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Waste Cashew Apple (*Anacardium occidentale*) as Feedstock for Simultaneous Production of Two Main Ecofriendly Fuels

Delphine N'guessan[1], Micaël Bedikou[1], Verdier Abouo[2], Lamine Samagaci[1], Charlotte Ehon[1], Camara Yacouba[1], Eric Akpa[1]

[1]Department of Biotechnologies, Felix Houphouët-Boigny University, Abidjan, Côte d'Ivoire
[2]Departement of Food Sciences, Felix Houphouët-Boigny University, Abidjan, Côte d'Ivoire
Email: bedikou.micael@ufhb.edu.ci

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Abstract

The present work investigated an effective low-cost production of bioethanol by the use of rejected cashew apples (CAs) in Ivorian plantations. Fresh CAs were cut into 8 - 10 mm slices and submitted to a drying cycle of two periods (for the sake of easing their rehydration) in an oven with forced air convection. Temperature was first set at 30˚C for 3 hours, and then raised at 50˚C until constant weight. Drying brought about 82% weight loss, and the dried slices were rehydrated in a ratio of 1:4 (w/v) in warm distilled water to reconstitute a 10 Brix degree (˚B) juice with 1.042 g/cm^3 density. The sugar content of the juice was increased to 20˚B (syrup) by thermal evaporation. The process was optimized using a response surface methodology (RSM) by applying a central composite plan in order to minimize heat-sensitive compound degradation. The optimal operating conditions for temperature and time of heating were precisely 68,239˚C and 83,314 min, respectively. The commercial baker's yeast *Saccharomyces cerevisiae* was used to seed the 20˚B cashew apple syrup following a batch fermentation at 30˚C. The total alcohol content recorded after 24 hours was 8.24% ± 0.11% made up of almost 97% of ethanol and isobutanol (a higher alcohol). Analysis of alcoholic profiles by flam ionization detector-gas chromatography (GC-FID) showed an ethanol content of 3.92% and an almost similar but higher quantity of isobutanol (4.05%) with the latter being a by-product. As bio-based isobutanol attracts more and more attention due to its wide application and excellent fuel performance as compared to ethanol, it emerged from this study that neglected cashew apples can be successfully employed as valuable raw material for the simultaneous production of both biofuels currently used as sustainable sources of renewable energy.

Keywords

Cashew Waste Valorization, Bioalcohol Production, Renewable Energy, Isobutanol, Ethanol

1. Introduction

Today, crude oil reserves, limited refining capacity and growing concern about environmental degradation offer excellent prospects for bioalcohols. For example, bioethyl alcohol manufactured from plant-based biomass represents renewable energy that reduces greenhouse gas emissions by more than 71% compared to fossil fuel [1]. It also reduces other pollutants emissions, improving air quality. However, the prices of raw materials have a considerable impact on production costs as they can represent 40% - 75% of the total costs depending on the type of feedstock. So, the promotion of biofuels from neglected biomass should contribute to reducing production costs. An attractive agroindustrial waste product, with potential as a bioethanol substrate, is cashew apples, the neglected part of *Anacardium occidentale* fruit. Indeed, their exploitation for bioethanol production is advantageous as they are rich in fermentable sugars (50 - 200 g/l of glucose and fructose), vitamin C, minerals and amino acids [2] [3], which are essential elements for yeast assimilation and growth. Moreover, the apples are readily available in large quantities as they are abandoned after harvesting the cashew fruit.

The use of cashew apple juice in biofuels is relatively new, and simple procedures are employed. In general, the juice is first extracted, treated with enzymes or gelatin powder to eliminate tannins and fermented [4]. Then, the treated juice is filtered allowing the yeasts to easily assimilate the sugars for growth and more ethanol production. There are reports of an average production of about 1.5% alcohol from a cashew apple [5], which highlights the huge economic potential of wasted cashew apples [2]. The fruits are seasonal and apples are highly perishable and prone to rapid microbial spoilage due to high moisture (85% - 90%) content. Generally, for preservation, cashew apples should be collected at most 3 days after nuts harvesting. However, it cannot be transported over long distances. The lack of appropriate processing technologies resulted, in 2021, in losses of about 9 million tons of cashew apples in Côte d'Ivoire, the world's leading producer of cashew nuts [6]. Although 1,050,000 tons were produced in 2023, the potential for ethanol production from fresh cashew apples in Côte d'Ivoire is still limited [7]. As large amounts of fresh cashew apple (33 kg) are required for the production of 1 liter of ethanol, the material collection areas should be far extended thus requiring high transport costs and prohibitive cost of bioethanol production.

