Chapter 16
Other Tropical Fruit Vinegars

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16.1 Introduction

The African continent has many different indigenous cereals, shrubs and fruit-bearing trees.

A number of these fruit trees, especially some of the exotic ones, have been domesticated and some are grown under agroforestry farming systems. The fruits produced by many of these indigenous trees are edible and can ripen within a very short period of time, which usually leads to an overabundance of the fruit at the time of harvest. Some of these are consumed fresh, but large quantities are wasted during peak harvest periods. This rapid post-harvest deterioration is due to the high temperature and humidity, poor handling, poor storage procedures, and microbial infections.

Fermentation is a relatively efficient and low-energy preservation process which increases the fruit's shelf life and decreases the need for refrigeration or other food preservation technologies. Indigenous fermented beverages and vinegars prepared from fruits are common in many parts of African continent. Nevertheless, the history of vinegar fermentation in Africa is obscure, because there are no documents and oral history is not precise. The absence of a written culture in most African countries makes the origin difficult to trace.

Vinegar can be made from any non-toxic raw material that provides a juice or solution containing fermentable sugars. Ideally, sugars should be present at levels sufficient to produce vinegar with an acetic acid content according to local standards.

Theoretically, 1 g of glucose will produce 0.67 g of acetic acid but, as this figure is never achieved in practice, at least 2% (w/v) sugar is required for every 1% (w/v) acetic acid in the final product. In most cases the raw material used in vinegar production contains sufficient nutrients to support the growth and metabolism of acetic acid bacteria (AAB). However, low-sugar juices can be supplemented with exogenous sugars or concentrated by evaporation or reverse osmosis.

L. Solieri, P. Giudici (eds), *Vinegars of the World*

16.2 Cocoa Vinegar

16.2.1 Cocoa Sweatings

Cocoa mucilage (sweatings) is a pale yellowish liquid, which is a waste by-product of the cocoa industry. It is derived from the breakdown product of the mucilage (pulp) surrounding the fresh cocoa beans of the tree *Theobroma cacao* and constitutes about 10% of the weight of the cocoa fruit (Adams et al., 1982).
Cocoa sweatings are a by-product obtained of the traditional cocoa fermentation, obtained by the activity of pectolytic enzymes which are secreted by some microorganisms involved in the fermentation process (Ansah and Dzogbefia, 1990). It is rich in soluble sugars and pectin, as well as having chemico-physical characteristics suitable for producing soft drinks, alcoholic drinks, vinegar, pectin, toffee, etc. (Opeke, 2005). The chemical composition of cocoa mucilage is shown in Table 16.1. Cocoa mucilage is free of alkaloids and other toxic substances. Children usually like collecting the mucilage for drinking due to its high sugar content before fermentation sets in.

Table 16.1 Chemical composition of cocoa mucilage

Composition	Percentage
Water	79.2-84.2
Dry substances	15.8-20.8
Non-volatile acids	0.77-1.50
Volatile acids	0.02-0.04
Glucose	11.60-5.32
Sucrose	0.11-0.90
Pectin	5.00-6.90
Starch	–
Protein	0.42-0.50
Ash	0.40-0.50

16.2.2 Alcoholic Fermentation

The initial pH of the pulp is approximately 3.6 due to its high citric acid content; this favours the growth of yeasts, together with a low level of oxygen. Different yeast species contaminate cocoa pulp, mainly *Kloeckera apiculata*, *Kluyveromyces marxianus*, *Saccharomyces cerevisiae*, *Pichia fermentans*, *Lodderomyces elongisporus* and *Candida bombi*. During the fermentation process, *Saccharomyces cerevisiae* is the most dominant yeast species due to its ability to tolerate high ethanol concentrations. Therefore *Saccharomyces cerevisiae* is the yeast most frequently used in fermentation of most fruit juices (Prashant and Rajendra, 1989). The succession of different yeast species active during alcoholic fermentation of cocoa pulp is summarized in Table 16.2.

