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Review

Fermented Cashew Apple Beverages: Current State of Knowledge and Prospects

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Abstract: The cashew apple constitutes approximately 90% of the total fruit mass produced by the cashew tree, with the remaining 10% being the cashew nut. Despite its high nutritional value, it is regarded as an agricultural byproduct. Numerous scientific studies have explored the technological and nutritional potential of the cashew apple by leveraging microorganisms in its fermentation process for beverage applications. This paper provides an overview of existing fermented cashew apple beverages and discusses perspectives for new fermented cashew apple products. Five fermented cashew apple beverages were recorded. These include wine, edible alcohol, probiotic and prebiotic beverages, and cashew apple-based vinegar. New fermented cashew apple beverages with organoleptic, nutritional, and functional properties can be considered. Among these are fermented cashew apple beverages such as kefir or kombucha-type drinks. A promising avenue for future research is the exploration of the indigenous microbiota of the cashew apple and their interactions within a consortium. This could lead to innovative developments in food technology and improvements in the organoleptic and nutritional characteristics of fermented cashew apple beverages.

Keywords: beverages; fermented; cashew apple; kefir and kombucha; probiotic and prebiotic; clarification



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1. Introduction

Traditionally classified in the family of Terebenthaceae, cashew trees are now part of the Anacardiaceae family, which also includes mango trees and pistachio trees. It is a dicotyledonous plant from the Sapindales order, and its scientific name is *Anacardium occidentale* L. The word “Anacardium” is derived from Greek and means “inverted heart” (ana: above; cardia: heart), referring to the fruit’s shape [1]. The name “acajou” comes from the language *Tupi*, which is local to its native region, the Amazonian forest. This name became “cashew” in English, “cajuil” in Spanish, and “acajou” or “cajou” in French [2,3]. Originally, the Amazonian Indigenous people were the ones who grew cashews before the Europeans found them. They brought them to Africa and Asia between the 16th and 17th centuries [4], but it was only in the twentieth century that more attention was drawn to Anacardium crops. The cashew tree (*Anacardium occidentale*) produces a unique fruit consisting of two distinct parts: nuts and apples. The nuts are the most valuable part of the fruit. The nuts are detached from the apple after the fruit is harvested. For every kilogram of cashew nuts, ten to fifteen kilograms of cashew apples are produced [5]. Cashew apples

are rich in vitamins, polyphenols, sugars, minerals, and dietary fibers [6]. Despite the high nutritional value of the cashew apple, it is estimated that globally more than 90% of apple production is abandoned and lost in the field after the nut harvest [7]. This fact is mainly due to the astringent profile of cashew apples, their high perishability, short shelf life (less than 24 h at 30 °C) in tropical regions, and an unfounded belief that they are highly toxic when consumed with dairy products [8,9]. Since the middle of the twentieth century, research on cashew apples has gained a great interest among scientists worldwide. Thus, several scientific studies have elaborated on the potential of processing cashew apples into juice through chemical, thermal, and physical treatments [10–13]. The cashew apple juices obtained from these studies are often judged to be astringent. Therefore, recent scientific research has analyzed means and methods to reduce the astringency of cashew apple juice. Many studies focusing on cashew apple juice sensory properties have used several clarifying methods to reduce its astringency [14–18]. The clarified or unclarified juice of the cashew apple has great technological potential in terms of its organic and mineral composition [19].

To explore the technological potential of cashew apples, numerous studies have examined the role of microorganisms in their processing, particularly in fermentation. Basically, fermentation consists of turning carbohydrates, found naturally in the cashew apple, into alcohol and organic acids. It also contributes to the juice properties by enhancing its organoleptic and nutritional quality while ensuring its stability [20].

Despite the growing interest in fermented fruit-based products globally, the potential of cashew apple fermentation remains underexplored, particularly in the domain of mixed fermentation using natural microbiota. This study aims to review the current state of knowledge on fermented cashew apple products, highlighting existing processing methods, nutritional and health benefits, and consumer acceptance. Furthermore, it identifies prospects for innovation in product development, commercialization, and the sustainable use of cashew apples, contributing to waste reduction and economic growth in cashew-producing regions.

2. Methodology

An online literature exploration was conducted using the following key terms as a search strategy: “cashew apple”, “fermented”, “clarification”, “beverage”, “fermentation microbiota”, “mixed fermentation”, “probiotic beverage”, and “prebiotic beverage”. Literature published only in French and English between 2000 and 2024 was collected from five databases: Google Scholar, Web of Science, ScienceDirect, Scopus, and Dimensions. A total of 119 scientific documents were analyzed. Additionally, the geographic scope of the articles was set to cover cashew-producing countries in Africa, Asia, and South America.

3. Chemical Composition of the Cashew Apple: An Asset for Fermentation

The fermentative and technological potential of cashew apples is related to their physicochemical composition [21]. Understanding the physicochemical composition of cashew apples is crucial for proper fermentation control. Several scientific studies worldwide have examined the phenolic, carbohydrate, mineral, and organic acid composition of cashew apple juice. Table 1 summarizes the physicochemical composition of cashew juice from all varieties of the world’s major producing countries. The cashew apple is a rich source of organic acids, soluble sugars, and other chemical components that can promote or influence fermentation. Simple sugars (glucose and fructose) constitute the primary source of energy for yeast and lactic acid bacteria. The high concentration of these carbohydrates, ranging from 36.5 to 65.8 g/L for glucose and from 13.9 to 110.3 g/L for fructose, ensures the rapid and efficient

