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Modelling of Local Processes for Preserving Safou Pulp (*Dacryodes Edulis* (G. Dom) H. J. Lam) in Brazzaville, Congo

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Abstract

Safou is a fruit rich in fat, whose traditional processing methods suffer from a lack of scientific data. Modelling of the kinetics of its sun drying, smoking, and transpiration during storage in the shade has been studied. The experimental curves show a faster evolution with the rack than with the tray during sun drying and with the endocarp facing downwards than with the endocarp facing upwards during smoking; these evolutions are also proportional to the mass and water content when the masses are similar. As a result, safou is dried in two and a half days with the rack compared to four days with the tray in the sun, and in two and a half days with the endocarp facing downwards compared to three and a quarter days with the endocarp facing upwards during smoking. The influence of the rack structure on the duration of dehydration was not observed during storage in the shade. From an economic and finished product quality perspective, sun drying of safou can be used as a preliminary process prior to oil extraction. Storage in the shade does not appear to be conducive to extending the shelf life of fresh safou, given the high temperatures recorded during the harvest periods. The experimental curves validate Peleg's empirical model better than Fick's diffusion model. The kinetic values of these two models give predictable values that are sometimes too far from the experimental values obtained.

Keywords

Safou; local storage; dehydration; kinetics; modelling

1. Introduction

Safou (Dacryodes edulis), an oilseed crop widely domesticated and valued in sub-Saharan Africa [1-14], is a highly perishable fruit [4, 15-22]. It softens 3 to 5 days after harvesting [23], which makes its storage and marketing particularly difficult [17, 24-28], leading to post-harvest losses sometimes exceeding 50% [8, 17, 29, 30]. In certain parts of Africa where there is limited access to energy resources [31], actors in the sector use various processing techniques, acquired from generation to generation, sometimes varying according to the crop, in order to build up reserves that can be used during periods of shortage [5, 8, 18, 32-37]. These practices, generally described as traditional, suffer from a lack of scientific data [8], even though they are part of everyday technology, sometimes innovative, contributing to food security for many populations [31]. Throughout the world, in general, and in Congo-Brazzaville in particular, sun drying and smoking are common techniques for processing foodstuffs for long-term preservation in rural and even urban areas [31, 38-43].

Safou, which is the subject of this study, is no exception to these practices [4, 44, 45], the first of which (sun drying) has even been the subject of proposals for improvement [18, 19, 46].

Safou is also dried in the open air in the sun in some parts of the country [4, 45] and smoked over hearths in others.

Apart from these two practices, in order to extend the shelf life of fresh safou before it is sold or consumed, newly harvested fruit is often spread out in sheds or kitchens to benefit from good ventilation and moderate temperatures, which slow down the softening process. This technique, practised in almost the entire sub-region, was reported by Kengué [4]. Dossou *et al.* [20, 47] studied the influence of storage conditions.

After harvesting, fruit and vegetables gradually lose quality due to deterioration, one of the causes of which is physiological ageing caused by transpiration, respiration, and the metabolism of plant tissues [31, 48, 49]. Transpiration, which is a natural loss of water, causes a loss of mass in stored products because, unlike living plants, they can no longer replace the water lost by drawing it from the soil.

In addition, two other processing techniques, which are rarely used, involve making a spread by softening the safou, a practice also used in Cameroon [8], and extracting oil from the pulp for cosmetic and food purposes.

These findings indicate the diversity of processing and preservation techniques for processing and preserving safou on a daily basis, which vary according to the culture. Sun drying, smoking, and transpiration during storage in the shade are governed by physical laws, in particular dehydration (or water desorption), the underlying mechanisms of which remain unknown to date. We are therefore interested in modelling the kinetics of water desorption in these three preservation techniques in order to understand how these dehydration processes take place.

2. Materials and Methods

2.1 Plant Material

Congo-Brazzaville, straddling the equator, benefits from two safou production cycles: the first between December and March, when safou fruits are harvested in the southern region of the country; the second between March and July, for safous in the northern zone. The study was conducted in May, which is one of the hottest months in Brazzaville, Congo.

The safou samples used in this study were sourced from the Plateaus and two Basin departments of the Plateaus and the two Basins, and were purchased at the Ngamakosso market in Brazzaville (Republic of Congo). The only selection criterion was the ripeness of the fruit (dark blue or black colour).

2.2 Study Methods

After purchase, the safous were transported to the laboratory where they were cleaned and weighed.

The experiments were conducted in accordance with local practices; that is, sun drying and smoking were carried out with half-pulps, while whole fruits were stored in the shade. In addition, for comparison purposes, we also monitored the storage of half-pulps in the shade.

2.2.1 Category of safous studied

Table 1. Category of fruits studied

	Sun drying	Smoking	Shade storage
Number	9	8	12
Diameter (cm)	4.44 ± 0.32	4.87 ± 0.38	5.37 ± 0.47
Thickness (cm)	0.65 ± 0.03	0.73 ± 0.04	0.83 ± 0.04
Mass (g)	62.1 ± 6.68	71.54 ± 11.17	73.51 ± 10.28
Category	II	II and III	II and III

Fruit mass was measured using a CONSTANT PN-Model precision balance (Model 14192-005R; max capacity: 620 g; precision: 0.01 g), and the morphological dimensions (fruit width (diameter) and pulp thickness) were determined using a calliper. These fruits are categorized as II and III as previously defined by Silou *et al.* [50] and then by Ondo Azi *et al.* [51] (Table 1).