To face these hindering reasons to their utilization as raw material for ethanol production, different techniques have been considered to extend the shelf life of cashew apples, which include modified atmosphere packaging [8], irradiation [9], cooling and freezing [10] and Freeze drying [11]. However, the major drawback of these processes is their high operating and capital cost [12]. Dehydration of fruit and vegetables is one of the oldest and easiest methods of food preservation techniques [13]. Dehydration, in general, is a process of removing moisture from solid or liquid food and brings about an extensive reduction in weight and volume that minimize packaging, storage, and transportation costs [14]. It is an appropriate way to curb losses and extend use to nonproduction periods [15]. Food dehydration can be achieved by different techniques such as drying and evaporation. Regarding dehydration by drying, the reference [16] accomplished the preservation of cashew apples by drying and grinding them into powder. The authors then rehydrated the powder into a must for alcoholic fermentation. However, a major limitation in the commercial exploration of cashew apple powder is the high capital investment in the drying unit operation [17]. Direct rehydration of dried slices of fruits to extract juice can be considered as an alternative to grinding [18]. As for the process of dehydration by evaporation, its relevance in the present study lies in the fact that cashew apple wine production usually requires an adjustment of initial sugar content to above 20% (w/v) by adding sucrose to obtain a higher final ethanol concentration [19]. Indeed, the concentration of juice to reach sugar levels beyond 40 g total soluble solids/100 g is traditionally accomplished by thermal evaporation [20]. This process could be validly considered as an alternative to the chaptalization of juices (the process of adding sugar). This study intends to explore the feasibility of using dried cashew apple-based concentrated juice as a plausible feedstock for bioethanol production.

2. Experimental Procedure

2.1. Collect, Treatment and Drying of Cashew Apples

Mature and ripe fruits of yellow and red varieties with pH and total soluble solid values of 3.7 ± 0.3 and 11.3 ± 2.2˚Brix (˚B), respectively were harvested at cashew plantations from different locations in Côte d'Ivoire: Yamoussoukro (6˚49'13"N 5˚16'36"W), Katiola (8˚08'14"N 5˚06'03"W) and Korhogo (9˚27'28"N 5˚37'46"W). The whole fruits collected were transported within less than 48 h to the laboratory and then, apples were picked from nuts, washed to remove dirt and contaminants, wiped up and weighed.

To obtain a good rehydration rate, specific preliminary provisions must be taken into account during the drying process. Indeed, at the beginning of the drying process, when the free water content is at its maximum, it is more effective to promote rapid air circulation to evaporate the free water than to set the temperature too high. So, the temperature at the beginning of dehydration should be low (28˚C - 30˚C) to avoid hardening of the tissue membrane making them hard and dry and therefore rendering them poorly rehydratable. Cashew apples were cut into 8 - 10 mm slices and arranged on trays covered with baking paper. The drying racks were introduced in an electric oven with forced air convection

(MMM Medcenter, Germany). A cycle of two periods in the drying of the goods was applied. The temperature at the beginning of dehydration was low (30˚C) and aimed at removing the free water. After 3 hours of good ventilation, came the second and longest drying phase which have consisted in removing bounded water from the inner layers of apples. To accomplish this step as quickly as possible, the temperature was raised to 50˚C until the difference between three successive weighings (every hour) did not exceed the value of 0.001. The dried apple slices were cooled, sealed in propylene bags and kept at room temperature (25˚C).