Table 16.2 Frequencies (%) of yeast species isolated during cocoa fermentation

Time (h)	Species	Frequency (%)
0	*Saccharomyces cerevisiae*	33.3
	Kloeckera apiculata	13.3
	Kluyveromyces marxianus	13.5
	Pichia fermentans	13.3
	Lodderomyces elongisporus	13.3
	Candida bombi	13.3
12	*Saccharomyces cerevisiae*	35.3
	Kloeckera apiculata	30.0
	Kluyveromyces marxianus	17.0
	Pichia fermentans	5.9
	Candida bombi	5.9
	Candida rugapelliculosa	5.9
24	*Saccharomyces cerevisiae*	22.7
	Candida bombi	20.0
	Candida rugopelliculosa	20.0
	Kluyveromyces marxianus	9.0
	Kloeckera apiculata	5.0
	Lodderomyces elongisporus	5.0
	Torulaspora pretoriensis	5.0
48	*Saccharomyces cerevisiae*	38.0
	Candida bombi	16.0
	Candida rugopelliculosa	16.0
	Candida pelliculosa	10.0
	Candida rugosa	10.0
	Torulaspora pretoriensis	10.0
72	*Candida rugopelliculosa*	20.0
	Candida pelliculosa	20.0
	Candida rugosa	20.0
	Saccharomyces cerevisiae	10.0
	Torulaspora pretoriensis	10.0

From Schwan et al., 1995

Alcoholic fermentation of cocoa mucilage is carried out in relatively simple vessels, such as open vats of wood or concrete, or earthenware pots, and without any form of temperature control, particularly when small vessels are used and the ambient temperature is suitable for yeast growth (25-30 °C). No starter cultures are generally used.

The progress of fermentation can be monitored visually by observing the rate of carbon dioxide evolution, but more reliably by determining specific gravity of alcohol content in the fermenting mucilage. The alcoholic fermentation generally ends within 48-72 hours.

Values of specific gravity, titratable acidity, and soluble solids during cocoa alcoholic fermentation are reported in Table 16.3.

Table 16.3 Chemico-physical parameters during alcoholic fermentation of cocoa mucilage (from Akinwale, 2000)

Time (days)	Specific gravity[a]	Titratable acidity[b]	Total soluble solids[a] (%)	pH
0	1.080	0.110	20.00	3.80
2	1.069	0.250	10.00	3.20
4	1.048	0.345	15.50	3.08
6	1.019	0.585	8.50	3.10
8	1.019	0.585	8.50	3.25
10	1.004	0.685	7.25	3.30
12	0.993	0.715	5.25	3.15
14	0.990	0.945	5.50	3.35

[a] Evaluated at 20 °C

[b] Calculated as % tartaric acid in 100 mL of cocoa wine.

Ethanol is the main product of alcoholic fermentation of the hexoses present in pulp mucilage. The transformation of a hexose by *S. cerevisiae* can be represented chemically by the Gay-Lussac equation:

$$\underset{\text{fermentable hexose (180 g)}}{C_6H_{12}O_6} \rightarrow \underset{\text{ethanol (92 g)}}{2C_2H_5OH} + \underset{\text{carbon dioxide (88 g)}}{2CO_2}$$

Other than to produce ethanol, little sugar can be used during alcoholic fermentation to increase yeast cell biomass, or to produce secondary by-products such as glycerol and succinic acid. This leads to a decrease in the yield of ethanol: a theoretical yield would be 95%, whereas a good practical yield is approximately 90%.

16.2.3 Acetification

When fermentation is complete, the cocoa alcoholic beverage may be centrifuged to remove yeast cells and is then mixed with a proportion of suitable 'seed' vinegar or 'mother of vinegar', which is generally a portion of previous successful acetification. AAB involved in vinegar production belonging mainly to the genera *Acetobacter* and *Gluconacetobacter* (Sievers and Swings, 2005). There have been no studies attempting to elucidate the AAB species involved in cocoa acetification.

16.3 Palm Wine and Vinegar

Palm wine is an alcoholic beverage traditionally produced from the sugary sap of various palms (tribe *Cocoineae*, family *Palmae*) throughout the tropics (Table 16.4). In Nigeria it is obtained from the sap of the raphia palm, *Raphia hookeri* and *Raphia vinifera*, and the oil palm tree *Elaeis guineensis* (Okafor, 1975).

Table 16.4 Composition of palm sap

Composition	Percentage
Sucrose	11.0
Glucose	0.95
Fructose	1.0
Raffinose	0.8
Ammonia	–
Vitamin C (mg/100 mL)	–
Vitamin B_{12}	–

From Okafor, 1975

Palm wine can be used as an alcoholic beverage or as alcoholic intermediate to produce palm wine vinegar.

16.3.1 Palm Sap

Palm sap is a sweet whitish liquid that gradually turns milky as a result of the growth of microorganisms which contaminate the sap as it oozes out of the tree, causing a spontaneous fermentation.

