

Research Article

Open-Pan Evapoconcentration Kinetics and Physicochemical Characteristics of Oil Palm Wine Syrups

**Eliane Therese Biassala¹, Bob Wilfrid Loumouamou^{1, 2, *} ,
Anicet Frederic Binaki¹ , Hubert Makomo³ , Sarah Theresia Blanche Mbaka¹ ,
Jean Mathurin Nzikou² , Thomas Silou¹ **

¹Laboratory of Food Chemistry and Technology & Faculty of Science and Technology, Marien Ngouabi University, Brazzaville, Republic of the Congo

²Process Engineering Laboratory & National Advanced School of Engineering, Marien Ngouabi University, Brazzaville, Republic of the Congo

³Laboratory of Organic and Analytical Chemistry of Bioactive Substances & Faculty of Science and Technology, Marien Ngouabi University, Brazzaville, Republic of the Congo

Abstract

Oil palm wine is highly perishable, and conversion into syrup offers a technically accessible route for local value addition. This study described open-pan evapoconcentration profiles and the immediate physicochemical quality of syrups prepared from four identified batches of oil palm wine. For each batch, 2 L of wine were heated at a nominal hotplate setpoint of 80 °C under regular manual stirring. Apparent total soluble solids were measured every 20 min, and five nonlinear equations were compared using the root mean square error, coefficient of determination, corrected Akaike information criterion, and physical admissibility of the fitted parameters. The syrups were characterized for pH, titratable acidity, moisture, dry matter, and water activity immediately after processing. Apparent soluble solids increased from 6.97-10.00 °Brix to 74.25-87.77 °Brix within 200-260 min, corresponding to concentration factors of 8.18-10.65. Apparent syrup recovery ranged from 6.83 to 11.24 g per 100 mL of feed. A simplified evaporation-balance equation best represented batches S1 and S4, whereas a power-law equation described S2 and S3; the selected fits gave R^2 values of 0.9713-0.9944 and root mean square errors of 1.434-2.976 °Brix. Final pH ranged from 3.92 to 4.08 and titratable acidity from 0.36 to 0.91 g acetic acid equivalents per 100 g. Water activity separated the products into two lower-moisture syrups (0.472-0.482) and two higher-moisture syrups (0.660-0.704). The results establish the feasibility of producing highly concentrated oil palm wine syrup and identify simple nonlinear equations that can support endpoint control. Replicated runs with direct product-temperature measurement and standardized evaporation geometry are required for process optimization.

Keywords

Elaeis Guineensis, Palm Wine, Open-Pan Evaporation, Nonlinear Modeling, Soluble Solids, Water Activity, Palm Syrup

*Correspondence: Bob Wilfrid Loumouamou (bwlumwahamu@gmail.com)

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1. Introduction

Palm sap is a sugar-rich plant exudate that is valued as a fresh beverage and as the raw material for fermented drinks, sugars, and syrups. Its composition depends on palm species, tapping practice, climate, and post-collection handling. Once collected, the sap is microbiologically unstable because its sugars support rapid development of yeasts, lactic acid bacteria, and acetic acid bacteria [1, 2]. In oil palm wine from *Elaeis guineensis*, these microbial groups act concurrently, consuming fermentable sugars and producing ethanol and organic acids [3, 4]. Metagenomic and metabolomic studies further show that oil palm wine contains a complex, changing ecosystem dominated by *Saccharomyces*, lactic acid bacteria, and acetic acid bacteria, with corresponding shifts in organic acids, sugars, and other metabolites [5, 6]. Refrigeration can slow this evolution but does not eliminate the inherent variability of a living fermented matrix [1, 2].

Concentration into syrup offers a practical means of reducing bulk, increasing soluble solids, and extending the range of products derived from palm sap and palm wine. Palm sugar syrups are commonly produced by atmospheric open-pan evaporation because the equipment is simple and locally accessible [7, 8]. More controlled operations, including ultrafiltration and vacuum evaporation, can reduce thermal load or modify syrup clarity, rheology, and composition [9]. Across nipa, palmyra, and date palm materials, both raw-material history and evaporation conditions influence final pH, moisture, water activity, color, viscosity, sugar profile, and antioxidant properties [10-13]. Open-pan processing is therefore not merely water removal: it concentrates acids and nonvolatile solids while promoting sucrose inversion, nonenzymatic browning, and heat-derived chemical changes [8, 13-15].