2.2. Rehydration

Rehydration experiments were performed by immersing 5 g of dried cashew apple slices into 100 ml of distilled water for 60 min [21]. The samples were then withdrawn, drained, gently blotted with paper towels to eliminate the surface water and then weighed. The rehydration ratios (RRs) were calculated using the following equation:

$$\text{RR} = \frac{\text{weight before rehydration}}{\text{weight after rehydration}} \tag{1}$$

2.3. Physicochemical Characterization of Dried and Fresh Cashew Apple

The moisture content of fresh and dried cashew apple was analyzed by following the method in [22]. Total sugar in samples was determined calorimetrically using phenol-sulphuric acid method as described in [23]. The reducing sugars were determined by DNS method [24]. Tannins content was quantified as described in [25]. The ascorbic acid (AA) content was determined by the method described in [26] based on the oxidation of 2,6-dichlorophenol indophenol by AA in an acetate buffer system. All the assays were made in triplicate and the results reported as an average ±2% sensitive deviation.

2.4. Cashew Apple Must Preparation and Fermentation

Two hundred grams (200 g) of dried cashew apple powder was mixed with 800 ml of distilled water in order to reconstitute a 10˚B natural juice. The mixture was blended (Panasonic blender, Japan), filtered through muslin cloth and the resulting juice was collected into a clean flask. The pH was recorded (3.7) and adjusted to 5.0 with some drops of a 3.5 g/l of calcium carbonate ($CaCO_3$) solution. The must to be fermented was first sterilized at 121˚C for 15 min, and the sterile cashew apple solution was left to settle at room temperature. Prior to fermentation, the must was adjusted to a 20˚B syrup to expect a final ethanol concentration between 5% and 12% [27].

2.5. Optimization of Must Concentration Using Response Surface Methodology

The concentration process of the 10˚B juice into 20˚B syrup was optimized using a response surface methodology (RSM) protocol frequently used in the field of agriculture, agrifood, biology and chemistry [28]. One of its objectives is to establish a mathematical model between the measured responses and a number of variables that influence them. In this work, it was proposed to establish a mathematical model between the response, Y, which is the soluble solids content in the juice expressed as ˚Brix and the variables. The variables studied (**Table 1**) were temperature (X_1 in ˚C) and the heating time (X_2 in minutes). The choice of temperatures comes from the proposed values for pasteurization, which ranged from 62˚C to 88˚C for fruit juices with pH < 4.5 [29]. The recorded pH of the reconstituted juice in this study is 3.7. Central composite factorial design (CCD) was used in the optimization of the conditions [30]. A 22 factorial CCD, with five replications at the center points ($n_0 = 5$) for a total of 13 experiments were used in the study (**Table 2**). 300 ml of the juice was poured in 800 ml beaker and placed inside a commercial water bath for experimentations. The second order model used to fit the response to the independent variables $Y = a_0 + a_1X_1 + a_2$ is below:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_{12} X_1 X_2 + a_{11} X_1^2 + a_{22} X_2^3 \quad (2)$$

Table 1. Experimental range of temperature and time values.

Variables	Low	High
Temperature of heating X_1 (˚C)	55	85
Time of heating X_2 (min)	60	120

Table 2. Central composite design (CCD) and experimental design matrix.

	Encode variables		Real values	
	X_1	X_2	X_1	X_2
Factorial trials	−1	−1	58.66	68.78
	1	−1	76.34	68.78
	−1	1	58.66	111.22
	1	1	76.34	111.22
Star trials	−1.41	0	55.00	90.00
	1.41	0	80.00	90.00
	0	−1.41	67.50	60.00
	0	1.41	67.50	120.00
Centre trials	0	0	67.50	90.00
	0	0	67.50	90.00
	0	0	67.50	90.00
	0	0	67.50	90.00
	0	0	67.50	90.00

2.6. Preparation of Yeast Starter and Alcoholic Fermentation

Saccharomyces cerevisiae (commercial baker's yeast) was used as inoculum. The starter culture was prepared using 0.3 g/l which was made into slurry with 3 ml of sterile warm water for 30 minutes. The slurry was used to seed 1/10th of sterile 10 and 20˚B musts for pre-fermentation [31]. The suspensions were then placed in a shaking bath (150 rpm) at 30˚C till an absorbance of 0.5 at 600 nm is obtained. The 10 and 20˚B preferments were used to inoculate the remaining 9/10th must already dispatch up into three separate fermenting flasks. A batch fermentation mode was carried for 24 h at 30˚C and was monitored for pH and soluble solids variation.

