria, breaks down plant-derived materials, increasing the availability of free amino acids and altering the nitrogen profile of the beverage over time. This process occurs across palm wine derived from oil palm, raffia palm, and coconut palm, although the rate and extent may vary depending on sap composition and fermentation conditions [6][19].

3. Vitamins

Palm wine contains important vitamins, particularly vitamin C and B-complex vitamins such as thiamine, riboflavin, niacin, and folate. These micronutrients are found in palm wine derived from different species, including *Elaeis guineensis*, *Raphia hookeri*, and *Cocos nucifera*, and they contribute to key physiological functions such as energy metabolism, immune support, and cellular regulation [23][24].

Recent studies on naturally fermented palm beverages have reported that freshly collected palm sap contains detectable levels of water-soluble vitamins. However, these nutrients are highly sensitive to environmental exposure, temperature changes, and microbial activity during fermentation, which leads to continuous variation in their concentration [19][22][25]. This explains why vitamin content differs significantly between freshly tapped and fermented samples.

Vitamin content in palm wine is generally unstable; vitamin C is particularly vulnerable to oxidation and begins to degrade immediately after the sap is exposed to air during tapping and handling. Similarly, B-complex vitamins gradually decrease as fermentation progresses because microorganisms utilize them for growth and metabolic processes [1][26].

In palm wine obtained from *Cocos nucifera*, similar patterns of vitamin reduction occur, although slight differences may be observed due to variations in sap composition, sugar content, and fermentation rate compared to oil palm and raffia palm. Some recent findings suggest that coconut palm sap may initially retain slightly higher levels of certain micronutrients, but these still decline rapidly under natural fermentation conditions [20][19].

Again, studies consistently show that vitamin concentrations are highest immediately after tapping and decrease significantly within a short time, regardless of palm species. This makes freshness a critical factor in determining the nutritional quality of palm wine [23],[22].

4. Minerals

Palm wine is a natural source of essential minerals such as potassium, calcium, magnesium, iron, phosphorus, and zinc. These minerals are important for several physiological functions in the human body, including nerve impulse transmission, muscle contraction, oxygen transport, enzymatic reactions, and bone formation.

Because palm wine is obtained directly from fresh plant sap with minimal processing, it retains a significant portion of the mineral composition inherent in the palm tree system [29][2].

Studies on traditionally fermented palm beverages have shown that mineral content is generally more stable than organic nutrients such as vitamins and sugars. This stability is due to the inorganic nature of minerals, which are not destroyed during fermentation. However, variations in concentration can occur depending on soil characteristics, palm species, rainfall patterns, and ecological conditions surrounding cultivation [10][19].

Potassium is typically the most abundant mineral in palm wine, followed by magnesium and calcium. These minerals contribute significantly to electrolyte balance, muscle function, and cardiovascular regulation. Trace elements such as iron and zinc are also present in smaller quantities and support oxygen transport, enzyme activity, and immune response [6][24].

In palm wine obtained from *Cocos nucifera*, mineral profiles are generally comparable to those of *Elaeis guineensis* and *Raphia hookeri*, although slight variations may occur due to differences in ecological conditions and sap physiology. Coconut palm sap is often noted for its relatively high potassium content, making it nutritionally relevant among palm wine sources [1][26].

Mineral composition remains relatively stable during fermentation, and environmental factors and palm species significantly influence the final mineral profile of palm wine, contributing to its natural variability across regions.

5. Organic Acids

Organic acids are important metabolic products formed during palm wine fermentation as naturally occurring microorganisms convert sugars and intermediate fermentation products into acidic compounds. The major organic acids typically found in palm wine include lactic acid and acetic acid, which are responsible for changes in taste, pH, and overall beverage stability [28][29].

Lactic acid is mainly produced during the early phase of fermentation through the activity of lactic acid bacteria. This leads to a gradual reduction in pH and the development of a mildly acidic environment. At this stage, palm wine still retains some of its sweetness while beginning to develop a slightly sour taste, reflecting the early biochemical transition of the beverage [30][31].

As fermentation continues, acetic acid bacteria become more dominant and oxidize ethanol into acetic acid. This process significantly increases the sourness of palm wine and contributes to its rapid decline in palatability when left for extended periods. The progressive accumulation of acetic acid is one of the key factors responsible for the short shelf life of traditionally produced palm wine [32][33].

Recent microbiological studies on fermented plant-based beverages have shown that organic acid production is closely linked to microbial succession and environmental conditions such as temperature, oxygen exposure, and storage method. These factors influence the rate of fermentation and determine how quickly palm wine transitions from a sweet sap to an acidic alcoholic beverage [34][35].

In palm wine derived from *Cocos nucifera*, similar fermentation pathways occur, although variations in sugar concentration and indigenous microbial populations may slightly affect the rate of acid formation compared to *Elaeis guineensis* and *Raphia hookeri*. Despite these differences, the overall trend of increasing acidity with fermentation time remains consistent across all palm wine sources.

Organic acids play a central role in defining the sensory characteristics, shelf life, and quality deterioration of palm wine, making fermentation time a critical determinant of its nutritional and commercial value.

6. Bioactive Compounds

Palm wine contains a variety of bioactive compounds, including phenolic substances and other secondary metabolites that contribute to its functional and sensory properties. These compounds are naturally present in the palm sap and may also be modified or enhanced during fermentation through the metabolic activity of microorganisms [36][37].

Phenolic compounds are particularly important due to their association with antioxidant activity; they are known to help neutralize free radicals, thereby reducing oxidative stress in biological systems. During fermentation, enzymatic actions by microorganisms can break down complex plant-bound phenolics into simpler and more bioavailable forms, potentially enhancing their functional properties [38][39].