A central processing difficulty is endpoint control. As evaporation proceeds, the mass of residual water decreases and the apparent soluble-solids trajectory becomes increasingly curved. An endpoint judged only from color and viscosity may consequently be reached abruptly, increasing the risk of under-concentration, excessive heating, or local scorching. Kinetic equations can summarize this evolution and provide operational coefficients for process comparison. In complex foods, however, empirical parameters should not be interpreted automatically as elementary reaction-rate constants; model selection must combine goodness of fit, information criteria, and physical plausibility [16]. Akaike's information criterion and its small-sample correction are particularly useful when several equations with different numbers of parameters are fitted to short experimental series [17-19].

Published work on palm syrups has mainly addressed non-fermented sap or date extracts. Far less is known about atmospheric concentration of oil palm wine after collection and refrigerated holding, especially in Central Africa. The present study therefore aimed to (i) describe the open-pan evapoconcentration trajectories of four identified oil palm wine batches, (ii) select physically admissible nonlinear equations for the

soluble-solids profiles, and (iii) characterize the physicochemical state of the resulting syrups immediately after production. The work was designed as a descriptive process study: each batch was concentrated once, so observed differences are interpreted as batch-level process responses rather than as causal effects of refrigerated holding time.

2. Manuscript Formatting

2.1. Raw Material and Study Design

Oil palm wine was obtained from *Elaeis guineensis* Jacq. in Linzolo, Pool Department, Republic of the Congo. The wine was transported to Brazzaville in an insulated container at approximately 10 °C. Four identified batches were held under refrigeration and processed after 1, 2, 3, or 4 days; these batches are designated S1, S2, S3, and S4, respectively. Each batch was subjected to one production run. Because batch identity and refrigerated holding time were not independently replicated, the experimental unit was the individual batch and the analysis was descriptive.

2.2. Open-Pan Evapoconcentration

For each run, 2000 mL of oil palm wine were transferred to an open vessel and heated on a hotplate set to a nominal 80 °C. The product was stirred manually and regularly with a wooden spatula throughout concentration. Apparent total soluble solids (TSS) were measured every 20 min with an SGW-733 digital refractometer. Highly viscous samples were subjected to controlled dilution before measurement. Heating was stopped when the product had developed a russet-brown color and a viscous to semi-solid consistency, before perceptible scorching. The hotplate setpoint was recorded, but the product temperature was not monitored continuously.

The concentration factor was calculated as final apparent TSS divided by initial apparent TSS. Because the starting material was measured volumetrically rather than gravimetrically, product recovery was expressed on a volume-of-feed basis as grams of syrup per 100 mL of initial wine:

$$\text{Apparent recovery} = (m_{\text{syrup}} / V_{\text{feed}}) \times 100 \quad (1)$$

2.3. Physicochemical Analyses

Physicochemical measurements were performed immediately after syrup production. The pH was measured with a calibrated VWR pH 1100 L meter. Titratable acidity was determined by titration with 0.1 mol L⁻¹ sodium hydroxide and expressed as grams of acetic acid equivalents per 100 g. Moisture was determined by oven drying at 105 °C to constant mass,

and dry matter was obtained by difference, following the principles of the Official Methods of Analysis of AOAC International [20]. Water activity (a_w) was measured after equilibration with a HygroLab instrument according to the measurement principle described in ISO 18787:2017 [21].

2.4. Nonlinear Modeling and Model Selection

Five equations were fitted separately to the apparent TSS trajectory of each batch. In Equations (2)–(6), $B(t)$ is apparent TSS at time t , B_0 is the measured initial value, B_∞ is an empirical asymptote, and k , n , k_1 , k_2 , a , and b are fitted coefficients.

$$B(t) = B_0 / (1 - kt) \quad (2)$$

$$B(t) = B_0 + (B_\infty - B_0)[1 - \exp(-(kt)^n)] \quad (3)$$

$$B(t) = B_0 + t / (k_1 + k_2t) \quad (4)$$

$$B(t) = B_0 + at^b \quad (5)$$

$$B(t) = B_0 + at + bt^2 \quad (6)$$

Parameters were estimated by nonlinear least squares in Python. Model performance was assessed using the root mean square error (RMSE), coefficient of determination (R^2), and corrected Akaike information criterion (AICc) [17–19]. A candidate was retained only when it combined a low AICc and RMSE, a high R^2 , and physically admissible parameters over

the observed time range. Peleg-type solutions that produced a negative k_2 and a singularity close to the experimental domain were rejected despite favorable numerical fit. The selected coefficients are process descriptors and were not interpreted as elementary chemical reaction constants.