2.7. Determination of the Physicochemical Properties of Cashew Apple's Musts and Wines

The pH of the samples was measured using a digital pH meter (Hanna HI 98129). Concerning the total soluble solids content (TSSC), a Brix Atago hand held refractometer with Brix scale values of 0% - 32% was used. Alcohol content (%: v/v), density (g/cm^3) and rate of fermentation (%) which are indicators of extent of sugar conversion into alcohol and CO_2 during a fermentation process were measured after centrifugation by means of an electronic densimeter model DMA-4500 (Anton Paar, Austria). The produced alcohol profiles and quantities were analyzed by gas chromatography (GC), Agilent 7890A Brand, coupled with a flame ionization detector (FID) injector. The column used was an Agilent HP type (30 m, 320 µm ID, and 0.25 µm). The data acquisition and processing system was obtained using a computer with Chemstation REVA.10.02 software. The chromatographic condition is described in **Table 3**. Standards were pure alcohols such as methanol (SIGMA-ALDRICH 0.790 g/ml), ethanol (Reide-deHaen 0.788 g/ml), isopropanol (SIGMA-ALDRICH 0.785 g/ml) and isobutanol (SIGMA-ALDRICH 0.803 g/ml).

Table 3. Gas chromatography experimental conditions.

Parameters and conditions	
Column Column volume	HP-5 30 m × 320 µm, 0.25 µm
Carrier gas Constant flow rate	Helium 1.7482 ml/min (30 cm/s)
Temperature programming	50˚C (0 min), 10˚C/min to 110˚C (0 min).
Analysis time	6.0 min
Injector	Split, 200˚C, split ratio 60:1
Detector	FID
Temperature detector	250˚C
Injection volume	1 µl

2.8. Statistics

Analysis of variance (ANOVA) and significant differences among the means were tested by LSD Fisher at the 95% confidence interval. Standard deviation was also recorded. The results were declared significant when P-value is <0.05. For descriptive statistics, the means and standard deviations were reported. The regression will be assessed by analyzing the coefficient of multiple determination (R^2), low values of root mean square error (RMSE) and mean absolute error (MAE) [32].

$$\text{MAE} = \frac{\sum_{i=1}^{n} \left| X_{r\,\text{exp},i} - X_{r\,\text{pre},i} \right|}{X_{r\,\text{exp},i}} \tag{3}$$

3. Results and Discussion

3.1. Drying

During the drying process of this study, a loss of 82.55% ± 0.6% weight was recorded after 24 hours. This rate falls within the range values from 80% to 90% already reported for dried fruits and vegetables, respectively [33] [34]. This equates to a reduction of 1 kg of fresh cashew apples to about 183 ± 14.14 g meaning that they're much smaller and lighter. Fresh fruits and vegetables are important sources of essential dietary nutrients such as vitamins, minerals and fibers. Since their moisture content is more than 80%, they are classified as highly perishable commodities. It is reported that over 20% of the world perishable crops are dried to increase shelf-life and promote food security. So, drying is an operation widely used in the agrifood industry and in an artisanal way by African farmers. In this respect, drying of the cashew apples could represent an alternative means of ensuring the stability of this perishable crop and contribute to its long-term utilization and valorization [35].

3.2. Physicochemical Parameters of Fresh and Dried Cashew Apples

The physicochemical parameters of fresh and dried cashew apples slices are reported in **Table 4**. The recorded moisture content of the dried samples was about the maximum permissible rate for dried fruits recommended by CODEX General Standard which is 20%. This rate would inhibit the growth of spoilage microorganism hence prolonged shelf life of the product. Significant amount of vitamin C, 334.55 ± 0.09 mg per 100 g, was determined in the fresh fruits presented in **Table 4**. This content was in accordance with the highest values of about 330 mg per 100 g reported in literature. Ascorbic acid is the principal nutritional compound in cashew apple. Indeed, the edible portion is reported to contain about four times the amount of ascorbic acid as compared to other tropical fruits including mango, orange, and pineapple [36]. As cashew apple is an excellent source of vitamin C, the ascorbic acid content was determined as a quality parameter to evaluate the dried product. Dried apple samples displayed

Table 4. Physicochemical parameters of fresh and dried cashew apple slices.