2.2.2 Monitoring of kinetics

For each storage method [52], three whole fruits and half-pulps were randomly selected for mass monitoring until stabilisation. After mass stabilisation, the samples were dried in an oven at 105 °C to determine the amount of residual water (m_r), defined by the formula:

$$m_r = m_{fp} - m_{fo} \quad (1)$$

where:

m_{fp}: final mass of the sample after the process.

m_{fo}: final mass of the sample after drying in the oven.

The water content is thus obtained by the equation:

$$\%(water) = \frac{m_0 - m_{fo}}{m_0} x100 \quad (2)$$

Where m_0, is the initial mass of the sample.

2.2.2.1 Solar drying in the open air

To better replicate local practices, drying was carried out on the roof of a house using two different supports: a tray and a drying rack. The rack was turned over to allow the samples to be aired (Figure 1). Every morning at 6 a.m., after weighing, the two supports carrying the samples were placed on the roof until 6 p.m. If there was no rain, then they were removed, and the samples were weighed again. They were then stored inside the laboratory, protected from the elements, to be exposed to the sun again the next morning, and so on.

a) Safou pulp on the tray

b) Safou pulp on the drying rack placed on the roof

Figure 1. Experimental equipment used.

2.2.2.2 Smoking drying

Smoke drying was carried out under traditional local conditions in the village of Kissila (Mvouti district) at the usual daily domestic rate. To this end, measurements were taken at 6:00 a.m. before the smoking system was set up, at 12:00 p.m. after breakfast, and at 6:00 p.m. after the main meal. A fan-powered grill commonly used for domestic smoking was used. It was placed one metre above the hearth and attached to a movable wire allowing height adjustments when the heat intensity varied, and was used as the smoking system (Figure 2). The half-pulps were spread out on the rack in alternating layers (top and bottom). For each sampling interval, the fire was maintained for 3 hours, even after the food had been cooked.

2.2.2.3 Storage in the shade

The whole fruits and half-pulps were spread out on the tray and rack of the oven and placed on the workbench in the laboratory. The mass was measured every morning at 6:00 a.m.

Figure 2. Traditional smoking of safou.

2.2.2.4 Meteorological data

For solar drying in the open air and storage in the shade, meteorological information was provided by AccuWeather for the city of Brazzaville (Table 2).

Table 2. Weather data for the city of Brazzaville during the study (May 2025)

Day	1	2	3	4	5	6	7	8	9	10	11
ΔT (°C)	24-34	23-32	23-34	23-32	23-30	21-32	23-33	23-33	23-32	23-33	23-34
Humidity (%)	85	60	87	81	73	81	89	77	62	83	62

Note. No temperature data was recorded for smoking.

2.2.3 Dehydration kinetics parameters

The kinetic parameters taken into account are used to plot dehydration curves representing either the variation in dry matter water content X as a function of time t or the dehydration rate $-\frac{dX}{dt}$ as a function of time t or as a function of dry matter water content X.

Using the measured masses m_t, the dry basis water contents are calculated using the formula below:

$$X = \frac{m_t - m_{fo}}{m_{fo}} \tag{3}$$

The instantaneous dehydration rates are determined by the formula:

$$-\frac{dX}{dt} = \frac{-[X(t+\Delta t) - X(t)]}{\Delta t} \tag{4}$$

2.2.4 Modelling

There are numerous studies on modelling the kinetics of plant drying, including those by [53-58]. To our knowledge, only two studies on safou have been conducted, one using an oven at three temperatures [59] and the other using a microwave at three power levels [46].

In this study, we wanted to test the Fick diffusion model developed by Crank (first-order kinetics) and the Peleg model (second-order kinetics), which are widely used in the agri-food industry. The drying curves were plotted using the reduced water content X^* as a function of time t ($X^* = f(t)$) given by the relationship:

$$X^* = \frac{m_t - m_{fo}}{m_0 - m_{fo}} \tag{5}$$

where m_t, the mass of the pulp at time t.

2.2.4.1 Fick's Diffusion Model (Crank)

The development of Fick's second law by Crank [60] led to the following expressions:

$$X^* = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}}{4L^2}t\right) \quad (6)$$

where n is the number of terms taken into account; D_{eff} (m^2 /j) is the effective moisture diffusivity; and L (m) is half the thickness of the sample.

For long drying times and small sample diameters or thicknesses, the terms in the summation of this equation corresponding to n>1 are relatively small. Thus, the latter can be simplified to the first term only, as follows:

$$X^* = \frac{8}{\pi^2}exp\left(-\frac{\pi^2 D_{eff}}{4L^2}t\right) = \frac{8}{\pi^2}exp(-kt) \quad (7)$$

with

$$D_{eff} = \frac{4L^2 k}{\pi^2} \quad (8)$$

where k (j^{-1}) is the first-order kinetic constant.

For whole fruits, only the width of the fruit will be taken into account as thickness.

2.2.4.2 Peleg's empirical model

Peleg [61] proposed a mathematical model to describe the moisture absorption of rice. Since then, this model has been widely used to describe sorption phenomena in food science. In the case of desorption, this model is written as:

$$X^* = 1 - \frac{t}{a+b.t} \quad (9)$$

with a ($j.\%^{-1}$) being Peleg's kinetic constant and b ($\%^{-1}$) being Peleg's capacity constant.

This equation can be linked to the mass of the sample by the relationship:

$$m_t = m_0 - \frac{(m_0 - m_{fo})t}{a+b.t} \quad (10)$$

The initial dehydration rate and the predicted final mass can thus be determined.

$$(R)_0 = -\left(\frac{\mathrm{d}m_t}{\mathrm{d}t}\right)_{t_0} = \frac{(m_0 - m_{fo})}{\mathrm{a}} \quad (11)$$

and

$$m_\infty = \lim_{t\to\infty} m = m_0 - \frac{(m_0 - m_{fo})}{\mathrm{b}} \quad (12)$$

2.2.5 Statistical processing

Statistical processing was performed using Excel 2010 and OriginPro 2021 software.