2.5. Data Analysis

All time-series observations were retained for primary modeling. Results are presented by batch without inferential comparison because there was one independent production run per batch. Analytical values in the physicochemical table describe the corresponding product and were not treated as independent process replicates.

3. Results

3.1. Evapoconcentration Profiles and Processing Outcomes

All four batches exhibited a prolonged region of gradual concentration followed by a steep increase in apparent TSS near the endpoint (Figure 1). Initial values ranged from 6.97 to 10.00 °Brix and final values from 74.25 to 87.77 °Brix. Batch S2 reached 87.77 °Brix after 200 min, whereas S1, S3, and S4 reached their endpoints after 220, 240, and 260 min, respectively. Small early fluctuations were observed in S3 and S4 before sustained increases became evident.

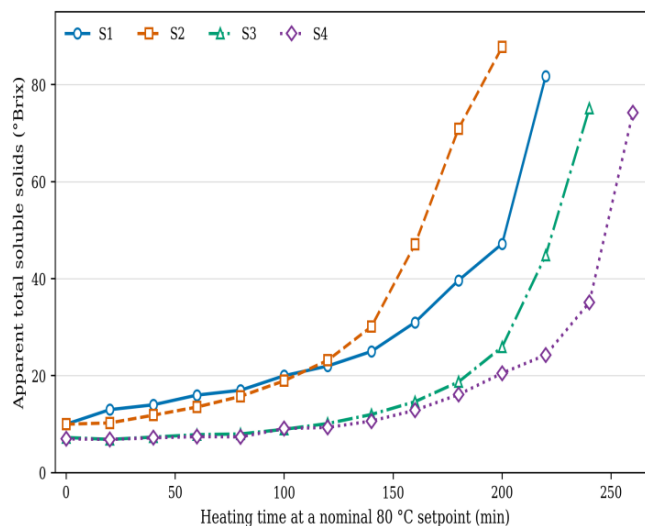


Figure 1. Evolution of apparent total soluble solids during open-pan evapoconcentration of four oil palm wine batches under regular manual stirring.

The concentration factor varied from 8.18 for S1 to 10.65 for S4 (Table 1). Final syrup mass ranged from 136.55 to 224.79 g, corresponding to an apparent recovery of 6.83–11.24

g per 100 mL of starting wine. These recovery values reflect the recovered product mass after repeated sampling and transfer of a highly viscous material.

Table 1. Batch description and technological outcomes of open-pan evapoconcentration.

Batch	Holding time (d)	Initial (°Brix)	Final (°Brix)	Process time (min)	Concentration factor	Syrup mass (g)	Apparent recovery (g 100 mL ⁻¹)	Concentration factor
S1	1	10.00	81.80	220	8.18	136.55	6.83	8.18
S2	2	10.00	87.77	200	8.78	170.67	8.53	8.78
S3	3	7.26	75.11	240	10.35	145.22	7.26	10.35
S4	4	6.97	74.26	260	10.65	224.79	11.24	10.65

Holding time identifies the refrigerated interval assigned to each batch; it was not an independently replicated treatment. Apparent recovery is expressed per 100 mL of feed.

3.2. Selected Nonlinear Models

The simplified evaporation-balance equation was selected for S1 and S4, whereas the power-law equation was selected

for S2 and S3 (Figure 2 and Table 2). The selected models yielded R^2 values of 0.9713-0.9944 and RMSE values of 1.434-2.976 °Brix. The strongest numerical fit was obtained for S3 with the power law ($R^2 = 0.9944$; RMSE = 1.434 °Brix; AICc = 14.56). Power-law exponents were 3.37 for S2 and 6.38 for S3, consistent with the particularly steep terminal curvature of these profiles.