Parameters	Fresh apple	Dried apple
Moisture (%)	86.21 ± 0.18a	20.01 ± 0.66b
Vitamin C (mg/100g)	334.55 ± 0.09a	147.20 ± 0.01b
Tannins (g EC/100g)	0.41 ± 0.07a	0.16 ± 0.01b
Total sugars (g/100g)	5.87 ± 1.58b	13.18 ± 2.21a
Reducing sugars (g/100g)	3.34 ± 0.14b	5.46 ± 0.41a
Rehydration ratio	nd	2.10

Mean values with the same superscript in a column are not significantly different ($P > 0.05$) according to the Fisher's LSD. nd = not determined.

about 41% losses of vitamin C when compared with the fresh one. It is well known that this vitamin is heat sensitive so that such range of content losses has already been reported. However, the vitamin C content recorded 147.20 ± 0.01 mg per 100 g, remained similar or higher than that of a number of fruits. As retention of ascorbic acid (an anti-oxidant compound) in a food product is desirable and attractive, several pretreatments such as ultrasound and osmotic dehydration are commonly used to minimize adverse changes occurring during drying [37].

The contents of individual and total sugars were statistically lower in fresh apples compared to dried fruits. Thus, drying process not only stabilizes the product by reducing the water activity but it also preserves fermentable sugars [38]. Regarding the determination of tannins content, a sharp decrease was observed in the dried cashew apple comparing to the fresh sample (from 0.41 ± 0.07 to 0.16 ± 0.01 g per 100g). It is generally reported that high temperature decreases the tannins content and thereby reduces the astringent taste in cashew apple commonly attributed to it [39] [40]. Furthermore, the reduction in tannins caused by drying will reduce the negative effects on yeast efficiency during fermentation as condensed tannins usually form insoluble compounds with proteins inhibiting microorganism's growth [41].

3.3. Rehydration Capacity of Dried Cashew Apple Slices

In the present study, the dried cashew apples exhibited a satisfactory ratio of rehydration of about 2.10 (**Table 4**). The reference [20] found similar ratio on evaluating the effects of ultrasound and blanching as a pre-treatment on drying cashew apple slices. They stated that this rehydration performance can be explained by the formation of micro-channels which turned into pores on the surface of dried cashew apple. In these conditions, the water penetration into the pores of the dried samples is easier during the rehydration process. It is important to note and generally accepted that the degree of rehydration is dependent on the degree of cellular and structural disruption that occurs during dehydration.

The 10˚B reconstituted apple must present a density of 1.042 g/cm^3 (**Table 5**), which is consistent with that of fresh cashew apple juice already reported in literature [35]. Density analysis of the wine indicated that fermentation was proceeding normally as values are inferior or equal to 1.010 [42]. Also, the recorded transformation rate of more than 80% is an indication of the efficiency of sugar to alcohol conversion. No attempt was made to remove tannins from the cashew apple must before fermentation by any particular clarification procedure. However, the alcohols yield produced after fermentation (8%; v/v) was higher than the average yield of 1.5% reported by [5] with the same material. Generally, for the production of cashew apple wine, the initial sugar content is usually adjusted to or above 20% (w:v) by adding sucrose to obtain a higher final ethanol concentration [19]. For this study, an alternative way of ameliorating the sugar content was thermal concentration. This could justify the better fermentation rate obtained.

3.4. Response Surface Analysis

The search for optimum conditions is aimed at minimizing the practically unavoidable degradation associated with all heat treatments. The responses of the analysis performed are recorded in **Table 6**. The search for optimum conditions is aimed at minimizing the practically unavoidable degradation associated with all heat treatments. The responses of the analysis performed are recorded in **Table 6**. After the deployment of the factorial matrix, the calculation of the coefficients by regression gives the results recorded in **Table 7**.

These results indicate that the coefficient of multiple determinations is 0.9404. The value obtained is higher than 0.85 and thus satisfactory. This is confirmed by the superiority of the Fischer criterion calculated value compared to its critical value in **Table 7** [Fcalc. (15.28690) > Fcritic. (0.00081)]. The coefficients of the model retained as significant are those for which the probabilities are lower than $P < 0.05$.