3. Results and Discussion

3.1 Kinetics

The measured masses are shown in Tables 3, 4, and 5.

Table 3. Masses measured during solar drying in the open air

		Try			Rack		
Time of sampling	Time (d)	ST1	ST2	ST3	SR1	SR2	SR3
3:30 p.m.	0	30.24	21.41	25.04	-	-	-
6:00 p.m.	0.0623	28.56	20.04	23.54	-	-	-
6:00	0.5625	27.00	18.66	22.12	25.74	21.05	26.68
16:50	1.0139	20.95	13.12	16.78	18.38	15.50	19.70

Table 3 Continued

Time of sampling	Time (d)	ST1	ST2	ST3	SR1	SR2	SR3
6:00	1.5625	19.95	12.20	15.94	16.94	14.42	18.40
6:30 p.m.	2.0833	17.33	9.90	13.28	13.60	12.03	15.07
6:00 **r**	2.5625	16.89	9.56	12.91	13.02	11.62	14.47
6:00 p.m.	3.0625	16.44	9.25	12.52	12.52	11.37	14.02
6:00	3.5625	16.22	9.10	12.32	12.23	11.21	13.80
6:30 p.m.	4.0833	14.78	8.02	10.68	10.80	10.61	12.93
7:40	4.6389	14.71	8.03	10.62	10.70	10.60	12.90
6:00 p.m.	5.0833	13.88	7.55	9.76	10.02	10.30	12.53
7:20	5.6389	13.94	7.64	9.81	10.13	10.38	12.60
7:25 p.m.	6.1424	13.62	7.49	9.53	9.83	10.22	12.40
7:00	6.6250	13.64	7.52	9.55	9.90	10.25	12.44
6:00 p.m.	7.0830	13.24	7.29	9.18	9.55	10.03	12.17
Oven at 105 °C		12.25	6.72	8.32	9.0	9.47	11.38

Note. r = rain

Table 4. Masses measured during smoking

		Endocarp at the top			Endocarp at the bottom		
Time of sampling	Time (d)	SMT1	SMT2	SMT3	SMB1	SMB2	SMB3
6:00	0	29.40	23.35	32.87	32.97	29.08	30.93
12:00 p.m.	0.25	24.54	20.12	29.41	28.24	24.75	26.58
6:00 p.m.	0.50	20.62	17.02	26.54	23.15	20.20	21.17
6:00	1.00	19.66	16.25	25.98	22.54	19.62	20.52
12:00 p.m.	1.25	17.60	13.83	23.24	19.70	17.26	17.75
6:00 p.m.	1.50	15.75	12.11	19.88	16.90	15.10	15.35
6:00	2.00	15.67	12.11	19.57	16.54	14.82	14.95
12:00 p.m.	2.25	14.37	11.17	17.75	14.70	12.95	12.88
6:00 p.m.	2.50	13.62	10.47	16.31	13.78	11.91	11.52
6:00	3.00	13.68	10.59	16.22	13.89	12.02	11.61
12:00 p.m.	3.25	13.07	10.05	15.36	13.60	11.71	11.23
6:00 p.m.	3.50	12.88	9.97	14.92	13.08	11.21	10.69
6:00	4.00	12.97	10.06	15.01	13.17	11.28	10.77
12:00 p.m.	4.25	12.88	9.96	14.87	12.98	11.15	10.59
Oven at 105 °C		11.83	9.09	12.98	12.06	10.34	9.72

Table 5. Masses measured during storage in the shade

	Try						Rack					
	Whole fruit			Half pulp			Whole fruit			Half pulp		
Time (d)	TTF1	TTF2	TTF3	TTH1	TTH2	TTH3	TRF1	TRF2	TRF3	TRH1	TRH2	TRH3
0	83.32	67.21	82.50	24.27	27.50	27.97	57.55	60.11	50.04	15.20	17.37	17.30
1	80.03	65.09	79.21	21.92	24.87	25.05	54.64	57.81	48.12	13.63	15.64	15.56
2	76.57	62.41	75.18^{s}	19.46	21.86	22.03	52.08^{s}	55.52	45.94	12.24	14.16	14.14
3	73.63	60.05	71.05^{m}	17.43	19.42	19.75	49.22 r	53.17^{s}	43.67^{s}	10.65^{s}	12.84^{s}	13.17
4	70.08	56.68	67.03	15.60	17.54	18.06		50.85	41.46^{m}	9.18	11.55	12.33
5	67.51^{s}	54.71	64.10^{r}	14.23	16.13	16.90		49.32^{m}	40.07	8.07	10.46^{m}	11.64
6	64.52^{r}	52.41^{s}		13.69	14.84	15.87		47.38 r	37.92 r	7.10^{m}	9.48	10.94
7		50.13		11.96	13.69	14.96				6.47	8.78	10.26
8		48.33^{m}		10.76	12.76	14.1				6.10	8.32	9.75
9		46.28		9.93	12.28	13.24				5.77	7.93	9.28
10		43.98 r		9.33	11.93	12.75				5.55	7.59	8.88
11				9.26	11.90	12.62				5.48	7.39	8.63
Oven at 105 °C	52.74	42.06	52.23	8.31	10.80	11.46	34.10	37.00	27.90	5.42	7.28	8.56

Notes. s =start of softening, m=appearance of mould on the softened area, r=rot

The mass evolution curves show a curvilinear staircase-like decrease during open-air solar drying and smoking (decreasing rate phase), without a temperature adjustment phase [62] for solar drying in the open air and smoking (decreasing speed phase) and a linear decrease (constant speed phase), slightly curvilinear in the case of half-pulps (decreasing speed phase), during storage in the shade, although it may vary slightly between day and night due to the difference in temperature, followed by stabilisation (Figure 1). This difference in decrease shows that water is not extracted in the same way from whole fruits and half-pulps. The constant-speed phase, which corresponds to the evaporation of surface water compensated by the movement of internal moisture driven by capillary forces and renewed at a sufficient speed, is rarely identifiable during the drying of plant products [63], but is observed in whole fruits during storage in the shade.