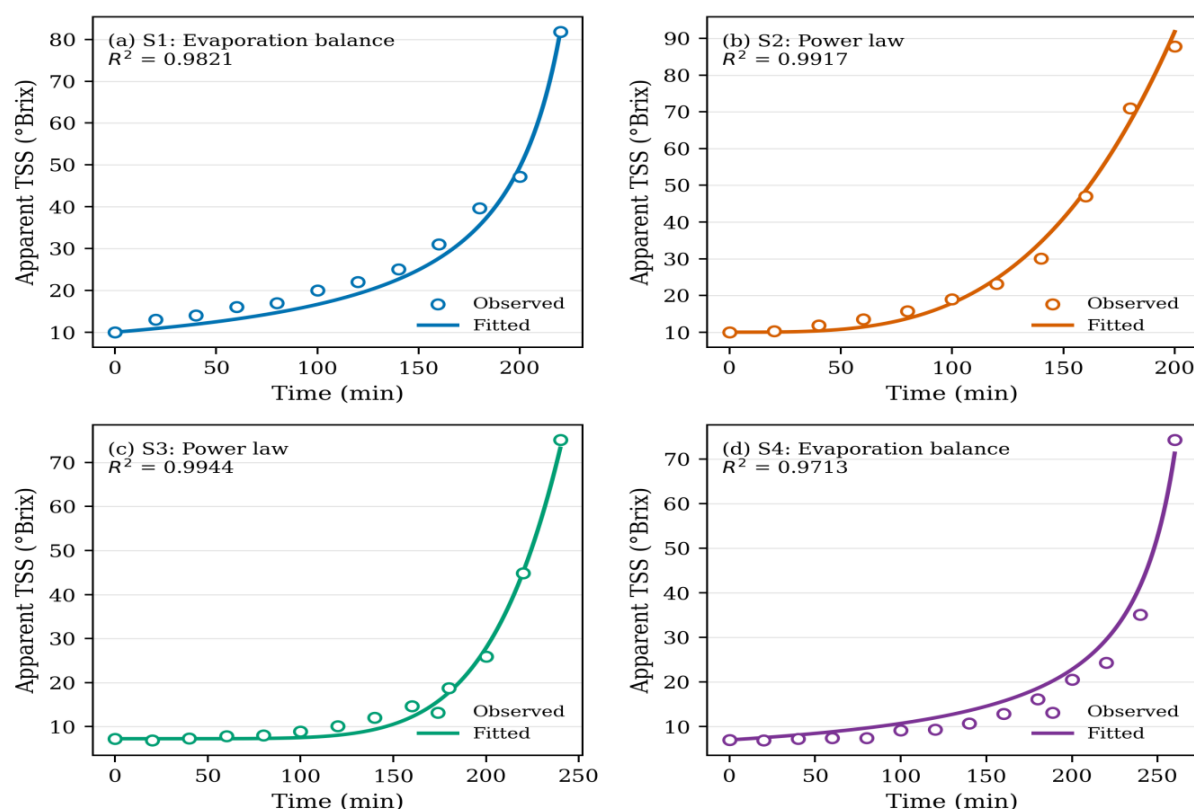


Figure 2. Observed apparent soluble solids and selected physically admissible nonlinear models for batches S1-S4. Panels (a) and (d) show the simplified evaporation-balance equation; panels (b) and (c) show the power-law equation.

Table 2. Selected nonlinear models, fitted coefficients, and performance statistics.

Batch	Selected model	Fitted coefficients	RMSE (°Brix)	R ²	AICc
S1	Simplified evaporation balance	$k = 0.00399 \text{ min}^{-1}$	2.598	0.9821	25.31
S2	Power law	$a = 1.44 \times 10^{-6}$; $b = 3.37$	2.307	0.9917	23.89
S3	Power law	$a = 4.30 \times 10^{-14}$; $b = 6.38$	1.434	0.9944	14.56
S4	Simplified evaporation balance	$k = 0.00347 \text{ min}^{-1}$	2.976	0.9713	32.87

AICc: corrected Akaike information criterion; RMSE: root mean square error. Coefficients are apparent process parameters for the equations defined in Section 2.4.

3.3. Immediate Physicochemical Characteristics

The syrups were acidic, with pH values from 3.92 to 4.08 and titratable acidity from 0.36 to 0.91 g acetic acid equivalents per 100 g (Table 3). S1 and S2 contained 22.46-23.74%

moisture and had water activities of 0.472-0.482. S3 and S4 contained 33.87-36.34% moisture and had higher water activities of 0.660-0.704. Thus, the products separated into two lower-moisture, lower- a_w syrups and two higher-moisture, higher- a_w syrups.

Table 3. Physicochemical characteristics of oil palm wine syrups immediately after production.