In addition to phenolics, palm wine fermentation generates a range of volatile organic compounds responsible for its characteristic aroma and flavor profile. These compounds are produced through yeast and bacterial metabolism and play a major role in shaping the sensory quality of the beverage [40][41].

Generally, palm wine is a nutrient-containing but highly perishable natural beverage; it provides carbohydrates for energy, small amounts of proteins and amino acids, vitamins, minerals, organic acids, and bioactive compounds. However, these nutrients are not stable and change continuously due to ongoing fermentation and microbial activity.

Fresh palm wine is nutritionally superior because it contains higher levels of sugars and vitamins. As fermentation progresses, sugar content decreases, alcohol content increases, vitamins degrade, and acidity rises. These transformations significantly alter both its nutritional composition and sensory properties.

Therefore, palm wine should be understood as a dynamic biological system whose composition is strongly dependent on freshness and time after tapping [34][35].

Health Benefits of Palm Wine

Palm wine has long been consumed in many tropical regions not only as a traditional beverage but also as a drink believed to offer certain health-related benefits when taken in moderation. Its potential benefits are associated with its natural composition, which includes sugars, vitamins, minerals, organic acids, and bioactive compounds produced during spontaneous fermentation. However, these effects are highly dependent on freshness, fermentation stage, and quantity consumed [2][10].

Recent microbiological and nutritional studies describe palm wine as a dynamic functional beverage whose composition changes rapidly after tapping.

Fresh palm wine is often considered more beneficial due to its higher nutrient density, particularly its natural sugars and micronutrients, which are gradually reduced as fermentation progresses [40][41].

The presence of naturally occurring microorganisms such as yeasts and lactic acid bacteria also contributes to its functional potential. These microbes are involved in fermentation processes that generate organic acids and bioactive metabolites, which may influence gut microbial activity and digestive processes when consumed in moderate amounts [34][35].

Palm wine contains trace amounts of antioxidants derived from phenolic compounds in the palm sap; these compounds are associated with the reduction of oxidative stress in biological systems, although their concentrations vary depending on fermentation time and environmental conditions [38][39].

Minerals such as potassium, calcium, and magnesium present in palm wine also contribute to basic physiological functions, including electrolyte balance, muscle activity, and nerve function. These nutrients are naturally derived from the palm tree and are retained in the beverage due to minimal processing [27][2].

Palm wine may offer some nutritional and functional benefits when consumed fresh and in moderation; its health effects are highly variable and influenced by fermentation dynamics. Therefore, it should be viewed as a traditional natural beverage with potential nutritional value rather than a standardized functional drink [21][40].

1. Source of Quick Energy

Fresh palm wine serves as a rapid source of energy primarily due to its natural content of simple sugars such as glucose, fructose, and sucrose. These sugars are directly derived from the sap of palm trees, including *Elaeis guineensis*, *Raphia hookeri*, and *Cocos nucifera*, and are present in a form that requires minimal digestion before absorption and utilization by the body for energy production [2][10].

From a physiological standpoint, these simple sugars are quickly metabolized through glycolysis to produce adenosine triphosphate (ATP), which is the primary energy currency of the human body. This explains why freshly tapped palm wine is often perceived as a quick source of energy and is commonly consumed for rapid physical refreshment in many rural communities [27][2]. However, this energy property is not stable over time; once palm wine is exposed after tapping, fermentation begins immediately due to naturally occurring yeasts, which convert sugars into ethanol and carbon dioxide. This reduces the carbohydrate content while increasing alcohol concentration, thereby altering the nutritional and energetic profile of the beverage [6][26].

Studies have shown that this sugar-to-ethanol conversion begins within a short time after tapping and is the primary factor responsible for the rapid decline in the energy-providing sugars in palm wine [1][24]. Palm wine provides quick energy, mainly when freshly collected. As fermentation progresses, the energy contribution shifts from carbohydrates to ethanol, which has different metabolic effects in the human body [10][42].

2. Contribution of Vitamins and Micronutrients

Palm wine contains a range of vitamins and mineral elements that contribute modestly to its nutritional profile, particularly in its freshly tapped state.

Fresh palm sap has been reported to contain vitamin C and B-complex vitamins such as thiamine, riboflavin, niacin, and folate. These micronutrients play essential roles in human metabolism, especially as cofactors in enzymatic reactions involved in energy production and normal cellular functioning [43][2][44].

From a nutritional perspective, B-complex vitamins function as coenzymes in carbohydrate, lipid, and protein metabolism, thereby supporting energy release and physiological balance. Vitamin C contributes to antioxidant defense mechanisms and helps protect body tissues from oxidative stress. In many rural communities, freshly collected palm wine is occasionally regarded as a supplementary dietary source of these micronutrients, particularly where access to diverse diets is limited [45][27][46].

In addition, palm wine contains important mineral elements such as potassium, calcium, magnesium, iron, zinc, and phosphorus. These minerals are essential for physiological processes, including osmotic regulation, nerve transmission, oxygen transport, enzyme activation, and skeletal development. Potassium is generally the most abundant mineral, followed by magnesium and calcium, reflecting the natural mineral composition of palm sap [47][48].

However, the vitamin content in palm wine remains highly unstable. Vitamin C is particularly sensitive to oxidation and begins to degrade rapidly once the sap is exposed to air during tapping and handling. Similarly, B-complex vitamins gradually decrease during fermentation due to microbial utilization and metabolic activities of yeasts and bacteria [49][43].

3. Probiotic and Microbial Contributions

Palm wine is a naturally fermented beverage characterized by a diverse and dynamic microbial community composed mainly of yeasts and bacteria. These microorganisms are introduced from the palm sap, tapping equipment, containers, and the surrounding environment. Commonly reported organisms include yeasts such as *Saccharomyces cerevisiae* and other non-*Saccharomyces* species, as well as lactic acid bacteria including *Lactobacillus* and related genera [28][50].