fermentation process. When compared to organic acids, the role of these compounds is of particular importance in maintaining a stable pH in cashew apple juice. This is achieved by creating an environment that is favorable for the growth of fermentative microorganisms while simultaneously inhibiting the growth of pathogens. Additionally, the antioxidant potential of the cashew apple is partly attributed to its high ascorbic acid (vitamin C) content. Indeed, ascorbic acid exhibits a remarkably high concentration, ranging from 49 mg to 256 mg per 100 mL on average, exceeding the levels typically found in citrus fruits. The cashew apple is also recognized for its high polyphenol content, particularly flavonoids. Table 2 provides an overview of 14 flavonoid compounds identified in the cashew apple. Flavonoids are considered essential allies for health, playing a key role in the prevention of cardiovascular diseases, cancer, diabetes, and neurodegenerative disorders [22]. The minerals present in cashew apples have been demonstrated to support fermentation processes, either directly or indirectly. For instance, potassium has been shown to be essential for yeast metabolism, promoting osmotic regulation and the synthesis of fermentation enzymes. Concurrently, magnesium has been observed to enhance yeast and bacterial growth. Furthermore, the bioactive compounds present in cashew apples, specifically polyphenols and tannins, have the potential to affect the fermentation of cashew juice. When present at low concentrations, these compounds impart antioxidant properties and positively contribute to the final product's aromas. However, at high concentrations, they may inhibit the growth of microorganisms, necessitating prior treatment such as clarification. The physical and chemical characteristics of apples vary depending on their geographical origin. This can be attributed to the influence of climate and agricultural practices in different regions, such as Colombia, Côte d'Ivoire, and Brazil.

Table 1. Physicochemical parameters of cashew apple juice from the world's major producers.

| Parameters | Values | Countries | References |
|---------------------|--------------------------------|-----------------------|------------|
| pH | 3.40–4.61 | India, Colombia | [11,21,23] |
| Total soluble sugar | 7–23% | Colombia, Brazil | [21,24] |
| Potassium | 69–1210 mg·L ⁻¹ | Nigeria, Brazil | [25,26] |
| Calcium | <ND–42 mg·L ⁻¹ | | |
| Sodium | 0.4–90 mg·L ⁻¹ | | |
| Magnesium | 62–1170 mg·L ⁻¹ | | |
| Zinc | 0.06–11.20 mg·L ⁻¹ | | |
| Iron | 0.07–6.97 mg·L ⁻¹ | | |
| Total polyphenols | 1.11–2.45 gGAE·L ⁻¹ | India | [27] |
| Flavonoids | 0.29–0.48 g·L ⁻¹ | Ivory Coast | [28] |
| Tannins | 1.71–1.92 gTA·L ⁻¹ | Colombia | [21] |
| Glucose | 36.5–65.8 g·L ⁻¹ | Ivory Coast, Colombia | [21,29] |
| Fructose | 13.9–110.3 g·L ⁻¹ | | |
| Sucrose | 2.5–5.3 g·L ⁻¹ | | |
| Ascorbic acid | 0.49–2.56 g·L ⁻¹ | Colombia | [21,27,30] |
| Oxalic acid | 0.098–0.16 g·L ⁻¹ | | |
| Citric acid | 0.53–0.56 g·L ⁻¹ | | |
| Tartaric acid | 0.67–0.75 g·L ⁻¹ | | |
| Fumaric acid | 0.12–0.18 g·L ⁻¹ | | |

GAE: gallic acid equivalent.

Table 2. Identified flavonoid compounds in the cashew apple [31–33].

| Compound | Cashew Apple (mg/g) |
|--|---------------------|
| Myricetin 3- <i>O</i> -galactoside | 0.0532 |
| Myricetin 3- <i>O</i> -glucoside | 0.0274 |
| Myricetin 3- <i>O</i> -xylopyranoside | 0.0124 |
| Myricetin 3- <i>O</i> -arabinopyranoside | 0.0104 |
| Myricetin 3- <i>O</i> -arabinofuranoside | 0.0097 |
| Myricetin 3- <i>O</i> -rhamnoside | 0.0400 |
| Total myricetin glycosides | 0.1511 |
| Quercetin 3- <i>O</i> -galactoside | 0.0465 |
| Quercetin 3- <i>O</i> -glucoside | 0.0144 |
| Quercetin 3- <i>O</i> -xylopyranoside | 0.0116 |
| Quercetin 3- <i>O</i> -arabinopyranoside | 0.0108 |
| Quercetin 3- <i>O</i> -arabinofuranoside | 0.0079 |
| Quercetin 3- <i>O</i> -rhamnoside | 0.0227 |
| Total quercetin glycosides | 0.1139 |
| Kaempferol 3- <i>O</i> -glucoside | Trace amount |
| 5-Methylcyanidin 3- <i>O</i> -hexoside | 0.0197 |
| Total glycosylated flavonoids | 0.2847 |

4. Cashew Apple Pre-Fermentation Treatments

4.1. A Strategy for the Reduction of Astringency

Astringency is one of the main reasons why cashew apples are not commonly consumed [9]. The astringent taste of cashew apples results from the precipitation reaction of salivary proteins with phenolic compounds, particularly the tannins present in cashew apples. From a sensory perspective, astringency is perceived by the oral epithelium as a combination of dryness, roughness, and throat irritation. In some cases, astringency may be perceived as a combination of bitterness and acidity [34]. These sensations are due to the formation of potent, water-soluble complexes resulting from the interaction of salivary proteins and tannins [35–38]. To enhance the palatability of cashew apples and derived products, especially cashew apple juice, it is crucial to eliminate or reduce astringency. Several researchers have developed methods to achieve this, including the use of clarifying agents, thermal treatments, microfiltration, fermentation, and ethanol vapor treatments.