The staircase-like decrease characterises the variations in water desorption during the day and night due to the sun setting in the evening, thus disrupting the drying process. Failure to take this into account would lead to the curvilinear patterns usually observed in plants: Massamba *et al*. [46] and Binaki *et al.* [59] on safou, Toğrul and Pehlivan [64] on apricots, Ferradji [65] on figs, Tetang *et al.* [66] on carrots, and Boy *et al.* [67] on apples and mangoes.

Traditional safou drying is therefore slower, compared to protected and temperature-controlled processes [31], because every evening, the samples must be brought back to the laboratory to protect them from bad weather or pests. This fact is clearly observed on days 2.08 and 3.56 during sun drying (Figure 3a), marked by a virtually constant change in mass due to the samples not being exposed on the third day of drying because of rain, thus demonstrating the disadvantage of open-air drying. It should also be noted that, from the fifth day for sun drying and from the third day for smoking, the samples rehydrate at night when stored indoors (Tables 3 and 4). This phenomenon of rehydration of the safou pulp during drying occurs at moisture contents rarely exceeding 15%, with varying degrees of variability in each drying process.

Water loss is faster with the drying oven rack than with the tray during sun drying. The rack, which facilitates aeration of the samples on both sides, has steeper slopes than the tray. The dehydration of the samples is therefore influenced by the structure of the supports.

Regarding smoking, half-pulps positioned with the endocarp facing downward dehydrate more rapidly, likely due to differences in texture between the epicarp and endocarp surfaces.

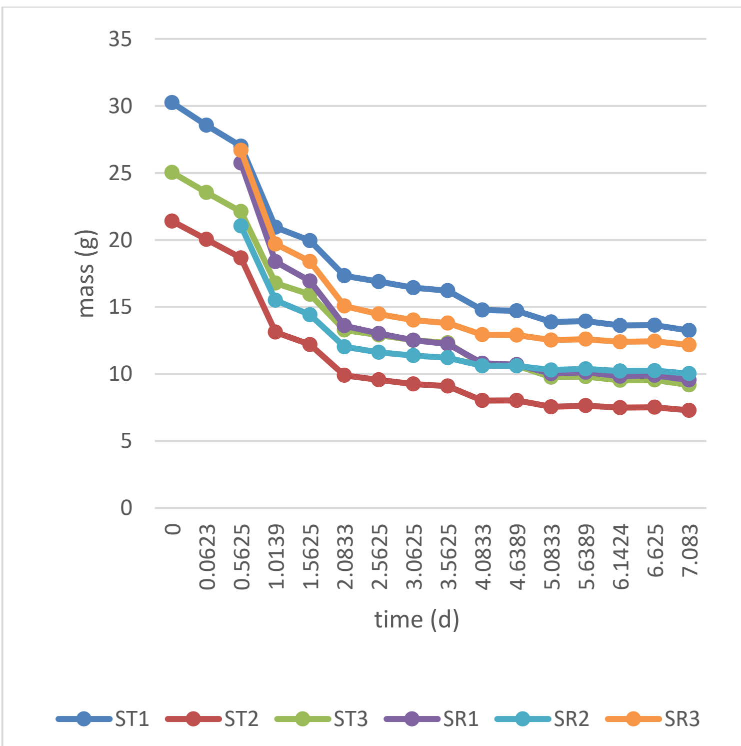
As a result, under our experimental conditions, safou dried in two and a half days on the rack and in four days on the tray during sun drying on the roof of a house, excluding the day when the samples were not exposed outside due to rain. Similarly, during smoking, the endocarp facing downwards dries in two and a half days and the endocarp facing upwards in three and a quarter days. Drying on a rack in the sun gives similar results to smoking with the endocarp facing downwards.

Furthermore, the residual water content obtained during these two processes is very favourable for oil extraction. A study conducted by Noumi *et al.* [68] on the effects of drying on the yield and quality of oil extracted from safou pulp showed that drying had a significant influence on extraction yield and that the final water content corresponding to maximum extraction yield and providing the best ratio of extracted oil quality to energy consumption was 6.17%.