Batch	Apparent TSS (°Brix)	pH	Titratable acidity (g 100 g ⁻¹)	Moisture (%)	Dry matter (%)	Water activity (a_w)
S1	81.80	4.08	0.49	23.74	76.26	0.482
S2	87.76	3.93	0.36	22.46	77.54	0.472
S3	75.11	3.92	0.82	36.34	63.66	0.704
S4	74.25	3.95	0.91	33.87	66.13	0.660

Titratable acidity is expressed as acetic acid equivalents. Values describe individual syrup batches and are not independent process replicates.

4. Discussion

4.1. Concentration Behavior and Kinetic Description

The four trajectories reveal the characteristic acceleration expected when a progressively smaller water mass carries a nearly conserved pool of dissolved solids. During the early phase, a given amount of evaporated water causes only a modest increase in apparent TSS. Near the endpoint, the same water loss produces a much larger increase because the denominator of the concentration ratio has become small. This behavior explains both the long low-slope region and the abrupt terminal rise. It also shows why visual endpoint control becomes increasingly sensitive late in open-pan processing. Similar

open-pan production of nipa syrup required heating to approximately 70 °Brix, and palm and date syrup studies report substantial changes in viscosity and soluble solids as water removal approaches the final stage [10-14].

The simplified evaporation-balance equation provided an economical description of S1 and S4. Its denominator, $1 - kt$, represents the progressive loss of the liquid fraction under an apparent near-linear evaporation assumption; k therefore summarizes the combined effects of heat transfer, exposed area, mixing, and changing composition. The power law was more suitable for S2 and S3, whose terminal acceleration was stronger than the simple balance could capture. Exponents greater than one quantify curvature, but they are not chemical reaction orders. This distinction is important because viscosity, boiling-point elevation, heat-transfer resistance, and sampling all change simultaneously during concentration [16].

Model acceptance depended on physical admissibility as well as numerical fit. A negative Peleg coefficient can place a denominator zero close to the observed domain and generate an artificial divergence. Rejecting such a solution prevents a statistically attractive but operationally impossible curve from being

used for extrapolation. The combined use of RMSE, R^2 , and AICc is therefore preferable to selecting a model from R^2 alone, particularly for the short series studied here [17-19]. For practical endpoint control, the selected equations can be recalibrated in future replicated trials and used to trigger more frequent measurements once the predicted terminal acceleration begins.

The shorter processing time and higher final apparent TSS of S2 cannot be attributed solely to its two-day refrigerated holding interval. Initial soluble solids, vessel conditions, evaporation area, manual agitation, and the evolving composition of each batch can all influence concentration rate. Palm wine studies demonstrate that sugar conversion, acidification, and microbial community structure vary during tapping and storage [3-6]. Accordingly, the present trajectories are most appropriately interpreted as individual batch responses.

4.2. Physicochemical Quality of the Syrups

The final pH range of 3.92-4.08 confirms that the concentrated products retained the acidic character of fermented oil palm wine. Previous studies of oil palm wine have documented simultaneous alcoholic, lactic, and acetic fermentation and a decline in pH as sugars are metabolized [3-6]. Concentrating such a matrix increases nonvolatile acid and solids concentrations, while the extent of volatile-acid loss depends on the open-pan conditions. The higher titratable acidity of S3 and S4 is consistent with batch-to-batch variation in the chemical history of the wine, but the unreplicated design does not support a storage-time effect.

Moisture content and water activity provided complementary evidence of endpoint differences. S1 and S2 combined approximately 23% moisture with a_w below 0.50, whereas S3 and S4 retained more moisture and had a_w values of 0.660-0.704. Water activity, rather than total moisture alone, governs the thermodynamic availability of water and depends on the concentration and identity of dissolved components [22]. The close ranking of moisture and a_w in this study indicates that water removal was the dominant separator of the products, although their different sugar, acid, and residual fermentation-metabolite profiles may also have contributed.

The very low a_w of S1 and S2 would be strongly restrictive to microbial growth. Nevertheless, a_w is not a lethality measurement, and high-sugar foods can be spoiled by specialized osmophilic yeasts. Experimental work has shown that some *Zygosaccharomyces rouxii* strains can grow at an a_w as low as 0.67 depending on the controlling solute and culture conditions [23]. This benchmark places S3 near a zone in which osmophilic spoilage remains plausible and S4 close to the reported lower boundary, whereas S1 and S2 are substantially below it. Commercial stability would still require hygienic packaging, microbial challenge or storage testing, and confirmation that a_w remains uniform throughout the product.