The methods of procuring the unfermented sap from palm trees vary according to the tree and the locality. One method includes the felling of the oil palm tree (*Elaeis guineensis*) and the collecting of the sap from a cut on the stem or by cutting the terminal bud. Tapping from a mature felled palm tree results in a different composition of palm sap compared with that obtained from living trees, and the palm wine produced, called 'down wine', differs from other palm wines because of its high contents of ethanol, methanol and propanol (Ayernor and Matthews, 1971). This type of palm wine is not highly appreciated in Nigeria because of its high alcohol content and because it may result in the gradual elimination of the palm tree population (Okafor, 1987). In another method of tapping, an incision is made at the base of the immature male inflorescence after removing the bracts. It is left to dry for 2 days after which the hole is reopened and the sap is collected in a gourd. The hole is reopened twice daily for 2-3 weeks, during which time the sap is tapped. This is the most acceptable method as it spares the life of the trees and produces a wine that commands a high price. Alternatively, the sap may be tapped through a hole under the terminal bud after clearing the tree. The sap of the *Raphia* palm is obtained by cutting the terminal bud.

The sap yield can vary depending upon the season of tapping and the type of palm. Up to 3 litres per day for 14-21 days of tapping the oil palm and 2-11 litres per day from the *Raphia* palm have been reported (Uraih and Izuagbe, 1990).

16.3.2 Microbiological Transformation

As the sap drips from the tapping hole, it is contaminated by microorganisms from the bark of the male inflorescence. Due to this contamination, distribution of the products to distant places is difficult, as it ferments rapidly, losing its sweet taste and becoming sour and milky-white within 24 hours and becoming unacceptable to the consumer (Uraih and Izuagbe, 1990).

The microorganisms associated with palm wine fermentation have been studied by various authors (Uraih and Izuagbe, 1990). The yeasts belong mainly to the genera *Saccharomyces*, *Schizosaccharomyces*, *Candida*, *Kloechera*, *Pichia* and *Endomycopsis*, whereas species of the genera *Lactobacillus*, *Acetobacter*, *Micrococcus*, *Serratia*, *Leuconostoc*, *Sarcina*, *Streptococcus*, *Zymomonas*, *Bacillus*, *Brevibacterium*, *Pediococus* and *Klebsiella* are the bacteria most frequently isolated. Moulds, such as *Penicillium* spp. and *Aspergillus* spp., have occasionally been found in palm wine. One of the most striking features of the micro-

biology of palm wine is the variability in microbial composition due to different tapping sites. Saps obtained from different palm trees spaced 2-4.5 m apart have been reported to exhibit great differences in the types of microorganisms present (Okafor, 1978). However, there are no systematic studies on the occurrence of these microorganisms in palm wine obtained using saps from different tapping sites.

Table 16.5 Changes in the taste, alcoholic content, sugar and acid content during spontaneous oxidation of palm wine (modified from Chinnarasa, 1968)

	Time (h)[a]			
Characteristics	**0**	**3**	**6-12**	**24**
Taste	Fresh, sweet	Sweet	Slightly sour	Very sour
Alcohol (%)	3.78	4.84	6.32	6.70
Sucrose (%)	6.80	4.18	1.48	0.35
Acetic acid (%)	0.49	0.54	0.57	0.69

[a] Hours after collection at 28-30 °C.

Modified from Chinnarasa, 1968

Fermentation of the sugars and other nutrients present in the juice by the indigenous microflora of the palm trees leads to alcohol and organic acid production (Table 16.5). According to his preliminary studies on spontaneous fermentation of palm sap, Bassir (1962) reported that the fermentation of the fresh palm sap into palm wine occurs in two stages. The first stage involves the production of organic acids by bacteria, whereas the second stage is triggered at pH 6.8 and ends at pH 4.4, and involves alcohol and organic acid production. There has been some criticism of this theory because it assumes that yeasts were solely responsible for the inversion of sucrose present in the sap, whereas it is known that several bacteria can also cause it. Yeasts and micrococci also seem to occur consistently in palm wine (Faparusi and Bassir, 1971; Okafor, 1975). Moreover, several studies on the succession of microorganisms in palm wine have consistently reported the development of *Acetobacter* after about 3 days; by this time alcohol is present in reasonable quantities (Faparusi and Bassir, 1972; Faparusi, 1973; Okafor, 1975). Since both bacteria and yeasts have been found at various stages of the fermentation, the fermentation of palm wine may well be due to the combined activities of those two groups of microorganisms. Recently Amoa-Awua et al. (2007) have reported that a concurrent alcoholic, lactic acid and acetic acid fermentation occurred during the tapping of palm wine from felled oil palm trees. Yeasts, mainly *S. cerevisiae*, started to grow immediately after tapping and alcohol concentrations became high in the product after the third day. Lactic acid bacteria, mainly *Lb. plantarum* and *Lc. mesenteriodes*, were responsible for a rapid acidification of the product during the first 24 hours of tapping, whilst the AAB belonging mainly to *Acetobacter* and *Gluconacetobacter* species became pronounced after the build-up in alcohol concentrations on the third day.