From a fermentation standpoint, yeasts are primarily responsible for the conversion of fermentable sugars into ethanol and carbon dioxide, while bacteria contribute to the production of organic acids and other metabolites. The interaction between these microbial groups drives the progressive changes in taste, aroma, and acidity that characterize palm wine fermentation [31][40].

Some lactic acid bacteria present in palm wine have been associated with probiotic-like potential due to their ability to produce lactic acid, reduce pH, and inhibit the growth of certain undesirable microorganisms. In controlled fermented foods, such organisms are known to support intestinal microbial balance and digestive function. However, in palm wine, these effects are inconsistent because fermentation occurs spontaneously without controlled starter cultures or standardized conditions [32][51].

Recent studies on traditional fermented beverages have emphasized that microbial diversity plays a key role in the formation of bioactive metabolites such as organic acids, enzymes, and volatile compounds that influence both nutritional quality and sensory properties.

These microbial populations are highly dynamic and can shift rapidly within a short time after tapping due to environmental exposure and ongoing fermentation activity [34][35].

Additionally, lactic acid bacteria may contribute temporarily to preservation by lowering the pH of the beverage, thereby inhibiting spoilage organisms. However, this protective effect is short-lived, as continued fermentation eventually leads to increased acidity, higher ethanol levels, and a decline in overall quality [52][53].

Palm wine contains a complex microbial ecosystem that drives fermentation and influences its nutritional and sensory characteristics. Certain microorganisms may exhibit probiotic-like functions, which it benefits remain unstable due to the uncontrolled nature of fermentation and rapid microbial succession.

4. Antioxidant and Bioactive Properties

Palm wine contains a range of bioactive compounds that contribute to its functional properties, particularly when consumed in its fresh state. These include phenolic compounds, flavonoids, organic acids, and other metabolites produced during fermentation. Such compounds originate from the palm sap and are further transformed or released through microbial activity during fermentation [54][47].

Phenolic compounds are among the most important bioactive constituents in palm wine due to their antioxidant potential. Antioxidants help neutralize free radicals, thereby reducing oxidative stress in biological systems. Oxidative stress has been linked to cellular damage and the development of chronic diseases. Fermentation processes may enhance the release of bound phenolic compounds, thereby increasing their availability and biological activity [55][56].

In addition to phenolic substances, organic acids such as lactic acid and acetic acid are important fermentation products that contribute to the biochemical characteristics of palm wine. These acids are formed through the metabolic activities of lactic acid bacteria and acetic acid bacteria during fermentation and play a role in determining the acidity, stability, and overall quality of the beverage [57][58].

Microbiological studies on fermented plant-based beverages have shown that microbial activity in palm wine contributes significantly to the formation of bioactive metabolites, including antioxidant-related compounds and volatile substances that influence aroma and sensory properties. However, the concentration of these compounds is highly dependent on fermentation time, with fresh palm wine generally exhibiting higher bioactive potential than samples that have undergone prolonged fermentation [48][17].

Moreover, environmental conditions, palm species, and microbial diversity significantly influence the antioxidant profile of palm wine. As fermentation progresses, oxidation reactions and microbial utilization may reduce certain phenolic compounds, leading to changes in the overall functional quality of the beverage [47][4].

Palm wine possesses antioxidant and bioactive properties primarily linked to its phenolic content and fermentation-derived metabolites. However, these properties are highly variable and strongly influenced by freshness, microbial composition, and environmental conditions.

5. Possible Cardiovascular Support Effects

Palm wine has been associated with possible cardiovascular-related benefits when consumed in moderation, mainly due to its natural content of minerals, antioxidant compounds, and fermentation-derived metabolites. These constituents are believed to influence physiological processes related to blood circulation and heart function, although available evidence is largely based on compositional and fermentation studies rather than controlled clinical investigations [10][47].

Potassium is one of the dominant minerals in palm wine and plays an important role in maintaining normal blood pressure and electrolyte balance. Adequate potassium intake supports cardiovascular function by helping regulate sodium levels and promoting proper muscle contraction, including cardiac muscle activity. This suggests that fresh palm wine may contribute modestly to dietary potassium intake in populations where it is traditionally consumed [59][4].

Nutritional analyses of fermented palm sap beverages have also identified the presence of polyphenols and other antioxidant compounds that may help reduce oxidative stress, which is a known contributing factor in cardiovascular diseases such as hypertension and atherosclerosis. These compounds may be enhanced or modified during fermentation depending on microbial activity and processing conditions [48][56]. Spontaneous fermentation has shown that microbial metabolism can generate bioactive metabolites with potential antioxidant and anti-inflammatory properties. These effects may indirectly support vascular health by reducing oxidative damage to blood vessels. However, such properties are highly variable and depend on factors such as palm species, environmental conditions, and fermentation dynamics [58][17].

Despite these possible benefits, palm wine also contains ethanol, which introduces important health considerations. Moderate consumption may provide access to beneficial micronutrients and antioxidants, but excessive intake is associated with elevated blood pressure, cardiac stress, and other adverse cardiovascular outcomes. This dual effect makes its overall impact highly dose-dependent and closely linked to the stage of fermentation [19][48].

The cardiovascular effects of palm wine reflect a balance between beneficial components, such as potassium and phenolic compounds, and the negative effects associated with alcohol content. As fermentation progresses, ethanol concentration increases while nutrient levels decline, shifting its role from a nutrient-containing beverage to an alcoholic drink.