4.1.1. Use of Clarifying Agents

The effectiveness of any clarification depends on the composition and concentration of the clarifying agent used and on the intrinsic characteristics of the food matrix to be clarified. These include phenolic composition, pH, temperature, shelf life, and cultivar type [39]. Clarification occurs via the adhesion of the clarifying agent to phenolic compounds in the food matrix or through a system of phenolic compound bonding in the food matrix through their ionic charges. Once formed, the particle complexes (clarifying agents/phenolic compounds or phenolic compounds/phenolic compounds) settle or flocculate [40]. Regardless of the clarifying agent used, the clarification process is always followed by filtration. Several clarifying agents are used in the cashew apple juice production process. Most clarifying agents are chemical or natural adjuvants, the most commonly used being cassava starch, rice starch, polyvinyl pyrrolidone (PVP), and gelatin, as indicated in Table 3 below. Depending on the clarifying agent used, the clarification mechanism may vary. For example, polyvinyl pyrrolidone eliminates tannins via a sedimentation mechanism, whereas rice or cassava starch eliminates tannins by flocculation or precipitation [19,41].

4.1.2. Thermal Methods

Heat treatment is also one method to reduce fruit astringency. However, it leads to the destruction of thermolabile compounds such as vitamins. Moreover, flavoring remains a major obstacle to the spread of this technique for eliminating astringency [42]. Several research projects have been carried out on cashew apples to evaluate the effect of heat treatments on the phenolic compounds that cause astringency. Heat treatments such as boiling, microwave cooking, blanching, and pasteurization have been applied to cashew apples. A hot water treatment was found to be very effective, reducing the tannin content by up to 96% without altering the organoleptic quality of cashew apples [43]. The decrease in astringency of cashew apples is attributed to the degradation of tannins induced by hot water [16].

4.1.3. Membrane Processes

To mitigate the undesirable effects of clarifying agents or thermal clarification methods, both of which can alter sensory and nutritional parameters, the utilization of membrane processes emerges as the best alternative for clarifying cashew apple juice. Membrane processes involve physical separations via a membrane under the influence of a pressure gradient [44]. The fruit juice industry is particularly interested in microfiltration because of its economic benefits and its ability to preserve nutritional and sensory properties [45,46]. For instance, applying microfiltration to cashew apple juice has effectively reduced tannin content while retaining nearly all ascorbic acid and volatile compounds [47,48]. Optimal results with microfiltration are achieved when cashew apple juice polysaccharides are hydrolyzed by tannase and/or cellulase enzymes before filtration, followed by concentration using reverse osmosis [49]. Additionally, the optimization of microfiltration and centrifugation through a neural network genetic algorithm for cashew apple juice leads to minimal retention of astringency (tannin content: 15.31 mg tannic acid/100 mL) while preserving the maximum amount of ascorbic acid (227 mg/100 mL) [50]. Table 3 shows a comparison of the characteristics of various methods used to remove astringency from cashews.

As stated above, there are various methods available for removing astringency from cashew apples. The selection of an appropriate astringency removal method should be guided by the technological, sensory, and nutritional characteristics designed for the final product. For instance, the use of polyvinyl pyrrolidone (PVP) resulted in the removal of 97% of total polyphenols from cashew apple juice. However, this clarification method adversely affected palatability, other sensory features, and nutritional attributes of the final product [51]. Conversely, the use of acid anhydride-modified laccase removed 44% of total polyphenols while yielding a final product with improved sensory quality [15]. Although polyphenols contribute to the astringency of cashew apples, they possess noteworthy biological properties, such as antioxidants, and also influence sensory aspects by modulating color, flavor, and astringency in beverages. In fact, their presence is often desirable in fermented products like wine. Therefore, when producing cashew apple wine, the clarification method used should aim to retain a higher proportion of polyphenols. Furthermore, the selected clarification methods should be cost-effective, easily applicable in processing units, and ideally preserve nutritional properties while enhancing the sensory characteristics of cashew apple juice. The adoption of clarification methods depends on the scale of the unit in question. Small units may use simple, cost-effective techniques, such as cassava starch or rice grits. On the other hand, larger-scale units may use more sophisticated clarification methods, such as membrane filtration.

Table 3. Comparison of different methods for removing astringency from cashew apples.

| | | Characteristics | | | | | | | | |
|------------------|------------------------------|--------------------------------|--------------------------|----------------------------------|---------------------------------|----------------------------------|--|--|-----------------|---------|
| | Methods of Elimination | Quantities of Clarifying Agent | Clarification Time (min) | Tannin Removal Mechanism | % Reduction in Condensed Tannin | % Reduction of Total Polyphenols | Impact of Clarification on the Sensory Quality of the Finished Product | Impact of Clarification on the Nutritional Quality of the Finished Product | Economic Aspect | Authors |
| Chemical | Polyvinyl pyrrolidone (PVP) | 1.4 g/L | ND | Precipitation and sedimentation | ND | 97 | Negative | Negative | ++ | [51] |
| | Ethanol vapor | 3.5 g/L | 720 | Tannin polymerization | ND | ND | Neutral | Neutral | - | [38] |
| Natural adjuvant | Cassava starch | 2 g/L | ND | Flocculation and/or coagulation | 42.85 | ND | Neutral | Neutral | - | [11] |
| | Rice groats | 10 g/L | 193 | Gelatinization and sedimentation | 42.14 | ND | Neutral | Neutral | - | [19] |
| | Gelatin | 0.67% (<i>p/v</i>) | 15 | Precipitation and sedimentation | 50 | ND | Neutral | Negative | + | [17] |
| | Moringa Oleifera seed powder | 10 g/0.25 L | 60 | Coagulation | 80 | ND | Negative | Neutral | - | [52] |
| | Dried okra powder | 0.3% | 30 | Sedimentation | 42.6 | ND | Neutral | Negative | - | [16] |
| | Defatted soya flour | 2% (<i>p/v</i>) | 240 | Precipitation and sedimentation | 34.3 | ND | Neutral | Neutral | - | [53] |
| | | 2.4% (<i>p/v</i>) | 120 | Sedimentation | ND | ND | Neutral | Neutral | - | [54] |
| | Sweet potato starch | 2.4% (<i>p/v</i>) | 120 | Sedimentation | ND | ND | Neutral | Neutral | - | [54] |