On the basis of this criterion, the coefficients such as the constant (intercept) *i.e.* a_0 and the coefficients a_1 and a_2 of the variables X_1 and X_2, respectively are retained. The mathematical model is $Y = a_0 + a_1{*}X_1 + a_2{*}X_2$ and by incorporating values $Y = 22.3919 + 4.2576{*}X_1 + 2.6737{*}X_2$. The graphic representation of the point cloud of standardized residuals shows a distribution around the x-axis line ($Y = 0$). This distribution lies within the interval [−1; 1] as illustrated in **Figure 1**.

Table 5. Physicochemical parameters of rehydrated cashew apple musts (10 and 20˚B) and their fermented wines.

	Alcohols (%; v/v)	Density (g/cm^3)	pH	Soluble solid matters (˚Brix)	Transformation rate (%)
10˚B Must	0	1.042 ± 0.00	5.0 ± 0.0	10 ± 0	0
10˚B Wine	4.84 ± 0.00	1.004 ± 0.00	4.43 ± 0.00	4.10 ± 0.00	85.02 ± 0.05
20˚B Must	0	1.082 ± 0.00	5.0 ± 0.00	20 ± 0	0
20˚B Wine	8.00 ± 0.11	1.01 ± 0.00	4.36 ± 0.00	4.80 ± 0.16	87.61 ± 1.00

Table 6. Experimentation values obtained in optimum conditions.

Trials	X_1 (˚C)	X_2 (h)	Y (response)
Factorial trials	58.66	68.78	19.96
	76.34	68.78	23.22
	58.66	111.22	20.42
	76.34	111.22	33.4
Star trials	55.00	90.00	18.82
	80.00	90.00	31.42
	67.50	60.00	18.82
	67.50	120.00	26.42
	67.50	90.00	23.82
Center trials	67.50	90.00	21.42
	67.50	90.00	22.88
	67.50	90.00	21.42
	67.50	90.00	22.42

Table 7. Summary information on regression analysis.

Coefficients	Probability	F calculated (Fcalc.)	Critical value of F (Fcritic.)	Multiple regression (R^2)
a_0	4.3178×10^{-9}	15.2869	0.0008	0.9404
a_1	0.0002			
a_2	0.0038			
a_1^2	0.0753			
a_2^2	0.7773			

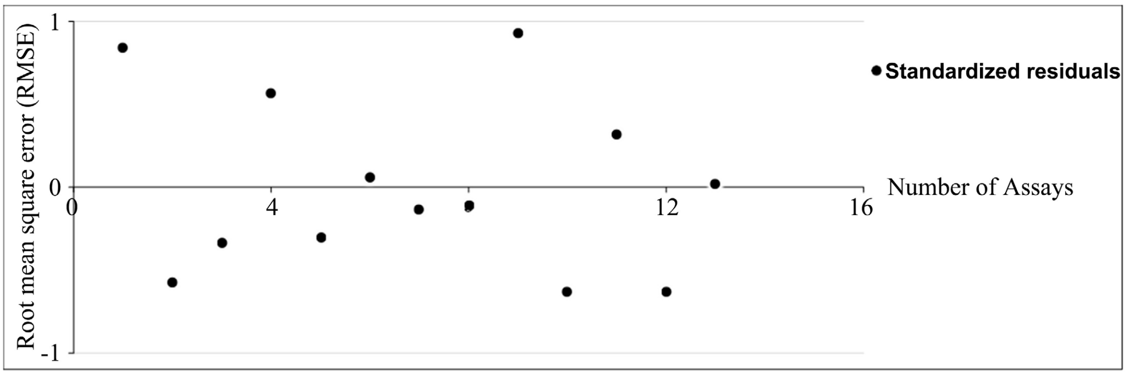


Figure 1. Scatterplot distribution of standardized residuals.