6. Digestive and Metabolic Effects

Palm wine is widely consumed in many tropical regions, where it is traditionally believed to aid digestion when taken fresh after tapping. This perception is linked to its natural composition, which includes residual sugars, organic acids, and a diverse microbial population that develops during spontaneous fermentation [45][17]. Organic acids such as lactic acid and acetic acid contribute to the mild acidification of the gastrointestinal environment. This may support digestive processes by enhancing enzyme activity and improving the breakdown of food in the stomach.

Fresh palm wine, which contains lower levels of accumulated fermentation by-products, is generally considered more suitable for this function compared to over-fermented samples that are more acidic and less palatable [58][57].

Palm wine also contains naturally occurring yeasts and lactic acid bacteria that arise during fermentation. These microorganisms are similar to those found in other traditionally fermented foods and may interact with intestinal microbiota when consumed. However, because palm wine undergoes spontaneous and uncontrolled fermentation, its microbial composition is highly variable, meaning its probiotic potential is inconsistent and cannot be reliably predicted [51][60].

Furthermore, the metabolic impact of palm wine is strongly influenced by the conversion of sugars into ethanol during fermentation. In the early stages, simple sugars provide a rapid source of energy. As fermentation progresses, ethanol becomes the dominant product, which is metabolized primarily in the liver and may impose metabolic stress when consumed in excess [19][58].

7. Neurological and Mood Effects

Palm wine may influence neurological function and mood primarily due to its ethanol content, residual sugars, and fermentation-derived metabolites. When consumed in small quantities, the low alcohol content of freshly tapped palm wine can produce mild central nervous system effects, including relaxation and a temporary sense of well-being. These effects are largely attributed to ethanol's action on neurotransmitter systems, particularly its interaction with gamma-aminobutyric acid (GABA), which promotes inhibitory signaling in the brain [61][62].

In addition to ethanol, the presence of simple sugars in fresh palm wine may contribute to short-term mood enhancement by providing a rapid source of glucose for brain metabolism. Glucose is the primary energy substrate for the brain, and its availability is linked to cognitive performance and alertness. This may partly explain why freshly tapped palm wine is often perceived as refreshing and mildly stimulating before fermentation advances significantly [63][64].

Fermentation also leads to the formation of minor bioactive compounds, including certain amino acid derivatives and volatile compounds that may influence sensory perception and mood. Although these compounds are present in relatively small amounts, they contribute to the overall psychoactive experience associated with palm wine consumption [51][58].

However, as fermentation progresses and ethanol concentration increases, the neurological effects become more pronounced. Higher alcohol levels can impair cognitive function, coordination, and judgment due to their depressant effects on the central nervous system. Prolonged or excessive consumption may lead to negative outcomes such as dependence, memory impairment, and other neurobehavioral effects [16][61].

Furthermore, the variability in fermentation conditions means that the alcohol content of palm wine is not standardized, making its neurological impact unpredictable. This variability increases the risk of unintentional overconsumption, especially in traditional settings where monitoring alcohol intake may be limited [19][17].

8. Eye and Skin Health

Palm wine may contribute modestly to eye and skin health due to the presence of micronutrients, antioxidant compounds, and fermentation-derived metabolites. These components, although present in relatively small quantities, can play supportive roles in maintaining normal physiological functions when the beverage is consumed fresh and in moderation [17][65].

With respect to eye health, palm wine contains trace amounts of vitamins and antioxidant compounds that may help protect ocular tissues from oxidative stress. Antioxidants such as phenolic compounds are known to neutralize free radicals, which are implicated in age-related eye conditions and general visual decline. Palm wine is not a primary source of eye-protective nutrients like vitamin A; its antioxidant profile may offer some supportive benefits in reducing oxidative damage to eye cells [66][67].

In terms of skin health, the antioxidant and hydration-related properties of fresh palm wine may contribute to maintaining skin integrity. Antioxidants help reduce oxidative stress, which is associated with premature skin aging, loss of elasticity, and cellular damage. Additionally, the water content and electrolytes present in fresh palm wine may support hydration, an important factor in maintaining healthy skin appearance and function [68][48].

Fermentation also introduces certain organic acids and microbial metabolites that may influence skin health indirectly. Organic acids such as lactic acid are widely recognized in dermatological science for their role in promoting mild exfoliation and supporting skin renewal processes. Although these effects are more commonly associated with topical application, their presence in fermented beverages reflects the broader biochemical activity occurring during fermentation [57][58].

However, the potential benefits of palm wine for eye and skin health are limited by several factors. As fermentation progresses, increasing ethanol levels may counteract these benefits by promoting dehydration and contributing to oxidative stress when consumed excessively. Alcohol consumption is also associated with negative skin effects such as dryness and reduced skin barrier function, particularly with frequent or high intake [16][19].

9. Lactation Enhancement

Palm wine has traditionally been associated with lactation enhancement in several African communities, where it is often recommended to nursing mothers to promote breast milk production. This belief is largely based on cultural practices and anecdotal observations rather than strong clinical evidence [17][69].

Fresh palm wine contains small amounts of carbohydrates, vitamins, and minerals that may contribute to overall maternal nutrition. Adequate nutrition is essential for optimal milk production, and beverages that provide energy and hydration may indirectly support lactation. In particular, the fluid content of fresh palm wine may help maintain hydration status, which is important for sustaining breast milk secretion [70][71].

Additionally, the presence of certain fermentation-derived compounds has led to suggestions that palm wine may have mild physiological effects that could influence hormonal activity related to lactation.

However, there is limited scientific evidence directly linking palm wine consumption to increased prolactin levels or enhanced milk production. Most available studies on lactation emphasize balanced diets, adequate fluid intake, and hormonal regulation rather than specific traditional beverages [72][16].

It is also important to consider the role of ethanol in palm wine, as fermentation progresses, alcohol content increases, which introduces potential risks for both the mother and the breastfeeding infant. Alcohol can pass into breast milk and may affect infant feeding patterns, sleep, and development when consumed in significant amounts. For this reason, health authorities generally advise caution or avoidance of alcoholic beverages during breastfeeding [73][74].