Table 3. Cont.

| Characteristics | | | | | | | | | | |
|---------------------------|--|--------------------------------|--------------------------|---|---------------------------------|----------------------------------|--|--|-----------------|---------|
| | Methods of Elimination | Quantities of Clarifying Agent | Clarification Time (min) | Tannin Removal Mechanism | % Reduction in Condensed Tannin | % Reduction of Total Polyphenols | Impact of Clarification on the Sensory Quality of the Finished Product | Impact of Clarification on the Nutritional Quality of the Finished Product | Economic Aspect | Authors |
| Enzymatic | Laccase modified by acid anhydrides (2-octenyl succinic anhydride) | ND | ND | Precipitation and sedimentation | 28.59 | 44.48 | Positive | Neutral | ++ | [15] |
| Use of thermal methods | Hot water treatment | ND | 20 | Thermal degradation of apple tannin compounds | 96 | ND | Neutral | Neutral | - | [39] |
| Use of membrane processes | 0.2 µm tubular ceramic membrane | ND | ND | Filtration | 97 | ND | Neutral | Neutral | ++ | [48] |

Legend: ND: not determined; ++: very expensive; +: expensive; -: less expensive.

5. Fermented Cashew Apple Products

Fermentation is a biochemical process in which microorganisms (bacteria, yeasts, and molds) transform a food matrix under specific conditions. This process depends on several factors, including the type of fermenting microorganisms, the nature of the food matrix, the conditions of the reaction environment (temperature, humidity, aeration, or absence of oxygen), and duration [55,56]. The physicochemical, nutritional, and organoleptic properties of cashew apples provide a great opportunity for their conversion into various fermented products. Fermented cashew products can be divided into two subgroups: fermented food products and fermented non-food products. In this article, we focus exclusively on fermented food products, specifically fermented beverages made from cashew apples.

5.1. Food Beverages Obtained from the Alcoholic Fermentation of Cashew Apples

Alcoholic fermentation is a biochemical process in which carbohydrates, particularly glucose, are broken down into ethanol and CO₂ by specific microorganisms, primarily yeasts, resulting in the release of energy [57]. Fermentation processes for ethanol production are among the oldest known methods [58]. Yeasts involved in alcoholic fermentation can be categorized into two groups. Those that belong to the genus *Saccharomyces*, predominant in alcoholic fermentation, and those outside this genus, the non-*Saccharomyces* such as *Hanseniaspora/Kloeckera*, *Pichia*, *Candida*, or *Metschnikowia*, all of which are involved in the initial stages of alcoholic fermentation [59]. Alcoholic fermentation leads to the production of various beverages, including beer, distilled spirits, and wine.

5.1.1. Cashew Apple Wine

Wine stands as one of the oldest beverages globally, valued not only for its taste but also for its therapeutic properties [60]. It is an alcoholic beverage typically produced by fermenting juice carbohydrates with yeast. Traditionally, wine is made by fermenting ripe grape juice using indigenous yeasts found on grape skins or by employing selected yeasts [61]. However, there is increasing interest in exploring tropical fruits, abundant in sugars, for crafting new wines with unique organoleptic characteristics [62]. Several studies have revealed that cashew apples, due to their taste, aroma, and color, offer a promising base for wine production. Cashew apple wine is typically derived from fermenting juice extracted from the fleshy stem of the cashew tree [63]. Given its adaptability and resilience during alcoholic fermentation, yeasts of the *Saccharomyces* genus are widely preferred by fermenters for cashew apple wine production, according to multiple authors. Table 4 below illustrates the various cashew wine production conditions and the microbial strains that are involved.

Table 4. Different cashew wine production conditions with the microbial strains involved.

| Microorganism Strains Used | Fermentation Time | Fermentation Temperature | Ethanol Content | Wine Sensory Characteristics | Country of Production | References |
|--|----------------------|--------------------------|-----------------|--|-----------------------|------------|
| <i>S. cerevisiae</i> var. <i>bayanus</i> | 36 to 51 days | 30 °C to 34 °C | 7% | Slightly yellowish color, moderate astringency and acidity | India | [23] |
| <i>S. cerevisiae</i> var. <i>ellipsoidea</i> | 6 months and 15 days | 28–30 °C | 8.25% | Color and taste accepted by panelists | India | [5] |
| <i>S. cerevisiae</i> | 48 days | 29 ± 2 °C | 10% | ND | Nigeria | [61] |

Table 4. Cont.

| Microorganism Strains Used | Fermentation Time | Fermentation Temperature | Ethanol Content | Wine Sensory Characteristics | Country of Production | References |
|--|-------------------|--------------------------|-----------------|---|-----------------------|------------|
| <i>S. cerevisiae</i> from Lallemand | 35 days | 17 °C to 22 °C | ND | Color and taste similar to grape wine, unpleasant aroma | Ghana | [64] |
| <i>S. cerevisiae</i> , <i>Torulaspora delbrueckii</i> , <i>H. opuntiae</i> | 48 h | 28 °C | 7% | Excellent organoleptic quality | Brazil | [65] |

ND: not determined.

The aforementioned scientific studies highlight the potential of cashew apples for wine production. The exclusive use of *Saccharomyces* yeasts in the production of cashew wine would have limited its organoleptic characteristics. To compete with other commercial wines, therefore, improvements in flavor and aroma are essential. One approach is to use a mixed ferment containing both *Saccharomyces* and *non-Saccharomyces* yeasts that are able to produce interesting volatile organic metabolites from cashew apple sugars. Brazilian researchers addressed this challenge by fermenting cashew apple juice with a mixture of conventional and non-conventional yeast strains. Two conventional strains of *S. cerevisiae* were paired with non-conventional strains of *Torulaspora delbrueckii* (isolated from cashew) and *H. opuntiae* (isolated from mango peel) to create a mixed fermentation for cashew apple wine. The resulting wine has excellent organoleptic qualities due to its richness in volatile compounds [65].