Palm wine usually possesses three desirable characteristics – fresh sugary taste, whitish coloration and vigorous effervescence. It has a variable alcohol content of

0.5-7.1% (v/v). The pH value at the time of consumption is usually between 3 and 5. A litre of palm wine provides approximately 300 calories, 0.5-2.0 g of protein and considerable amounts of vitamins (Okafor, 1987). The major components of the palm wine are sugars, alcohols, organic acids and protein. Although it is produced mainly in rural areas by tappers in Nigeria, the bulk of the beverage is consumed in urban areas.

Although no systematic studies have been carried out on AAB occurring in palm vinegar, it is very probable that species of the genus *Acetobacter* are responsible for ethanol oxidation of palm wine to acetic acid.

16.3.3 Ogogoro

This distilled beverage is produced from palm wine in Nigeria and some other West African countries, such as Ghana, where it is referred as *akpeteshi* (Okafor, 1987). It is a colourless liquid with an alcohol content of 26.8-39.9% (w/v). It is consumed mainly by low-paid workers due to its relatively cheap price, but it is also used for traditional ceremonies and as a solvent in various medicinal concoctions.

The traditional method of *ogogoro* production involves the pooling of palm saps in a metal drum where they are thoroughly mixed and allowed to ferment for 24 hours with occasional stirring. The fermentation usually takes place between 25 and 30 °C at a pH between 4.0 and 4.5. The fermented sap is then distilled over a fire and the vapour is condensed. The first distillate is usually discarded and successive distillates are collected and often re-distilled to obtain a product with a higher alcohol content.

16.4 Cashew Vinegar

16.4.1 Cashew

The cashew tree (*Anacardium occidentale*) is a medium-sized fruit-bearing tree, widespread throughout the tropics, having a high productivity and growing on poor soils due to its high drought resistance. The fruit consists of a kidney-shaped nut and a pseudoapple with a brilliant yellow or red skin colour. The cashew apple is five to ten times as heavy as the nut when ripe and is found to contain 85% juice with 10% sugar (Table 16.6), most of which is invert sugar (Ohler, 1979).

The cashew fruit is a climacteric fruit and shows a prominent increase in respiration coincident with ripening. It reaches its respiratory peak very fast due to a large amount of ethylene being produced concomitant with the evolution of aromatic volatiles, and thus also has a short storage life. Togun (1977) estimated that more than 3000 tonnes of cashew apples are wasted annually in cashew plantations in Oyo State alone. The Federal Government of Nigeria has recognized the great potential of cashew as an important commodity crop and source of industrial mate-

rials, and added cashew utilization and production to the mandate of the Cocoa Research Institute of Nigeria (CRIN) in 1971 (Cashew Coup and CRIN, 1999).

Table 16.6 Chemico-physical parameters of cashew juice

Parameter	Value
Specific gravity	1.030
Total reducing sugar (g/l)	788
Sugar (%)	8.19
Total titratable acidity (%)	0.36
Soluble solid (°Brix)	4.4
Extract (w/v) (%)	8.04
Refractive index	1.3395
pH	3.8
Amino acid	4.238
Total nitrogen (%)	0.039
Crude protein (%)	0.2438
Potassium (g/l)	1.53
Calcium (mg/l)	68
Sodium (mg/l)	105
Magnesium (mg/l)	16.0
Zinc (mg/l)	22
Ash (w/v) (%)	0.455
Potential alcohol	5.0

From Osho, 1995

16.4.2 Alcoholic Fermentation, Acetification and Clarification

Cashew juice is obtained by removing the nut from the apples, cutting the fruits into small pieces and squeezing them by hand or with a machine. The juice is often clarified by filtering through a sieve. A large number of different yeasts can colonize the cashew juice due to the somewhat low pH (3.8-4.0). Therefore it is often pasteurized and fermentation is started by inoculating a desired yeast starter, such as *Saccharomyces cerevisiae*. After fermentation, back-slopping with seed vinegar harvested from the previous batch is carried out to produce cashew vinegar.