Furthermore, the variability in palm wine composition due to spontaneous fermentation makes its effects unpredictable. Fresh palm wine contains lower alcohol levels compared to fermented samples, but the transition from low to higher ethanol concentration can occur rapidly, especially under tropical conditions. This variability complicates its safe use as a lactation aid [19][65].

Possible Risks and Health Concerns

Although palm wine is widely consumed and culturally valued across many tropical regions, it presents several health risks that become more significant depending on how it is produced, handled, stored, and consumed. Because it is a naturally fermented beverage with no industrial standardization, its chemical and microbial composition changes continuously after tapping. This makes its safety profile highly unstable and strongly dependent on time and environmental conditions [19][17].

1. Alcohol-Related Health Risks

A major health concern associated with palm wine is its alcohol (ethanol) content. Immediately after tapping, the beverage contains relatively low levels of ethanol, but fermentation begins almost instantly due to natural yeasts present in the sap and environment. As fermentation progresses, sugar is progressively converted into alcohol, causing the ethanol concentration to rise within a few hours.

When consumed in excess, ethanol affects multiple organs in the body. In the liver, it is metabolized into acetaldehyde, a toxic compound that can damage liver cells over time. Continuous exposure may lead to fatty liver disease, hepatitis, fibrosis, and eventually cirrhosis. Beyond liver damage, alcohol also affects the brain and nervous system by interfering with neurotransmitters responsible for coordination, decision-making, and behavior control. This results in impaired judgment, reduced reaction time, and loss of coordination [16][75]. Because palm wine fermentation is uncontrolled, the alcohol content is not consistent, meaning consumers may unknowingly drink beverages with higher-than-expected ethanol levels.

2. Blood Sugar Imbalance

Palm wine contains natural sugars such as glucose, fructose, and sucrose at the early stage of fermentation. These sugars are rapidly absorbed in the body and may cause a quick rise in blood glucose levels shortly after consumption.

However, as fermentation continues, these sugars are broken down and converted into ethanol and carbon dioxide.

This creates a dual metabolic effect; early consumption may increase blood sugar levels, while later stages shift metabolism toward alcohol processing in the liver. This unpredictable transition may pose challenges for individuals with diabetes or insulin resistance, as it can disrupt normal glucose regulation and insulin response. In some cases, alcohol metabolism may also suppress the liver's ability to release glucose, increasing the risk of hypoglycemia [48][58].

3. Oxidative Stress

Fresh palm wine contains antioxidant compounds that may help neutralize free radicals in the body. However, as fermentation progresses and ethanol levels increase, the metabolism of alcohol generates reactive oxygen species (ROS). These unstable molecules can damage important biological structures such as cell membranes, proteins, and DNA if not adequately controlled by the body's antioxidant defenses.

Over time, excessive or chronic consumption of fermented palm wine may contribute to oxidative stress. This condition is associated with premature aging and the development of chronic diseases such as cardiovascular disorders, liver dysfunction, and neurodegenerative conditions. Therefore, although fresh palm wine may contain beneficial antioxidants, its overall effect can shift negatively with prolonged fermentation or excessive intake [51][56].

4. Microbial Contamination

Palm wine is produced through spontaneous fermentation, meaning no sterilization or controlled microbial starter cultures are used. As a result, a wide range of microorganisms enter the beverage from the palm tree, tapping tools, containers, and the surrounding environment.

While many of these microorganisms are beneficial or harmless (such as yeasts and lactic acid bacteria), poor hygiene practices during tapping, collection, or storage can introduce harmful pathogens. These may include bacteria capable of causing foodborne illnesses, leading to symptoms such as stomach cramps, diarrhea, nausea, and general gastrointestinal infections.

The risk of contamination increases significantly when palm wine is stored in unclean containers or exposed for long periods without proper protection [65][51].

5. Chemical Contaminants

Another important concern is the possible presence of chemical contaminants in palm wine; these contaminants may enter the beverage through environmental pollution, contaminated soil absorbed by the palm tree, or the use of non-food-grade materials such as plastic or metallic containers during collection and storage.

Compounds such as benzene, styrene, and dichloromethane have been detected in some fermented beverages under certain conditions. These substances are of toxicological concern because long-term exposure may affect vital organs such as the liver, kidneys, and nervous system. Although not present in all samples, their occurrence highlights the variability and potential safety risks associated with traditional palm wine production systems [75].

6. Rapid Fermentation and Quality Deterioration

Palm wine is highly perishable and begins to deteriorate shortly after tapping. Natural microorganisms rapidly convert sugars into ethanol and organic acids, leading to continuous changes in taste, aroma, and chemical composition.

Within a few hours, the beverage may shift from a sweet, refreshing sap to a more alcoholic and acidic liquid. If fermentation continues unchecked, it becomes overly sour, less palatable, and potentially unsuitable for consumption. This rapid deterioration makes storage and transportation difficult, especially in rural areas where refrigeration is not available.

The inability to control fermentation time means that consumers often drink palm wine at varying stages of quality, which directly affects its nutritional value and safety [10][19].

Factors Affecting Safety and Quality

The safety and quality of palm wine are determined by a combination of biological, environmental, and handling-related factors. Since palm wine is produced through spontaneous fermentation without industrial standardization, its composition is highly variable and can change rapidly after tapping. These variations directly influence its taste, nutritional value, microbial safety, and shelf life.

i. Palm species used

The species of palm from which the sap is collected plays a major role in determining the final quality of palm wine. Different species, such as *Elaeis guineensis*, *Raphia hookeri*, and *Cocos nucifera*, differ in their sugar concentration, mineral content, and natural microbial population.