5.1.2. Other Alcoholic Beverages from Cashew Apples: The Case of Feni

In India, a wide range of fruits, including table apples, bananas, jackfruit, pineapples, grapes, and cashew apples, serve as raw materials in the alcoholic beverage industry [66]. One of India's most popular alcoholic beverages is Feni, a liquor distilled from the fermented juice of the cashew apple. In 2009, Feni was awarded a geographical indication, which attests to its unique origin and quality [67]. The production process of Feni involves a series of traditional unit operations that may vary from one production unit to another. Initially, the cashew juice is typically extracted either manually or using a screw press, depending on the production facility. Subsequently, the extracted juice is left to ferment spontaneously for 48 to 72 h in either a concrete or plastic vat. During spontaneous fermentation, some production units may periodically stir the juice using a hand stirrer.

Feni is obtained through a series of two distillations of the fermented juice in a traditional distillation system known as "Bhati". The liquor, called "Urrakh" in the local Konkani language, is the outcome of the first distillation of the fermented cashew juice. This process involves passing the vapors from the boiling fermented juice through serpentine copper pipes immersed in cold water. The urrakh is then mixed with fresh fermented cashew apple juice and distilled again in the bhati. The result of this second distillation is Feni drink, which has specific organoleptic characteristics with an alcohol content ranging between 42 and 43% v/v [68].

5.2. Food Beverages Derived from the Lactic Fermentation of Cashew Apples

5.2.1. Fermented Cashew Apple Juice Used as a Prebiotic Drink

Prebiotics are non-digestible dietary carbohydrates (such as raffinose oligosaccharides, fructo-oligosaccharides, galacto-oligosaccharides, or inulin) that provide health benefits by

selectively stimulating the growth and activity of one or a limited number of bacteria in the colon, thus improving the health of the host [69]. In 2008, dietary prebiotics were defined as “a selectively fermented ingredient that induces specific changes in the composition and/or activity of the gastrointestinal microbiota, thereby conferring health benefits on the host”. Several criteria are used to classify a compound as a prebiotic: it must be resistant to the acidic pH of the stomach, it cannot be hydrolyzed by mammalian enzymes, and must not be absorbed in the gastrointestinal tract. It can be fermented by the intestinal microbiota and the growth and/or activity of intestinal bacteria can be selectively stimulated by this compound and this process improves the health of the host [70]. Given the increasing prevalence of chronic diseases among the human population in recent years, consumers are becoming more conscious of the connection between health and diet. Consequently, the consumption of prebiotic foods is on the rise due to their biological benefits. These benefits include prebiotics’ ability to maintain and restore balance to the gut microbiota when bacterial equilibrium is disrupted [71,72]. They have been shown to lower the risk of conditions such as irritable bowel syndrome and Crohn’s disease [73] and to positively impact cognitive functions like learning and memory, potentially serving as a treatment for disorders such as schizophrenia [74]. Prebiotics can be obtained through bioconversion technology, achieved by fermenting fruits and vegetables with probiotic bacteria. Indeed, probiotic microorganisms possess enzymes (malolactic enzymes, proteases and peptidases, glycosidases, polysaccharide degrading enzymes, esterases, ureases, phenol oxidases, and lipases) that produce oligosaccharides and polymers such as prebiotic carbohydrates (fructo-oligosaccharides, inulin, and galacto-oligosaccharides). Probiotic microorganisms also produce a range of metabolites responsible for important B-complex vitamins [75,76]. Unclarified and pasteurized cashew apple juice was fermented with *Lactobacillus* spp. (*L. acidophilus*, *L. casei*, and *L. plantarum*), *Leuconostoc mesenteroides*, and *Bifidobacterium longum* to produce fructo-oligosaccharides (FOS) and raffinose family oligosaccharides (RFO). Cashew apple juice was fermented with each probiotic strain at 37 °C for 48 h. The results showed that the cashew apple juice fermented with *L. acidophilus* had the highest percentage of FOS 1-kestose, nystose, and 1F- β -fructofuranosyl-nystose, while the cashew apple juice fermented with *L. plantarum* had the highest percentage of RFO (raffinose and stachyose). Cashew apple juice fermented with *L. mesenteroides* and *B. longum* had the lowest percentages of FOS. The study also found that *L. casei* did not produce any oligosaccharides when used as an inoculum to ferment cashew apple juice [77].

5.2.2. Fermented Cashew Apple Juice Used as a Probiotic Drink

The term “probiotic” originates from the Greek words ‘pro’ and ‘biotic’, meaning ‘life’. Probiotics are defined as live microorganisms that, when consumed in adequate amounts, confer health benefits to the host. Traditionally, probiotic beverages were primarily associated with dairy products. However, there is now a growing trend and significant challenge for the food industry to incorporate probiotic cultures into plant-based products such as fruits, vegetables, and cereals [78]. Lactic acid bacteria are predominantly used as probiotics due to their numerous functional properties, including enhancing nutrient bioavailability, degrading antinutrients, exhibiting antimicrobial effects, displaying antioxidant activities, synthesizing vitamins, and improving sensory quality [79,80]. Lactic fermentation not only offers probiotic and nutritional benefits, but also impacts the sensory qualities of juices by producing lactic acid. Certain strains can even influence the polyphenolic composition. For instance, in a study, unclarified pasteurized cashew apple juice underwent fermentation with *L. plantarum* at 30 °C for 72 h. Biochemical analysis revealed a significant increase in condensed tannins and a decrease in hydrolyzable tannins, effectively reducing astringency. Additionally, the fermented juice exhibited a substantial population of *L. plantarum*

at 6.56 log CFU/mL and contained new compounds like benzenepropanol, 3-methyl-1-butanol, ethyl acetate, and acetic acid derived from bacterial metabolism, thus enhancing the organoleptic qualities of cashew apples [81]. In another study, gelatin-clarified cashew apple juice was fermented with *L. casei* at 30 °C ± 2 for 16 h after adjusting the juice's pH to 6.4. Following fermentation, the juice could be stored at 4 °C for up to 42 days. The fermented juice had a high cell density of *L. casei* and gained new flavor and aroma [82].