Apparent Brix and gravimetric dry matter did not coincide, particularly for S1 and S2. This is analytically plausible be-

cause a refractometer reports a sucrose-equivalent concentration from refractive index, whereas dry matter measures all nonvolatile residue. Organic acids, residual ethanol and other fermentation products, as well as dilution of highly viscous samples, can therefore affect apparent Brix. For process control, refractometry remains rapid and useful, but batch calibration against gravimetric solids is advisable before defining a commercial endpoint.

4.3. Thermal Chemistry and Process Development

The russet-brown endpoint is consistent with nonenzymatic browning in an acidic, sugar-rich matrix. Studies of palm and date syrups show that open heating modifies color, reducing sugars, Maillard reaction products, and 5-hydroxymethylfurfural (HMF) more strongly as temperature and residence time increase [8, 13-15]. HMF can arise through acid-catalyzed dehydration of hexoses, especially fructose, and is widely used as an indicator of thermal history in carbohydrate-rich foods [24, 25]. Because the present dataset does not contain a validated quantitative HMF series, product ranking should rely on the reported physicochemical measurements. Future process optimization should pair TSS kinetics with validated HMF, color, individual-sugar, and rheological measurements.

The main technological contribution of this work is the integration of complete concentration trajectories with physically screened nonlinear models and immediate product characterization for a Central African oil palm wine. Its interpretation is bounded by one run per batch, the absence of continuous product-temperature measurement, and unstandardized manual agitation and evaporation geometry. Replicated experiments should therefore control vessel surface area, heating power, agitation, and actual product temperature; establish a complete mass balance; and assess microbiological stability after packaging. Those additions would allow the effects of raw-wine history and process conditions to be separated and a reproducible endpoint specification to be developed.

5. Conclusions

Open-pan heating at a nominal 80 °C hotplate setpoint converted four oil palm wine batches into syrups with 74.25-87.77 Brix in 200-260 min. The concentration trajectories accelerated markedly near the endpoint. A simplified evaporation-balance equation described two batches, while a power-law equation described the other two after physically inadmissible solutions were excluded. The syrups differed most clearly in moisture and water activity: two products reached a_w below 0.50, whereas the other two remained at 0.660-0.704. These results demonstrate the technological feasibility of oil palm wine syrup and provide a quantitative basis for improved endpoint monitoring. Direct temperature measurement, replicated processing, standardized agitation and evaporation geometry, validated thermal-marker analysis, and packaged-

product stability testing are the next steps toward process optimization and commercial specification.

Abbreviations

AICc	Corrected Akaike Information Criterion
a_w	Water Activity
HMF	5-Hydroxymethylfurfural
RMSE	Root Mean Square Error
TSS	Total Soluble Solids

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Author Contributions

Eliane Therese Biassala: Data curation, Investigation, Methodology, Writing – original draft

Bob Wilfrid Loumouamou: Conceptualization, Formal

Analysis, Software, Supervision, Visualization, Writing – review & editing

Anicet Frederic Binaki: Validation, Writing – review & editing

Hubert Makomo: Supervision, Validation, Writing – review & editing

Sarah Theresia Blanche Mbaka: Investigation, Resources, Writing – review & editing

Jean Mathurin Nzikou: Conceptualization, Supervision, Validation, Writing – review & editing

Thomas Silou: Conceptualization, Supervision, Validation, Writing – review & editing

Data Availability Statement

All observations used in the primary analyses are reported in [Table A1](#). Structured data and analysis code are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

[Table A1](#) reports every apparent soluble-solids observation used for the nonlinear fits.

Table A1. Raw apparent soluble-solids time series used in the primary analyses.

Time (min)	S1 (°Brix)	S2 (°Brix)	S3 (°Brix)	S4 (°Brix)
0	10	10	7.26	6.97
20	13	10.26	6.87	6.86
40	14	11.86	7.34	7.19
60	16	13.54	7.85	7.43
80	17	15.74	7.99	7.38
100	20	18.95	8.94	9.1
120	22	23.18	10.14	9.33
140	25	30.1	12	10.65
160	31	47.06	14.64	12.87
180	39.67	70.94	18.72	16.11
200	47.2	87.77	25.93	20.52
220	81.8	-	44.82	24.28
240	-	-	75.11	35.1
260	-	-	-	74.26

A dash indicates that the batch had already reached its processing endpoint.