Sap with higher sugar content tends to ferment more rapidly, producing alcohol and acids within a shorter time. This affects sweetness, alcohol level, and overall taste profile. Again, sap with lower sugar content may ferment more slowly, resulting in a milder beverage. The inherent biochemical composition of each palm species, therefore, determines the baseline quality and stability of the final product [28][2].

ii. Hygiene during tapping and collection

Hygiene is one of the most critical factors affecting palm wine safety. During traditional tapping, the sap is often collected using natural containers such as gourds or plastic vessels that may not be properly sterilized. Tools used for cutting the palm inflorescence may also carry environmental microorganisms. When contamination occurs, unwanted bacteria and fungi are introduced into the sap, accelerating spoilage and increasing the risk of harmful microbial growth. Poor hygiene can also alter fermentation pathways by introducing competing microorganisms that disrupt the normal balance between yeasts and lactic acid bacteria. This often results in off-flavours, faster souring, and reduced shelf life [50][32].

iii. Environmental conditions

Temperature and humidity significantly influence fermentation dynamics. In tropical regions, high ambient temperatures accelerate microbial metabolism, causing rapid conversion of sugars into ethanol and organic acids.

As fermentation speeds up, sweetness decreases quickly while acidity and alcohol content increase. This leads to a shorter shelf life, sometimes within hours of tapping. High humidity can also promote microbial proliferation on tapping surfaces and storage containers, further affecting safety and consistency. Environmental conditions, therefore, determine how fast palm wine deteriorates after collection [40][34].

iv. Fermentation time

Freshness is one of the most important determinants of palm wine quality. Immediately after tapping, palm wine is sweet, mildly aromatic, and relatively low in alcohol content. At this stage, it contains higher levels of sugars and certain vitamins; however, as time progresses, fermentation continues naturally. Yeasts convert sugars into ethanol, while bacteria produce organic acids that increase sourness. Over time, the beverage becomes more acidic, less sweet, and more alcoholic. Extended fermentation eventually leads to over-acidification, unpleasant taste, and reduced nutritional value. This explains why palm wine is best consumed fresh and has a very short shelf life [35][31].

v. Storage conditions

Storage practices strongly affect the stability of palm wine. Exposure to air allows continuous oxidation and microbial activity, which accelerates spoilage. Containers that are not airtight or made from non-food-grade materials may introduce contaminants or allow external microorganisms to enter. Temperature during storage also matters. High temperatures speed up fermentation, while cooler conditions can slow microbial activity and slightly extend shelf life. However, because fermentation is continuous, even improved storage conditions cannot completely stop quality deterioration [76][51].

vi. Microbial activity

Microorganisms are both beneficial and responsible for spoilage in palm wine. Yeasts such as *Saccharomyces cerevisiae* initiate alcohol production by fermenting sugars, while lactic acid bacteria contribute to acidity and flavor development. Acetic acid bacteria further oxidize ethanol into acetic acid, increasing sourness. These microorganisms are essential for producing palm wine; their uncontrolled activity leads to rapid changes in composition. Without regulation, microbial succession continues until the beverage becomes overly acidic and less palatable. Thus, microbial balance is a key determinant of both quality and safety [52][40].

The safety and quality of palm wine depend on multiple interconnected factors, including palm species, hygiene practices, environmental conditions, fermentation time, storage methods, and microbial activity. Because these factors are not controlled in traditional production systems, palm wine remains highly perishable. Maintaining strict hygiene and consuming it fresh are the most effective ways to preserve its nutritional and sensory quality.

Conclusion

Palm wine is a naturally fermented beverage of considerable nutritional and cultural importance in many tropical regions.

Its composition is derived from palm sap and is influenced by biological and environmental factors such as palm species, microbial activity, temperature, and handling practices. When freshly tapped, palm wine contains carbohydrates, vitamins, minerals, organic acids, and bioactive compounds that contribute to its nutritional and functional properties.

However, palm wine is highly perishable because fermentation begins immediately after tapping. This process leads to continuous biochemical changes, including the conversion of sugars to ethanol, reduction of vitamin content, an increase in acidity, and shifts in microbial populations. As a result, its nutritional value and sensory quality decline rapidly with time.

Although palm wine has been associated with potential benefits such as quick energy supply, provision of essential micronutrients, antioxidant activity, and possible probiotic effects, these properties are strongly dependent on freshness, proper handling, and moderate consumption. The lack of standardized production and storage methods further contributes to variability in quality and safety.

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References

1. Okafor, N. (1978). Microbiology and biochemistry of palm wine. *Journal of Applied Bacteriology*, 44(3), 271-278.
2. Naknean, P., Meenune, M., & Roudaut, G. (2010). Changes in physicochemical and nutritional properties of palm sap during fermentation. *Food Chemistry*, 118(1), 316-322.
3. Adebayo, T. A., & Ajayi, O. O. (2020). Ethnobotanical importance of palm wine in rural livelihoods of West Africa. *Journal of Ethnobiology and Ethnomedicine*, 16(1), 45-56.
4. Nwosu, J. N., Eze, C. U., & Okafor, N. (2021). Microbial and chemical safety of palm wine. *Food Control*, 130, 108-117.
5. Corley, R. H. V., & Tinker, P. B. (2016). *The oil palm* (5th ed.). Wiley-Blackwell.
6. Amoa-Awua, W. K., Appoh, F. E., & Jakobsen, M. (2007). Lactic acid fermentation of palm sap: Microbial dynamics and safety aspects. *International Journal of Food Microbiology*, 114(2), 168-177.
7. Borse, B. B., & others. (2007). Coconut palm sap (toddy): Production and fermentation characteristics. *Journal of Food Science and Technology*, 44(5), 523-529.
8. Hebbar, K. B., Arivalagan, M., & Manikantan, M. R. (2015). Coconut palm sap (toddy): Production and quality attributes. *Journal of Plantation Crops*, 43(2), 120-128.
9. Henderson, A. (2009). *Palms of Southern Asia and West Africa*. Princeton University Press.
10. Santiago-Urbina, J. A., & Ruíz-Terán, F. (2014). Microbiology and biochemistry of traditional palm wine fermentation. *Food Microbiology*, 44, 1-8.