5.3. Food Products Derived from the Mixed Fermentation of Cashew Apples Cashew Apple Vinegar

Vinegar is defined as “a liquid suitable for human consumption made from an agricultural product”. Its raw materials typically include starch and sugars. Vinegar is produced through a double fermentation process involving both alcoholic and acetic fermentation, resulting in a sufficient quantity of acetic acid. Typically, vinegar contains acetic acid diluted to 4–6%, which not only slows down microbial growth but also contributes to the sensory properties of food. It serves various purposes, such as flavoring, preservation, and as a base for human and animal remedies [83]. Vinegar's history dates back at least 10,000 years, with records of its use by the Romans and Greeks. Initially, vinegar was produced through the spontaneous fermentation of wine exposed to air [84]. In the fermentation process, ethanol is oxidized to acetic acid by a mixed culture of acetic bacteria and yeast. These bacteria primarily stay on the surfaces of plants and fruits, with species like *Acetobacter aceti*, *Acetobacter pasteurianus*, and those of the *Gluconobacter* genus being predominant [81,85].

Cashew apple juice is particularly suitable for natural vinegar production due to its high sugar content and widespread availability. Several scientific studies have explored the production of cashew apple vinegar. For instance, researchers from the Beninese Research Institute, in collaboration with stakeholders from the cashew nut sector, have developed an artisanal vinegar production process [86]. Exceptionally, vinegar is not a fermented beverage derived from cashew apples, but rather a culinary ingredient resulting from mixed fermentation.

6. Microorganisms Involved in the Fermentation of Cashew Apple Beverages and the Overall Process of Their Production

6.1. Microorganisms Involved in the Fermentation of Fermented Cashew Apple Beverages

Fermented beverages derived from cashew apples are produced using either non-native or native microbial strains. Table 5 summarizes the different microorganisms (non-native and native) involved in the fermentation process of various cashew apple-based beverages.

Table 5. Native and non-native microorganisms involved in the fermentation of cashew apple fermented beverages.

| | Alcoholic Fermentation of Cashew Apples | Lactic Fermentation of Cashew Apples | Mixed Fermentation of Cashew Apples |
|--|--|---|---|
| Native microorganisms involved in the fermentation process | <i>T. delbrueckii</i> [65], <i>C. krusei</i> , <i>C. norvegica</i> , <i>C. magnoliae</i> , <i>C. parapsilosis</i> , <i>C. colliculosa</i> , <i>C. norvegica</i> , <i>C. parapsilosis</i> [87], <i>P. membranifaciens</i> [88], <i>P. kudriavzevii</i> [89], <i>Hanseniaspora</i> spp. [90], <i>S. cerevisiae</i> , <i>S. uvarum</i> [91] | ND | ND |
| Non-native microorganisms involved in the fermentation process | <i>S. cerevisiae</i> var. <i>bayanus</i> [23], <i>S. cerevisiae</i> var. <i>ellipsoidea</i> [5], <i>S. cerevisiae</i> [60], <i>S. cerevisiae</i> from Lallemand [63], <i>S. cerevisiae</i> , <i>H. opuntiae</i> [65]. | <i>L. acidophilus</i> , <i>L. casei</i> , <i>L. plantarum</i> , <i>L. mesenteroides</i> , <i>B. Longum</i> [77], <i>L. plantarum</i> [82] | <i>S. cerevisiae</i> , acetic acid bacterial biofilm [86] |
| Fermented food products | Wine and edible spirits | Probiotic and prebiotic beverages | Vinegar |

ND: not determined.

According to the available data, cashew apple harbors native microbiota rich in alcoholic fermentation, which varies depending on the geographical region where it is cultivated. This microbiota is diverse, comprising both *Saccharomyces* and non-*Saccharomyces* yeasts. Unfortunately, this native alcoholic flora is rarely utilized in the industrial processing of cashew apples. Moreover, to our knowledge, very few scientific studies have focused on identifying the native bacterial flora (lactic acid and acetic acid bacteria) associated with cashew apples. Further research on the technological potential of the alcoholic, lactic, and acetic fermentation microbiota of cashew apples is essential to foster innovation and enhance the value chain of this sector.

6.2. Overview of the Production Processes of Fermented Cashew Apple Beverages

Figure 1 illustrates a comprehensive process for transforming cashew apples into various fermented (wine, probiotic, prebiotic, vinegar) and distilled (Feni) beverages.