References

- [1] Hebbar, K. B., Pandiselvam, R., Manikantan, M. R., Arivalagan, M., Beegum, S., Chowdappa, P. Palm Sap-Quality Profiles, Fermentation Chemistry, and Preservation Methods. *Sugar Tech.* 2018, 20(6), 621-634. <https://doi.org/10.1007/s12355-018-0597-z>
- [2] Hai, A., Rambabu, K., Al Dhaheri, A. S., Kurup, S. S., Banat, F. Tapping into Palm Sap: Insights into Extraction Practices, Quality Profiles, Fermentation Chemistry, and Preservation Techniques. *Heliyon.* 2024, 10(15), e35611. <https://doi.org/10.1016/j.heliyon.2024.e35611>
- [3] Amoa-Awua, W. K., Sampson, E., Tano-Debrah, K. Growth of Yeasts, Lactic and Acetic Acid Bacteria in Palm Wine During Tapping and Fermentation from Felled Oil Palm (*Elaeis guineensis*) in Ghana. *Journal of Applied Microbiology.* 2007, 102(2), 599-606. <https://doi.org/10.1111/j.1365-2672.2006.03074.x>
- [4] Karamoko, D., Djeni, N. T., N'Guessan, K. F., Bouatenin, K. M. J.-P., Djè K. M. The Biochemical and Microbiological Quality of Palm Wine Samples Produced at Different Periods During Tapping and Changes Which Occurred During Their Storage. *Food Control.* 2012, 26(2), 504-511. <https://doi.org/10.1016/j.foodcont.2012.02.018>
- [5] Djeni, T. N., Kouame, K. H., Ake, F. D. M., Amoikon, L. S. T., Dje, M. K., Jeyaram, K., et al. Microbial Diversity and Metabolite Profiles of Palm Wine Produced from Three Different Palm Tree Species in Côte d'Ivoire. *Scientific Reports.* 2020, 10, 1715. <https://doi.org/10.1038/s41598-020-58587-2>
- [6] Djeni, T. N., Keisam, S., Kouame, K. H., Assohoun-Djeni, C. N., Ake, F. D. M., Amoikon, L. S. T., et al. Dynamics of Microbial Populations and Metabolites of Fermenting Saps Throughout Tapping Process of Ron and Oil Palm Trees in Côte d'Ivoire. *Frontiers in Microbiology.* 2022, 13, 954917. <https://doi.org/10.3389/fmicb.2022.954917>
- [7] Saputro, A. D., Van de Walle, D., Dewettinck, K. Palm Sap Sugar: A Review. *Sugar Tech.* 2019, 21(6), 862-867. <https://doi.org/10.1007/s12355-019-00743-8>
- [8] Naknean, P., Meenune, M. Impact of Clarification of Palm Sap and Processing Method on the Quality of Palm Sugar Syrup (*Borassus flabellifer* Linn.). *Sugar Tech.* 2015, 17(2), 195-203. <https://doi.org/10.1007/s12355-014-0308-3>
- [9] Makhoulf-Gafsi, I., Baklouti, S., Mokni, A., Danthine, S., Attia, H., Blecker, C., Besbes, S., Masmoudi, M. Effect of Ultrafiltration Process on Physico-Chemical, Rheological, Microstructure and Thermal Properties of Syrups from Male and Female Date Palm Saps. *Food Chemistry.* 2016, 203, 175-182. <https://doi.org/10.1016/j.foodchem.2016.02.055>
- [10] Phetrit, R., Chaijan, M., Sorapukdee, S., Panpipat, W. Characterization of Nipa Palm's (*Nypa fruticans* Wurmb.) Sap and Syrup as Functional Food Ingredients. *Sugar Tech.* 2020, 22(1), 191-201. <https://doi.org/10.1007/s12355-019-00756-3>
- [11] Saengkrajang, W., Chaijan, M., Panpipat, W. Physicochemical Properties and Nutritional Compositions of Nipa Palm (*Nypa fruticans* Wurmb.) Syrup. *NFS Journal.* 2021, 23, 58-65. <https://doi.org/10.1016/j.nfs.2021.04.004>
- [12] Le, D. H. T., Chiu, C.-S., Chan, Y.-J., Wang, C.-C. R., Liang, Z.-C., Hsieh, C.-W., Lu, W.-C., Mulio, A. T., Wang, Y.-J., Li, P.-H. Bioactive and Physicochemical Characteristics of Natural Food: Palmyra Palm (*Borassus flabellifer* Linn.) Syrup. *Biology.* 2021, 10(10), 1028. <https://doi.org/10.3390/biology10101028>
- [13] Julai, K., Sridonpai, P., Ngampeerapong, C., Tongdonpo, P., Suttisansanee, U., Kriengsinyos, W., On-Nom, N., Tangsuphoom, N. Effects of Extraction and Evaporation Methods on Physico-Chemical, Functional, and Nutritional Properties of Syrups from Barhi Dates (*Phoenix dactylifera* L.). *Foods.* 2023, 12(6), 1268. <https://doi.org/10.3390/foods12061268>
- [14] Naknean, P., Meenune, M., Roudaut, G. Changes in Properties of Palm Sugar Syrup Produced by an Open Pan and a Vacuum Evaporator During Storage. *International Food Research Journal.* 2013, 20(5), 2323-2334.
- [15] Makhoulf-Gafsi, I., Krichen, F., Ben Mansour, R., Mokni, A., Sila, A., Bougatef, A., Blecker, C., Attia, H., Besbes, S. Ultrafiltration and Thermal Processing Effects on Maillard Reaction Products and Biological Properties of Date Palm Sap Syrups (*Phoenix dactylifera* L.). *Food Chemistry.* 2018, 256, 397-404. <https://doi.org/10.1016/j.foodchem.2018.02.145>
- [16] Van Boekel, M. A. J. S. Kinetic Modeling of Food Quality: A Critical Review. *Comprehensive Reviews in Food Science and Food Safety.* 2008, 7(1), 144-158. <https://doi.org/10.1111/j.1541-4337.2007.00036.x>
- [17] Akaike, H. A New Look at the Statistical Model Identification. *IEEE Transactions on Automatic Control.* 1974, 19(6), 716-723. <https://doi.org/10.1109/TAC.1974.1100705>
- [18] Hurvich, C. M., Tsai, C.-L. Regression and Time Series Model Selection in Small Samples. *Biometrika.* 1989, 76(2), 297-307. <https://doi.org/10.1093/biomet/76.2.297>
- [19] Burnham, K. P., Anderson, D. R. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. 2nd ed. New York, NY: Springer; 2002.
- [20] AOAC International. Official Methods of Analysis of AOAC International. 21st ed. Rockville, MD: AOAC International; 2019.
- [21] International Organization for Standardization. Foodstuffs-Determination of Water Activity (ISO 18787:2017). Geneva, Switzerland: ISO; 2017.
- [22] Barbosa-Cánovas, G. V., Fontana, A. J., Schmidt, S. J., Labuza, T. P., Eds. Water Activity in Foods: Fundamentals and Applications. Ames, IA: Blackwell Publishing; 2007.
- [23] Tokuoka, K., Ishitani, T. Minimum Water Activities for the Growth of Yeasts Isolated from High-Sugar Foods. *Journal of General and Applied Microbiology.* 1991, 37(1), 111-119. <https://doi.org/10.2323/jgam.37.111>