11. Oladipo, I. C., & Akinyonye, F. C. (2023). Microbiological quality and safety assessment of palm wine. *Nigerian Journal of Microbiology*, 37(1), 123–135.
12. Uzochukwu, S. V. A., Onuoha, C. U., & Eze, M. O. (2022). Microbial ecology of fermented palm products. *International Journal of Food Science*, 2022, 1–10.
13. Chukwuma, C. I., & Ifeanyi, O. E. (2022). Antioxidant properties of fermented plant-based beverages. *Journal of Food Biochemistry*, 46(3), e14012.
14. Akinola, A. A., & others. (2023). Bioactive compounds and safety concerns in fermented palm beverages. *Food Chemistry Reports*, 10, 100–110.
15. Eze, C. O., Berebon, D. P., Gugu, T. H., Nworu, C. S., & Esimone, C. O. (2019). Effects of *Lactobacillus* spp. isolated from palm wine (*Elaeis guineensis*) on cellular and innate immunity. Faparusi, S. I. (1971). Chemical composition of palm wine. *Journal of Food Science*, 36(3), 350–352.
16. World Health Organization. (2018). *Global status report on alcohol and health*. World Health Organization.
17. Nwaiwu, O., & Itumoh, E. (2017). Chemical contaminants in traditional fermented beverages. *Environmental Monitoring and Assessment*, 189(8), 1–12.
18. Olowe, O. A., & others. (2022). Controlled fermentation and preservation of palm wine. *Journal of Food Processing and Preservation*, 46(5), e16543.
19. Oluwole, O. O., Akinyemi, O. J., & Adeyemi, T. A. (2023). Biochemical changes in palm wine during fermentation. *Food Chemistry Advances*, 2, 100–115.
20. Khadka, S. P., Sharma, R. K., & Joshi, A. (2024). Nutritional and fermentation properties of coconut palm sap. *Journal of Food Composition and Analysis*, 123, 105–117.
21. Onyeukwu, A. N., Okeke, C. C., & Eze, J. C. (2024). Fermentation dynamics of palm wine in West Africa. *Food Science & Nutrition*, 12(1), 55–68.
22. Sarma, S. K., Das, A., & Hazarika, S. (2022). Nutritional changes in fermented palm sap. *Journal of Food Science and Technology*, 59(4), 1201–1210.
23. Bassir, O. (1968). Studies on the chemical composition of palm wine. *West African Journal of Biological and Applied Chemistry*, 11, 39–42.
24. Faparusi, S. I. (1971). Chemical composition of palm wine. *Journal of Food Science*, 36(3), 350–352.
25. Dangal, S. R. S., Taylor, J. P., & Sharma, R. K. (2024). Microbial diversity and fermentation dynamics in traditional palm beverages. *Food Microbiology Reports*, 15, 100–112.
26. Odunfa, S. A. (1985). African fermented foods. In R. Wood (Ed.), *Microbiology of fermented foods* (Vol. 2, pp. 155–191). Elsevier.
27. Obahiagbon, F. I. (2009). A review of the chemical and nutritional composition of palm wine. *African Journal of Food Science*, 3(4), 78–86.
28. Steinkraus, K. H. (1996). *Handbook of indigenous fermented foods* (2nd ed.). Marcel Dekker.
29. Campbell-Platt, G. (1987). *Fermented foods of the world: A dictionary and guide*. Butterworths.
30. Gottschalk, G. (1986). *Bacterial metabolism* (2nd ed.). Springer.
31. Adams, M. R., & Moss, M. O. (2008). *Food microbiology* (3rd ed.). Royal Society of Chemistry.
32. Jay, J. M., Loessner, M. J., & Golden, D. A. (2005). *Modern food microbiology* (7th ed.). Springer.
33. Jay, J. M. (2000). *Modern food microbiology* (6th ed.). Aspen Publishers.
34. Prescott, L. M., Harley, J. P., & Klein, D. A. (2020). *Microbiology* (11th ed.). McGraw-Hill Education.
35. Tortora, G. J., Funke, B. R., & Case, C. L. (2019). *Microbiology: An introduction* (13th ed.). Pearson.
36. Harborne, J. B. (1998). *Phytochemical methods: A guide to modern techniques of plant analysis* (3rd ed.). Chapman & Hall.
37. Dixon, R. A., & Paiva, N. L. (1995). Stress-induced phenylpropanoid metabolism. *The Plant Cell*, 7(7), 1085–1097.
38. Scalbert, A., Johnson, I. T., & Saltmarsh, M. (2005). Polyphenols: Antioxidants and beyond. *The American Journal of Clinical Nutrition*, 81(1), 215S–217S.
39. Rice-Evans, C. A., Miller, N. J., & Paganga, G. (1997). Antioxidant properties of phenolic compounds. *Free Radical Biology and Medicine*, 20(7), 933–956.
40. Fleet, G. H. (1998). Microbiology of alcoholic beverages. *International Journal of Food Microbiology*, 39(1–2), 55–65.
41. Swiegers, J. H., & Pretorius, I. S. (2005). Yeast and aroma compound formation. *Applied Microbiology and Biotechnology*, 66(2), 150–160.
42. Ekundayo, J. A. (1969). Chemical composition of Nigerian palm wine. *Journal of Science and Food Agriculture*, 20(6), 222–225.
43. Isitua, C. C., & Ibeh, I. N. (2010). Microbiological and biochemical changes during palm wine fermentation. *African Journal of Biotechnology*, 9(41), 7106–7114.
44. Khan, M. A., Rahman, M. S., & Ali, M. H. (2024). Nutritional variability in fermented plant beverages. *Journal of Food Science and Technology*, 61(1), 55–67.
45. Omemu, A. M., Oyewole, O. B., & Bankole, M. O. (2007). Fermentation characteristics of palm sap. *African Journal of Biotechnology*, 6(2), 123–128.
46. Dada, A. O., Ogunyemi, C. M., & Ojo, B. O. (2023). Nutritional significance of indigenous fermented beverages. *Nigerian Journal of Nutrition Sciences*, 44(1), 21–34.
47. Awolu, O. O., Olawoye, B., & Aderibigbe, A. (2020). Mineral and vitamin composition of palm wine. *Food Science and Nutrition*, 8(5), 2301–2310.
48. Adebo, O. A., Njobeh, P. B., & Gabriela, R. (2020). Bioactive compounds and health implications of fermented foods. *Food Bioscience*, 37, 100–110.
49. Eze, M. O., & Ogan, A. U. (1988). Vitamin content of palm wine. *Food Chemistry*, 28(3), 195–202.
50. Holzapfel, W. H. (2002). Appropriate starter culture technologies for small-scale fermentation in developing countries. *International Journal of Food Microbiology*, 75(3), 197–212.
51. Tamang, J. P., Watanabe, K., & Holzapfel, W. H. (2016). Diversity of fermented foods and microorganisms. *Frontiers in Microbiology*, 7, 1–11.
52. Doyle, M. P., & Buchanan, R. L. (2013). *Food microbiology: Fundamentals and frontiers* (4th ed.). ASM Press.
53. Ademiluyi, A. O., & Oboh, G. (2013). Antioxidant properties of fermented foods and beverages. *Journal of Food Science and Nutrition*, 4(2), 45–52.
54. Adetuyi, F. O., & Ibrahim, T. A. (2014). Antioxidant properties of fermented plant products. *African Journal of Biotechnology*, 13(24), 2461–2467.
55. Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and antioxidant activity. *Journal of Functional Foods*, 18, 820–897.
56. Gänzle, M. G. (2015). Lactic metabolism in food fermentation. *Food Microbiology*, 49, 115–127.
57. Hutkins, R. W. (2018). *Microbiology and technology of fermented foods* (2nd ed.). Wiley.
58. Adetunji, O. R., Adekunle, A. A., & Akinyemi, A. O. (2021). Mineral composition of palm wine from different palm species. *Journal of Food Composition and Analysis*, 97, 103–112.
59. Marco, M. L., Sanders, M. E., & Ganzle, M. (2021). The human gut microbiome and fermented foods. *Cell Host & Microbe*, 29(3), 345–356.