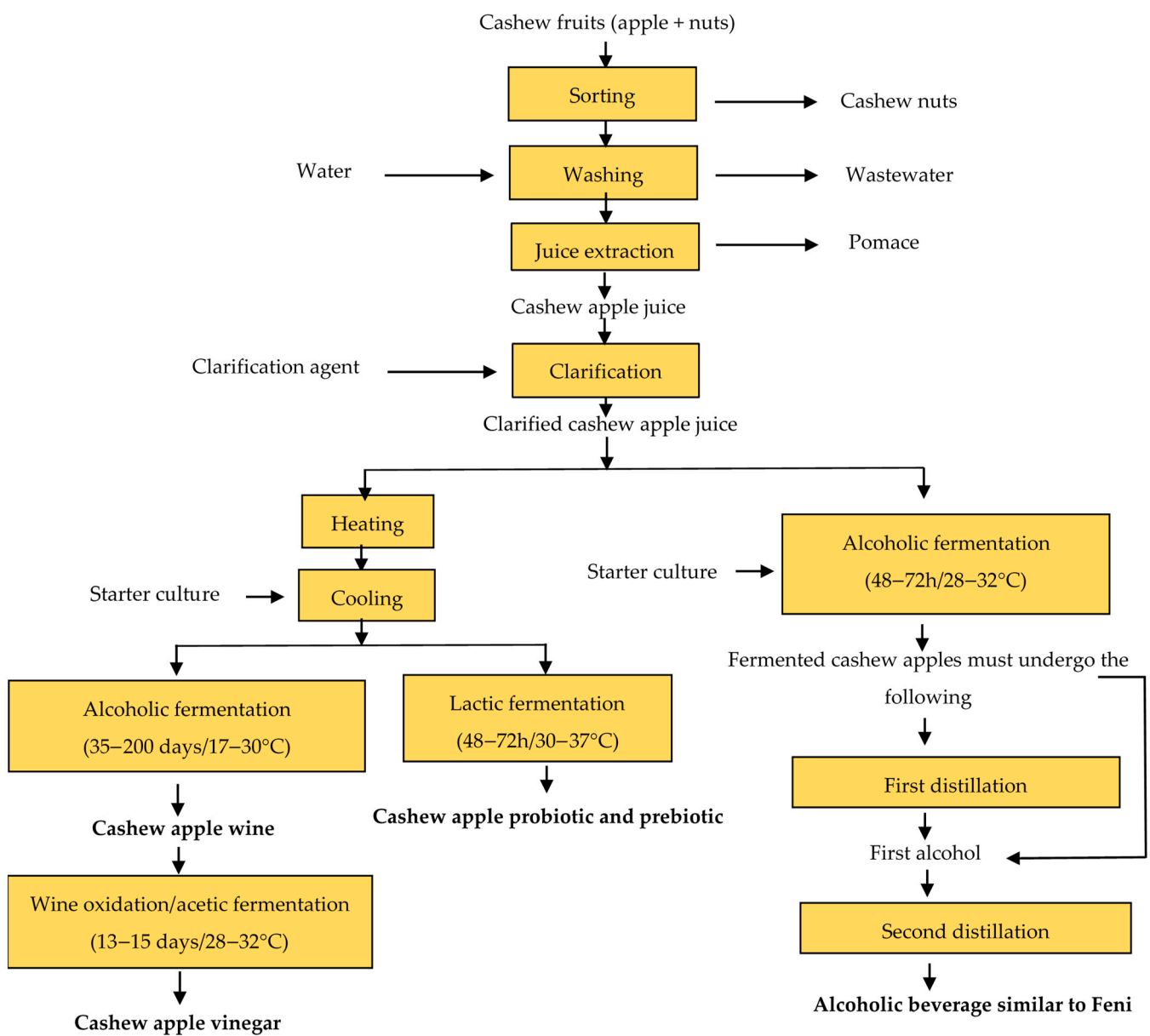


Figure 1. Process flow diagram for the production of fermented cashew apple beverages.

Several key aspects stand out in this technological diagram, notably the clarifying agent used, the starter culture for inoculation, and the time–temperature combination for

fermentation. The clarifying agent may vary from one production unit to another, depending on the type of fermented beverage desired. The choice of starter culture depends on whether the beverage is alcoholic or probiotic. Regarding the time–temperature combination, it varies according to the type of starter culture used and the specific characteristics of the final product.

7. Innovative Prospects of New Beverages Made from Cashew Apples

As only a small proportion (10%) of the world's cashew apples are processed, scientific research and the agri-food industry have been quick to find ways to convert this food resource into fermented alcoholic beverages, such as cashew wine and cashew spirits [5,7,23]. However, during the fermentation and distillation of alcoholic beverages, compounds such as ethanol, methanol, and acetaldehyde can be found in the final product [92,93]. Ethanol and acetaldehyde are recognized as potential human carcinogens [94], while methanol is recognized as a lethal contaminant of traditional fermented beverages [95]. For instance, the mean exposure to acetaldehyde from alcoholic beverages was calculated to be 0.112 mg/kg body weight/day. The margin of exposure was determined to be 498, and the estimated lifetime risk of cancer was found to be 7.6 in 10,000 [96]. However, there are ways to modulate alcoholic fermented beverages to reduce or inhibit ethanol, methanol, and acetaldehyde. Mixed alcohol–lactic fermentation appears to be a better option for modulating cashew apple fermented beverages. In fact, drinks produced by lactic fermentation are considered functional drinks and have beneficial effects on health, such as enhancing the immune system, improving memory, and enhancing cardiac performance [97]. It is regrettable that beverages produced through the lactic fermentation of cashew apples are not as widely consumed and prevalent in tropical countries as those produced through alcoholic fermentation of cashew apples. The combination of lactic and alcoholic fermentation represents an opportunity to improve the organoleptic and nutritional qualities of cashew apple fermented beverages. Indeed, mixed fermentation could involve microorganisms able to modulate the structure of polyphenols and decrease naturally the astringency of the beverage. In addition, some of their metabolic pathways could increase their release or conversion into more bioavailable and active forms. Indeed, although cashew apples contain 14 bioactive flavonoid compounds, their bioaccessibility may be limited due to their association with the cell wall, glycosylation, or polymeric forms [98]. The potential of fermentation to enhance the antioxidant properties of flavonoids is linked to the hydrolytic activity of the microorganisms involved in the process. Indeed, several microorganisms (yeasts and bacteria) produce enzymes belonging to the hydrolase class that act on flavonoid glycosides [99]. During fermentation, glycosyl hydrolases convert flavonoid glycosides into their corresponding aglycones, which exhibit higher bioactivity in humans compared to their glycosylated precursors [100]. Moreover, potential synergistic interactions between yeast and lactic bacteria strains could provide a tool for the implementation of new symbiotic and nutraceutical fermented beverage technologies [101]. For all those reasons, mixed fermented beverages such as kefir and kombucha, both of which are recognized as functional and therapeutic drinks [102,103], could be very interesting to produce from cashew apples.