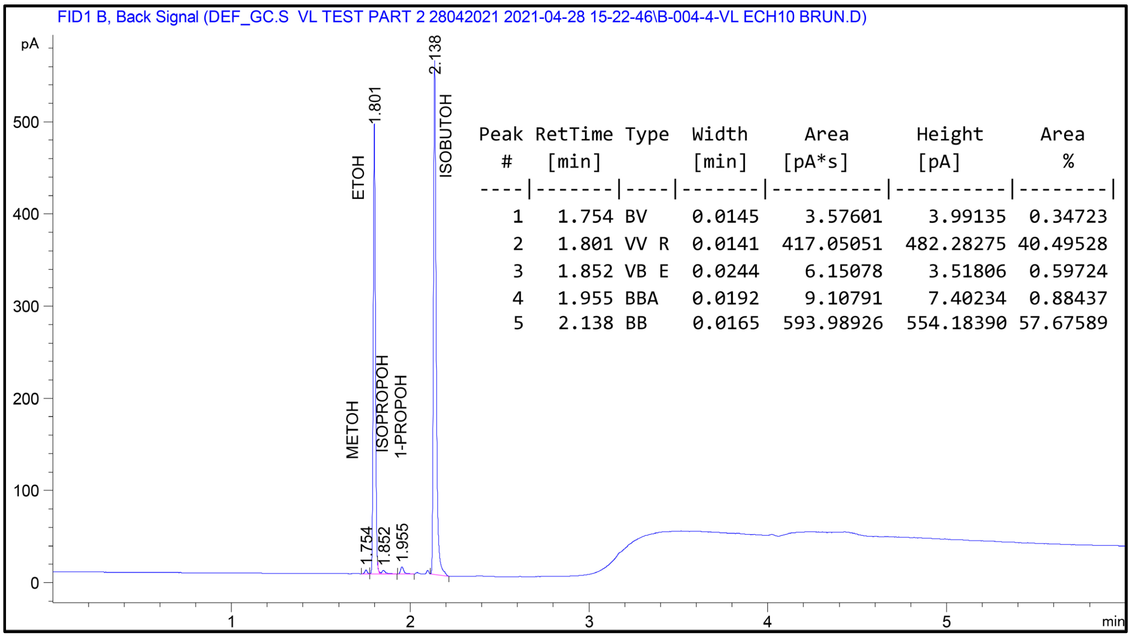
3.5. Optimization

By using the Excel software solver, the values obtained for optimal heating temperature (X_1) and optimal operating time (X_2) are X_1 Opt = 68.239˚C and X_2 Opt = 83.314 min, respectively. The temperature value fell within the range of 62 to

88˚C recommended for acidic juices [29]. However, these values may vary depending on the equipment used by the artisan or manufacturer. For example, in the case of fruit juice production that requires the preservation of the sensory and nutritional qualities of fresh fruit, manufacturers could integrate the monitoring of health-promoting components, such as vitamin C, as an additional element of response, in order to refine the methodology. Juice concentration is a common practice in the industry. Indeed, it responds to economic constraints, related to production, storage and transport costs, and also to a new tendency of industries, to use concentrates to produce drinks and juices. The industrial concentration of fruit juices is usually performed by multistage vacuum evaporation processes, in which the water is removed at high temperatures and the sugar concentration raised because of the process. Indeed, in most industries, the concentration levels of the fruit juices range from 42 to 65˚B [43]. In these conditions, the concentrates are more stable, presenting higher resistance to microbial and chemical deterioration than the natural juice as a result of water activity reduction. Although thermal treatment ensures safety and extends shelf life of the cashew apple juice, it often leads to undesirable changes in sensory qualities. Alternative processing technologies involving non thermal inactivation of microorganisms are being widely investigated. One of the alternative ways of concentration would be to use of osmotic evaporation which has the advantage of being carried out at normal conditions of temperature and atmospheric pressure. However, the techno-economic feasibility of using osmotic evaporation for juice concentrate in fruit juice industry is yet to be evaluated.

The physicochemical properties of concentrated (20˚B) cashew apples juice and the fermented wine made thereof were also summarized in **Table 5**. The cashew apple juice was concentrated to a density of 1.082 g·m^{-3}. So, the total soluble solids decreased from 20˚B in the must to 4.80 ± 0.16˚B in the fermented wine. The residual sugar observed at the end of the process indicates that the yeast has efficiently utilized the major proportion of fermentable sugars contained in the must. The heat treatment on cashew apple juice for syrup production may have acted to release more simpler sugars [44], hence making them available for *Saccharomyces cerevisiae* growth. The extent of the conversion of sugar into alcohols was evidenced by the high rate of transformation recorded (**Table 5**). The alcohol content of the cashew wine which has reached 8% ± 0.11% is in the order of the value reported [16]. These authors produced wine with 7% alcohols from dried cashew apple by increasing by 20˚B the initial must with sucrose. Indeed, 20˚B is generally the recommended initial sugar content to expect a final ethanol concentration between 5% and 12% [19].