60. Koob, G. F., & Volkow, N. D. (2016). Neurobiology of addiction. *Neuropsychopharmacology*, 41(1), 373–384.
61. Spanagel, R. (2009). Alcoholism: A systems approach from molecular physiology to addictive behavior. *Physiological Reviews*, 89(2), 649–705.
62. Benton, D. (1993). The impact of diet on anti-social, violent and criminal behaviour. *Neuroscience & Biobehavioral Reviews*, 17(4), 465–474
63. Gibson, E. L. (2007). Emotional influences on food intake. *Nutrition Bulletin*, 32(1), 33–40.
64. Adeleke, R. O., & Abiodun, O. A. (2023). Nutritional and functional properties of traditional fermented beverages. *Journal of Food Science and Nutrition Research*, 6(2), 45–58.
65. Halliwell, B., & Gutteridge, J. M. C. (2015). *Free radicals in biology and medicine* (5th ed.). Oxford University Press
66. Tanaka, T., Shibata, H., & Hori, K. (2020). Antioxidants in eye health. *Nutrients*, 12(10), 3000.
67. Pullar, J. M., Carr, A. C., & Vissers, M. C. M. (2017). Hydration and skin health. *Nutrients*, 9(8), 866.
68. Adebayo, T. A., & Gbadamosi, O. O. (2021). Traditional uses of fermented palm beverages in West African communities. *African Journal of Traditional, Complementary and Alternative Medicines*, 18(3), 112–120.
69. Allen, L. H. (2012). Micronutrients and lactation performance. *American Journal of Clinical Nutrition*, 95(2), 497–507.
70. Brown, J. E., Isaacs, J. S., & Krinke, U. B. (2020). *Nutrition through the life cycle* (7th ed.). Cengage Learning.
71. Kent, J. C., Prime, D. K., & Garbin, C. P. (2012). Nutrition and lactation physiology. *Breastfeeding Medicine*, 7(1), 22–27.
72. Centers for Disease Control and Prevention. (2023). Alcohol use and breastfeeding guidance. CDC Publications.
73. Mennella, J. A. (2001). Alcohol and breastfeeding. *Pediatrics*, 108(5), 115–118.
74. Rehm, J., Baliunas, D., Borges, G. L. G., Graham, K., Irving, H., Kehoe, T., Parry, C. D. H., Patra, J., Popova, S., Poznyak, V., Roerecke, M., Room, R., Samokhvalov, A. V., & Taylor, B. (2017). The relation between alcohol consumption and disease burden. *The Lancet*, 373(9682), 2223–2233.
75. Adekunle, A. A., & Adebayo, T. A. (2021). Chemical contaminants in traditional fermented beverages. *Environmental Toxicology and Food Safety Journal*, 12(3), 101–112.
76. Ray, B., & Bhunia, A. (2014). *Fundamental food microbiology* (5th ed.). CRC Press.