7.1. Cashew Apple Juice as a Substrate for Fermented Beverages like Kombucha

Kombucha is a traditional non-alcoholic, slightly effervescent beverage made through the aerobic fermentation of sweetened green or black tea with a symbiotic culture of yeast, acetic acid, and lactic acid bacteria. It originated in north-eastern China around 220 BC and is consumed for its refreshing, nutritional, and therapeutic potential [104,105]. Kombucha is known for its organoleptic attributes and health-enhancing properties, depending on the

food-based fermentation, offering consumers new beverage choices and potential health benefits [106]. The fermentation microbiota of kombucha is complex and varies depending on the raw material used, the sugar source, and the fermentation conditions [107]. A scientific study has shown that the microbial community in kombucha consists of bacteria and yeasts that develop in two mutually non-exclusive compartments: the beverage and the biofilm floating on top. The microbiota of the biofilm is composed of *Candida* sp. (73.5–83%) and *Komagataeibacter* (50%), while the microbiota of the drink is dominated by *Candida* sp., *Lachancea* sp., and *Komagataeibacter* (50%) [108]. Many scientific studies have confirmed that kombucha fermentation involves microbiota including lactic acid bacteria (*Lactobacillus* spp., *Lactococcus* spp., *Oenococcus* spp., etc.), acetic acid bacteria (*Komagataeibacter* spp., *Acetobacter* spp., *Gluconobacter* spp., etc.), and yeasts (*Zygosaccharomyces* spp., *Saccharomyces* spp., *Schizosaccharomyces* spp., *Brettanomyces* spp., *Candida* spp., *Pichia* spp., *Torulaspora* spp., etc.) [109,110]. According to the Kombucha Code of Practice provided by Kombucha Brewers International, kombucha can be made from various plant-based raw materials. Consequently, several scientific studies have successfully produced fermented fruit juice beverages using kombucha cultures with grape, pomegranate, cherry, orange, plum, apricot, strawberry, persimmon, papaya, and apple juice [111,112]. To date, to our knowledge, there is no evidence on the production of kombucha drinks with cashew apples. Focusing on its biochemical composition, the cashew apple could serve as an excellent fruit for producing a kombucha-type fermented beverage.

7.2. Cashew Apple Juice as a Substrate for Fermented Beverages like Kefir

Kefir is a symbiotic medium of microorganisms that is characterized by irregular granules of white or yellow protein and a soluble polysaccharide matrix, the kefiran or kefir grain. The kefir microbiota resides in the kefiran and is characterized by a spectrum of lactic acid bacteria, yeasts, and acetic acid bacteria. Its microbiota depends on its source and geographical region [113,114]. Kefir is believed to possess health benefits, including the reduction of symptoms associated with lactose intolerance, the stimulation of the immune system, and cholesterol-lowering, anti-mutagenic, and anti-carcinogenic properties [115]. The water kefir microbiota consists of a combination of yeasts, mainly *Kluyveromyces*, *Lachancea*, *Hanseniaspora*, *Zygotorulaspora*, *Candida*, and *Saccharomyces*, a group of lactic acid bacteria mainly in the genera *Lactobacillus*, *Lactococcus*, *Leuconostoc*, and *Streptococcus*, and a group of acetic acid bacteria in the genera *Acetobacter* [116]. Several scientific studies have demonstrated the production of kefir using fruit juices. Six Mediterranean fruit juices (apple, quince, grape, kiwi, prickly pear, and pomegranate) were used to develop several kefir-type fermented beverages in southern Italy. All the fruit juices underwent lactic fermentation, with a general decrease in soluble solids and an increase in volatile organic compounds. The overall quality assessment indicated that, among the Mediterranean fruit juices tested, apple and grape beverages were most favored by tasters. Therefore, these results support the possibility of developing kefir-type fruit beverages with high added value and functional properties [117]. To our knowledge, no group of researchers has yet studied the possibility of producing fruit kefir based on cashew apples. Considering its biochemical composition, the cashew apple would be an ideal raw material for the production of a fermented beverage like kefir.

8. Conclusions and Future Perspectives

Despite its high nutritional value, approximately 90% of the world's cashew apple production is discarded as food waste. Over the years, scientific research has successfully transformed cashew apples into high-quality fermented products such as wine, edible alco-

hol, probiotic drinks, and vinegar. However, there remains significant potential to further innovate and enhance the sensory, nutritional, and functional properties of these beverages.

Future research should prioritize the exploration of the indigenous microbiota of cashew apples which may serve as a reservoir of novel microbial strains with unique metabolic capacities. Bioprospecting efforts could lead to the discovery of yeasts and bacteria capable of degrading phenolic compounds responsible for astringency, thereby improving the overall palatability of fermented cashew beverages. In addition, it would be highly valuable for future studies to evaluate the nutritional composition of cashew apple-based fermented beverages across various aspects, particularly bioactive compounds. Additionally, biofortification strategies should be developed to enrich these beverages with probiotics that produce bioactive compounds such as aromatic esters, antioxidants, and essential vitamins, thus increasing their appeal within the functional food market.

Another promising avenue is the development of alcohol-free or low-alcohol cashew-based fermented beverages, catering to the growing demand for healthier drink alternatives. Moreover, the establishment of a robust regulatory and safety framework will be essential to ensure consumer confidence, facilitate global trade, and enable the widespread commercialization of fermented cashew apple products.

To fully realize the potential of cashew apples in the fermented beverage industry, a collaborative approach involving researchers, industry stakeholders, and local producers is imperative. By advancing scientific innovation and regulatory support, cashew-based fermented products can be elevated from a sustainable waste-reduction initiative to a valuable and competitive sector in the global beverage market.

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