- [24] Capuano, E., Fogliano, V. Acrylamide and 5-Hydroxymethylfurfural (HMF): A Review on Metabolism, Toxicity, Occurrence in Food and Mitigation Strategies. *LWT-Food Science and Technology*. 2011, 44(4), 793-810. <https://doi.org/10.1016/j.lwt.2010.11.002>
- [25] Antal, M. J., Jr., Mok, W. S. L., Richards, G. N. Mechanism of Formation of 5-(Hydroxymethyl)-2-Furaldehyde from D-Fructose and Sucrose. *Carbohydrate Research*. 1990, 199(1), 91-109. [https://doi.org/10.1016/0008-6215\(90\)84096-D](https://doi.org/10.1016/0008-6215(90)84096-D)

Biography



Eliane Therese Biassala is an Assistant Professor accredited by the African and Malagasy Council for Higher Education (CAMES) at the Faculty of Science and Technology, Marien Ngouabi University, Brazzaville, Republic of the Congo. She holds a PhD in Food Chemistry and Technology from the same university. She is a member of the Multi-disciplinary Food and Nutrition Research Team within the Regional Center of Excellence in Food and Nutrition and is also affiliated with the National Institute for Research in Exact and Natural Sciences. Her research interests include food chemistry and technology, food formulation, physicochemical and nutritional characterization of plant resources, analytical chemistry, extraction of bioactive compounds, and the valorization of indigenous agricultural products. Dr. Biassala has authored and co-authored several scientific publications on fruit and vegetable products, oilseeds, essential oils, food preservation, composite flours, and the development of value-added foods from plant resources available in the Republic of the Congo.