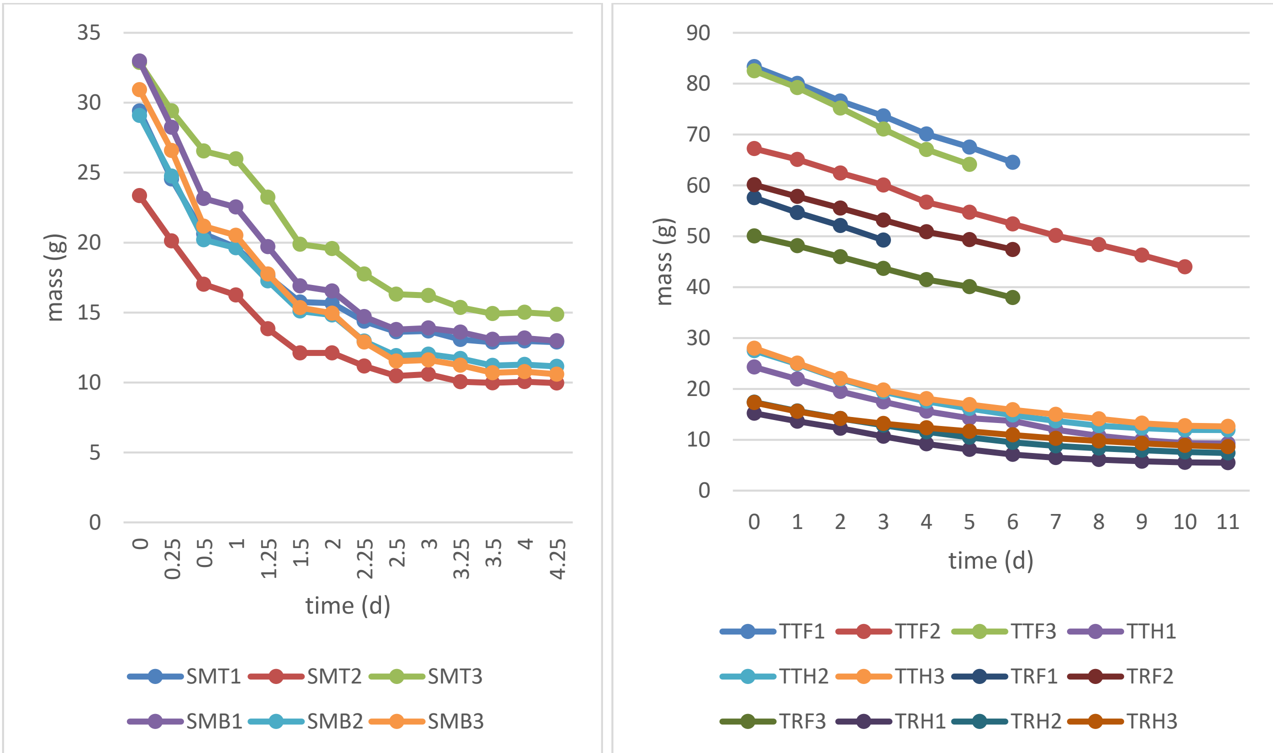
On the other hand, smoking, which appears to be a faster means of preserving safou pulp than drying in the open air, if maintained continuously until stabilisation, requires a study on the nutritional quality of smoked safou, which is currently underway, for a better assessment of the process. A study conducted in Congo-Brazzaville on traditional smoking of Atherura spp. meat reported a potential association with cardiovascular disease [40].

We also compared the results of sun drying with oven drying. Despite the stepwise decrease in mass, sun drying showed unexpected performance during the exposure of samples to the sun. The drying speed of safou in the sun appears to be similar to that of oven drying at 50°C, which shows a stabilization from the 36th hour. When only periods of sun exposure are considered, the mass evolution curves merge with those of drying in an oven at 50°C. Figure 2 shows, for example, the mass evolution curves of samples dried in the sun on a rack and in an oven at 50°C.

The superposition of the curves clearly shows the similarity between these two methods when the intervals during which the safou is stored indoors are not taken into account. This suggests that if the safou were dried continuously in the sun on the roof of a house under the experimental conditions of the study, it would be ready in a day and a half. The only constraint for this method is that the products must be sheltered at night, which delays the drying process by almost half and causes them to rehydrate towards the end of the operation. These two factors, which greatly delay the drying of safou in the sun, could confirm, certainly for other reasons, the conclusions drawn by Dissa [69] on mangoes and by Danjouma [70] on tomatoes, who recorded decreases in drying speed after the first day of drying by exposure to the sun compared to drying in dryers at 50°C due to the temperatures of the products approaching that of the air.



a) Sun drying



b) Smoking c) Storage in the shade

Figure 3. Change in mass during each storage process.