The clarification can be effected by filtration or by fining. Generally filtration is preferred, as it reduces the bacterial population and removes vinegar eels if present (Cruess, 1958; Frazier and Westhoff, 1978; Adams et al., 1982). In the fining method, clarifying agents such as casein, gelatin, bentonite, sodium alginate and isinglass are mixed with the cashew vinegar and the mixture is allowed to stand until clear vinegar appears (Prescott and Dunn, 1959). Pasteurization of the clarified cashew vinegar should also be necessary. The bottles should be completely filled and tightly capped or corked with treated corks to prevent the entry of air. The temperature and time of pasteurization vary according to microbial contamination and conditions of filling. Generally speaking, a temperature of 60-66 °C for about 30 minutes is sufficient for adequate cashew vinegar pasteurization.

16.5 Other Tropical Alcoholic Fermented Beverages with Potential for Vinegar Production

16.5.1 Burukutu

Sorghum beer is a popular alcoholic beverage in sub-Saharan Africa. It is known as *burukutu* in the northern Guinea savanna region of Nigeria, the Benin Republic and Ghana, and by various other names in other parts of West Africa. It is brewed from Guinea corn (*Sorghum bicolor*), the prevalent grain in this area (Odunfa and Oyewole, 1985; Kayodé et al., 2007).

As in the conventional lager beer process, the method for preparing burukutu consists of three phases: malting, mashing and fermentation. However, depending on geographical location, variations may occur in the process. The procedure described here is based on a report by Faparusi et al. (1973). Sorghum grains are steeped in water overnight. The grains are then put into a basket and the water drained off. The grains are spread on mats in a bed about 6 cm thick and covered with banana leaves to allow the grains to germinate. In this phase (malting period), the grains are watered on alternate days and periodically turned over. The purpose of malting is to effect the hydrolysis of starch in the sorghum to fermentable sugars. Germination starts within 24 hours after steeping and continues until the plumule (portion of the young shoot above the cotyledons) attains a certain length; this is usually within 4-5 days. The malted grains are spread out in the sun to dry for 1-2 days. The dried malt is ground in a disc mill, and then mixed with *garri* (a starch powder produced from the tuber of the cassava plant, *Manihot utilissima*) and water. The resulting mixture (garri-malt-water), which is in a ratio of roughly 1:2:6 by volume, is stirred and allowed to ferment for 2 days. At the end of the fermentation the mixture is boiled for about 4 hours and then left to mature for another 2 days. The resulting drink is a cloudy liquid with a sour taste.

The sorghum malt contains mainly yeasts and moulds. In the fermenting mixture the yeasts isolated belonged to the species *Saccharomyces cerevisiae*, whereas the main bacterial species are *Leuconostoc mesenteroides* and *Lactobacillus* spp. The acidity of the fermenting mixture falls from about pH 6.4 to about pH 4.2 within 24 hours and drops to 3.7 after 48 hours. At the end of the 2 day maturing stage, the dominant microorganisms are *Acetobacter* spp. and *Candida* spp. (Faparusi et al., 1973). The yeasts and bacteria are killed by boiling. Unlike some other alcoholic beverages, the specific characteristic of burukutu is a vinegary taste and sharp smell. There is up to 0.4-0.6% of acetic acid in fully matured burukutu beer.

16.5.2 Plantain Drink

Apart from cereals, another source of sugars for producing alcoholic and vinegary beverages are bananas and plantains, which can be subjected to spontaneous fermentation to produce a plantain beer called *agadagidi*. Due to hot and humid cli-

matic conditions in southern Nigeria and Cameroon, plantains and bananas can be affected by quick over-ripening and bacterial spoilage. These overripe bananas are peeled, sliced and soaked in containers to ferment. The most frequently isolated microorganisms are *Saccharomyces*, *Leuconostoc* and *Streptococcus*. *Bacillus* and *Micrococcus* species also occur occasionally (Sanni and Oso, 1988; Sanni, 1989). The nutrient content of the beverage produced is very high (Ketiku and Scott-Emuakpor, 1975; Sanni and Oso, 1988).

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