The chromatographic profiles and quantities of alcohols obtained after fermentation are depicted in **Figure 2** and in **Table 8**. The methanol content was in the order of the tolerated levels for wines, *i.e.* 0.02%. As for the ethanol content (3.92%), it seems to be relatively lower compared to that of isobutanol (4.05%), which is however a minor by-product of alcoholic fermentation. These results



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Peak RetTime Type  Width     Area      Height     Area
  #   [min]        [min]   [pA*s]      [pA]        %
----|-------|----|-------|----------|----------|--------|
   1   1.754 BV    0.0145    3.57601    3.99135  0.34723
   2   1.801 VV R  0.0141  417.05051  482.28275 40.49528
   3   1.852 VB E  0.0244    6.15078    3.51806  0.59724
   4   1.955 BBA   0.0192    9.10791    7.40234  0.88437
   5   2.138 BB    0.0165  593.98926  554.18390 57.67589
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Figure 2. Chromatographic (GC/FID) profiles of bioalcohols produced during batch fermentation of 20˚B cashew apple syrup using *Saccharomyces cerevisiae* as fermentation strain.

Table 8. Quantification of the different alcohols obtained in the concentrated cashew apple wine analyzed by GC/FID.

Alcohols	% (v/v)
1-Methanol	0.0152
2-Ethanol	3.92
3-Isopropanol	0.0001
4-Propanol	0.0168
5-Isobutanol	4.048

are very surprising in the sense that naturally, during the alcoholic fermentation processes implemented to date, this higher alcohol (isobutanol) is produced in small quantities of about 0.02%. Historically, researchers have even sought to reduce its production in yeast in favor of ethanol, because it can alter the flavor of wine or beer. However, in the context of the search for new renewable fuels to replace gasoline, higher alcohols such as isobutanol are promising candidates [45]. Indeed, at equal volume, isobutanol contains 82% of calorific energy compared to gasoline, and against 67% for ethanol. Ethanol also tends to absorb water, corrode pipelines and damage engines while isobutanol has the advantage of not mixing easily with water. This higher alcohol could therefore be a potential replacement for ethanol. So far, only genetically engineered organisms have been reported to produce a maximum of 5% of isobutanol. As the yeast *Saccharomyces cerevisiae* is concerned, extremely low concentrations of isobutanol production were reported to date [46]. This study opens up new prospects for the twin production of isobutanol and ethanol from local bioresources.

4. Conclusion

This study was initiated to investigate an effective low-cost production of bioethanol by the use of rejected cashew apples in Ivorian plantations. Almost 82% weight loss was recorded with 20% moisture, which was the maximum permissible rate for dried fruits for a shelf-stable product. Indeed, drying reduced the weight and volume of the products, which would minimize transportation costs and subsequently impact on the final cost of raw materials. The dried slices were successfully rehydrated into a 10˚B juice with 1.042 g/cm^3 density. A 20˚B mush with a density of 1.082 g/cm^3 concentrate was achieved by thermal evaporation, which should make them as competitive as molasses in terms of initial sugar concentration for alcoholic fermentation. Characterization of the wine produced from the dried cashew apple-based concentrate showed an efficient rate of fermentation confirmed by the low residual sugar content. A significant amount of two alcohols (Isobutanol and Ethanol) was produced as expected. In view of the aforementioned results, it can be assumed that this sizeable quantity of cashew apple can be explored as a useful bio-resource for the twin alcohol production. Thus, promoting dried cashew apple-based products would allow creating awareness and confidence among farmers regarding cashew apple processing for better economic returns. For further studies, we are considering osmotic dehydration, a pre-drying treatment, to minimize adverse changes that occur during drying. Generally, sugar solutions such as sucrose or glucose are used for fruits, but the novelty of this process is to use agricultural waste as an osmotic agent to avoid adding to production costs.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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