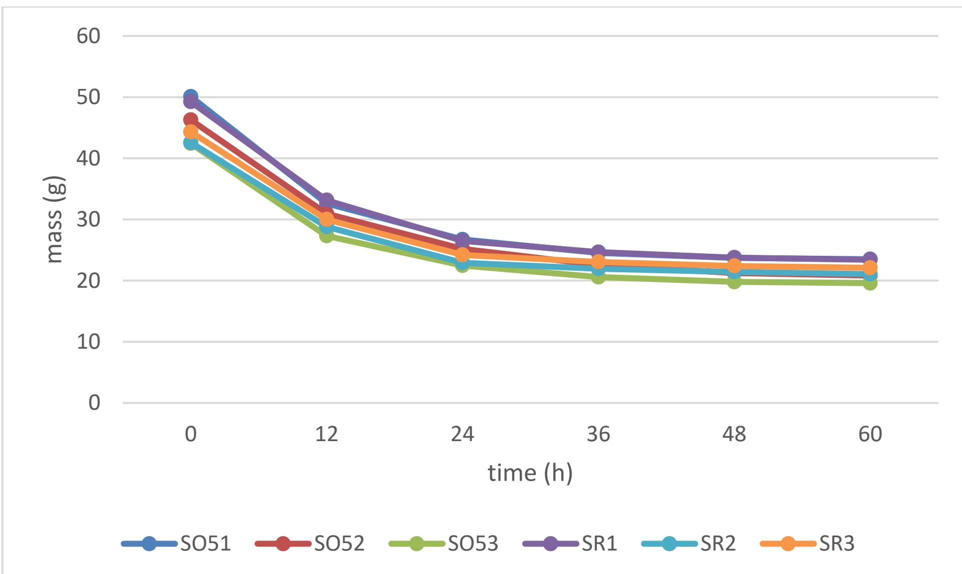
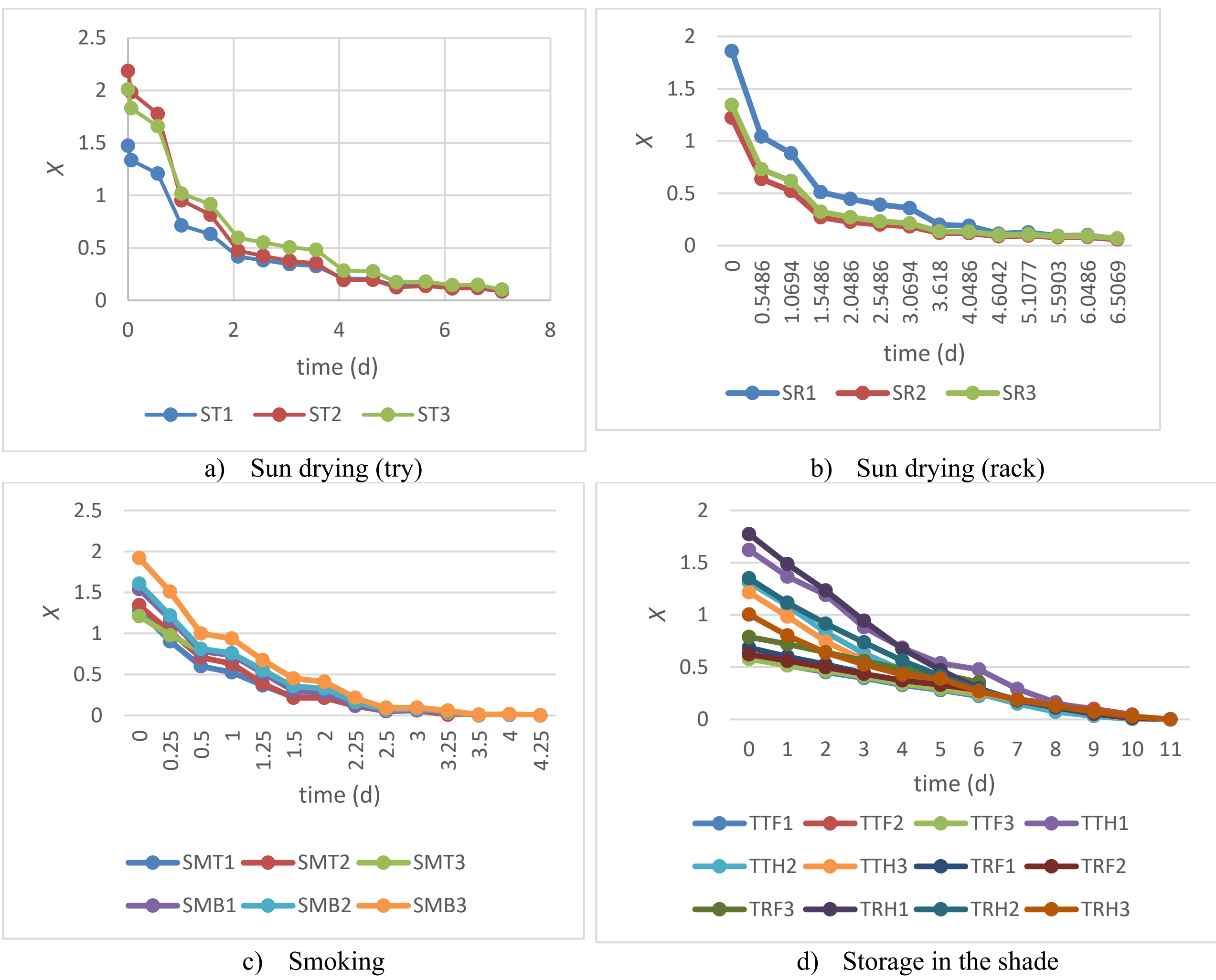


Figure 4. Drying on a rack in the open air during exposure to sunlight and drying in an oven at 50°C.

Nevertheless, sun drying in tropical countries is an unavoidable alternative to energy problems, provided that it is applied to suitable foodstuffs [31]. With temperatures sometimes approaching 40°C (Table 1), the equatorial climate offers a real opportunity for drying food products, alleviating energy difficulties in developing countries and in areas far from urban centres and without electricity [71].

Similarly, observation of the products obtained and monitoring of their preservation over a period of three months allowed us to note that sun-dried safou had characteristics that were practically similar to those of safou dried in an oven at 50°C (no pest attack and no trace of dust noticeable during drying, low fungal contamination in places). The fact that the safou was not attacked by birds or insects during open-air drying is further evidence in favour of open-air drying. The study conducted by [43] on mango drying, revealing that sun drying boosted the nutritional properties of mangoes more than oven drying, except for fungal contamination, which can be controlled [22], could encourage this practice. The work of Bouverat-Bernier [72] and Odile [73] also showed, respectively, that the essence (aroma) content was preserved at 95% and the green colour of certain leaves was maintained when the drying temperature was below or equal to 55°C.

Furthermore, during storage in the shade, dehydration of safou is initially less pronounced in whole fruits than in half-pulps. The curves for half-pulps follow the typical pattern, with a curvilinear decrease followed by stabilisation, whereas this pattern is barely visible in whole fruits. The curvilinear decrease followed by stabilisation is barely visible, unlike those of whole fruits, which show a linear decrease, clearly observable in sample TTF2, which would have been more resistant to softening. Contrary to the results obtained during sun drying, the loss of mass appears to be slightly faster with the tray than with the rack for half-pulps (Figure 3c). The structure of the support does not seem to influence the rate of dehydration in a controlled environment, but rather seems to be linked to the difference in mass, which appears to contradict the results obtained in the oven by Binaki *et al.* [59]. The curves for the pulp stored on the tray, which has a higher mass, show steeper initial slopes than those for the pulp stored on the rack, which has a lower mass. The same observation, although slight, is also made for whole fruits. This proportionality between mass and the rate of dehydration of safou is also observed, within each process, during the evolution of the moisture content of the samples (Figure 5, Table 6).



a) Sun drying (try) b) Sun drying (rack)

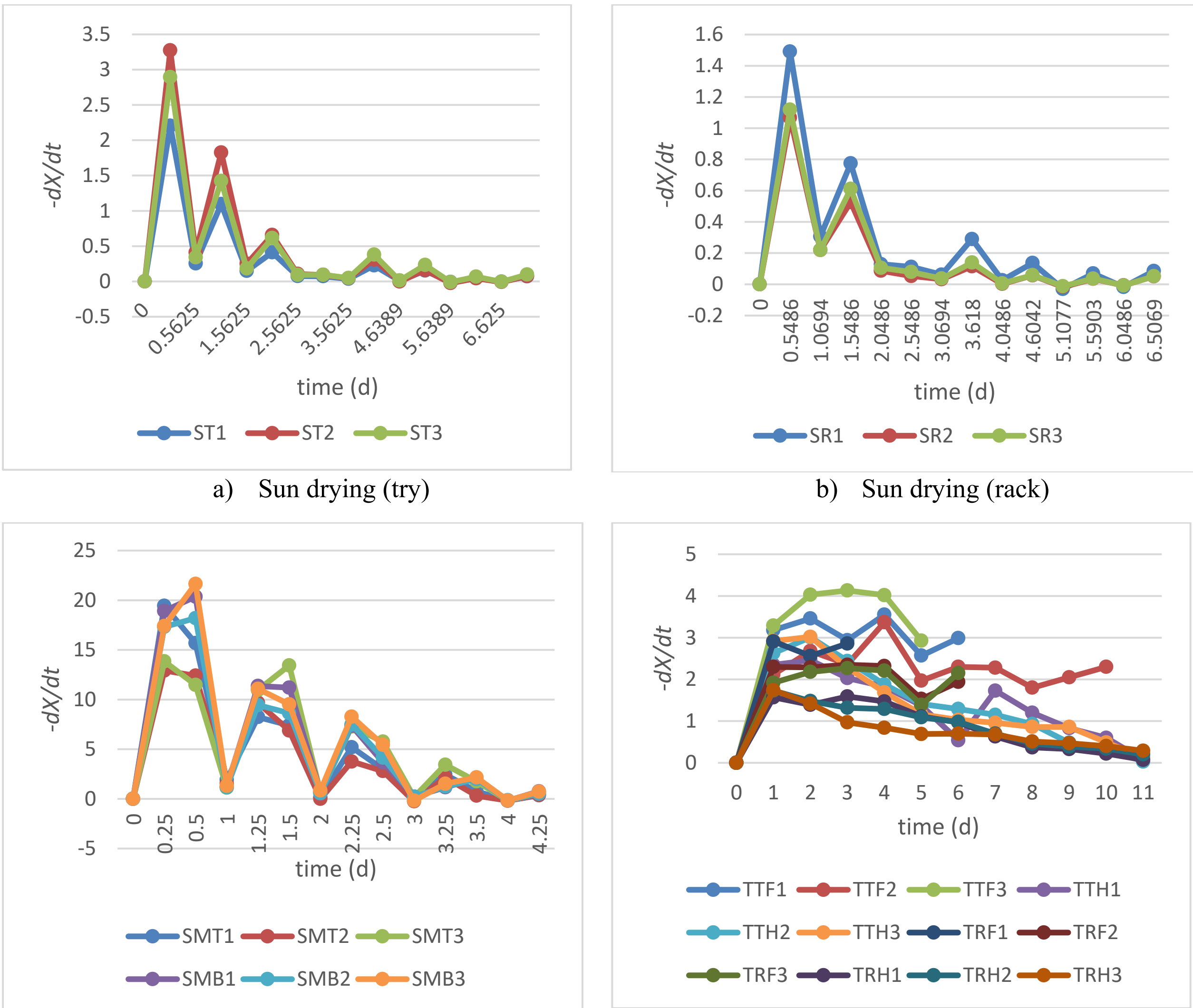
c) Smoking d) Storage in the shade

Figure 5. Variations in dry matter water content over time.

Table 6. Water content of the pulps and fruits studied

Sample	ST1	ST2	ST3	SR1	SR2	SR3	FT1	FT2	FT3	FB1	FB2	FB3
%water	59.49	68.61	66.77	65.03	55.01	57.34	59.76	61.07	60.51	63.42	64.44	68.57
Sample	TTF1	TTF2	TTF3	TTH1	TTH2	TTH3	TRF1	TRF2	TRF3	TRH1	TRH2	TRH3
%water	36.70	37.42	36.69	65.76	60.73	59.03	40.75	38.45	44.24	64.34	58.09	50.52

These two facts are clearly observable in the curves showing instantaneous velocity $-dX/dt$ as a function of time t. Samples with a high water content (sun drying and smoking) or a greater mass (storage in the shade) have higher initial instantaneous velocities than samples with a lower water content or a smaller mass, respectively (Figure 6, Tables 3, 4, 5, and 6).



a) Sun drying (try) b) Sun drying (rack)

c) Smoking d) Storage in the shade

Figure 6. Instantaneous dehydration rate during each preservation process.

Thus, in addition to temperature, the kinetic curves of safou dehydration also appear to vary proportionally with mass and water content within the same species. When the masses are different, it is proportional to mass, but when the masses are similar, it becomes proportional to water content.

Beyond the kinetic study, this study also shows us that fresh whole safou is difficult to preserve in the shade compared to half pulp. Whole fruits soften between the 2nd and 6th days, as reported in the literature [29, 8, 17, 30, 23], appear to be more fragile than pitted half-pulps. The softening spreads throughout the whole fruit, generally within two days [47], followed by mould attack and then rotting, whereas it appears to slow down in the pulp halves (samples TRH1 and TRH2, Table 5). This slowdown in softening observed in the half-pulps seems to be linked to their accelerated dehydration, estimated to be at least double that of whole fruits when assessing successive water loss yields (mass of water lost/previous mass of the sample). The softening of safou pulp, therefore, appears to be a joint process involving its high water content and softening enzymes, as reported in the literature [74-76, 8, 10, 22].

3.2 Modelling

The values of the coefficients of determination (R^2), reduced chi-square (χ^2), and estimated parameters are presented in Table 7.

Table 7. Statistical data for the two models

		Peleg				Fick		
		R^2	χ^2	a	b	R^2	χ^2	k
Sun drying	ST1	0.9814	0.0020	1.35 ± 0.14	0.86 ± 0.04	0.9387	0.0060	0.40 ± 0.04
	ST2	0.9748	0.0029	1.14 ± 0.14	0.85 ± 0.04	0.9361	0.0068	0.50 ± 0.05
	ST3	0.9688	0.0034	1.54 ± 0.20	0.83 ± 0.05	0.9222	0.0080	0.38 ± 0.04
	SR1	0.9906	0.0007	0.86 ± 0.06	0.90 ± 0.02	0.9507	0.0036	0.56 ± 0.04
	SR2	0.9903	0.0007	0.65 ± 0.05	0.95 ± 0.02	0.9356	0.0045	0.64 ± 0.06
	SR3	0.9890	0.0008	0.73 ± 0.06	0.93 ± 0.02	0.9400	0.0042	0.60 ± 0.05
Smoking	FT1	0.9859	0.0013	0.69 ± 0.06	0.88 ± 0.03	0.9526	0.0039	0.73 ± 0.06
	FT2	0.9810	0.0018	0.82 ± 0.08	0.84 ± 0.04	0.9453	0.0049	0.70 ± 0.06
	FT3	0.9753	0.0025	1.47 ± 0.16	0.72 ± 0.06	0.9212	0.0072	0.49 ± 0.05
	FB1	0.9792	0.0021	0.85 ± 0.09	0.82 ± 0.04	0.9447	0.0051	0.70 ± 0.06
	FB2	0.9850	0.0015	0.90 ± 0.08	0.81 ± 0.03	0.9495	0.0046	0.68 ± 0.06
	FB3	0.9804	0.0020	0.93 ± 0.09	0.80 ± 0.04	0.9431	0.0053	0.67 ± 0.06
Storage in the shade	TTF1	0.9995	0.0000	8.85 ± 0.21	0.15 ± 0.04	0.7218	0.0137	0.09 ± 0.02
	TTF2	0.9986	0.0002	9.41 ± 0.26	0.15 ± 0.03	0.8151	0.0176	0.12 ± 0.02
	TTF3	0.9901	0.0008	6.50 ± 0.78	0.23 ± 0.19	0.7422	0.0164	0.13 ± 0.03
	TTH1	0.9964	0.0004	5.40 ± 0.23	0.54 ± 0.03	0.8987	0.0101	0.17 ± 0.02
	TTH2	0.9942	0.0006	4.28 ± 0.24	0.63 ± 0.03	0.9154	0.0086	0.19 ± 0.02
	TTH3	0.9981	0.0002	4.10 ± 0.13	0.68 ± 0.02	0.9286	0.0066	0.18 ± 0.02
	TRF1	0.9994	0.0000	8.27 ± 0.36	0.07 ± 0.14	0.2665	0.0169	0.05 ± 0.05
	TRF2	0.9989	0.0000	9.20 ± 0.32	0.27 ± 0.07	0.6832	0.0127	0.07 ± 0.02
	TRF3	0.9980	0.0000	10.18 ± 0.47	0.13 ± 0.09	0.6531	0.0138	0.07 ± 0.02
	TRH1	0.9878	0.0016	4.40 ± 0.36	0.55 ± 0.05	0.8907	0.0132	0.21 ± 0.03
	TRH2	0.9955	0.0006	4.70 ± 0.23	0.55 ± 0.03	0.9009	0.0110	0.20 ± 0.02
	TRH3	0.9993	0.0000	4.63 ± 0.09	0.58 ± 0.01	0.9176	0.0083	0.19 ± 0.02

Based on these results, the experimental curves validate Peleg's model better than Fick's diffusion model, with R^2 values ranging from 0.9995 to 0.9753 and from 0.9526 to 0.2665, respectively, and χ^2 values ranging from 0.0000 to 0.0034 and from 0.0036 to 0.0176. The fitting results of Peleg's model indicate that during traditional safou preservation processes, water dehydration occurs in two stages: free water is first removed quickly (decay), followed by the slow removal of bound water (stabilization). On the other hand, the validation of Fick's model, observed in sun drying and smoking, means that this water is extracted by diffusion before being evaporated from the surface of the sample. The same results were obtained during microwave drying of the same species [46], but in reverse, and during oven drying [59]. The intimate mechanisms of water desorption from safou pulp, similar to those of other plants [55, 77], appear to be contrary to those of other metabolites such as fat, where the adjustment of experimental data to first-order kinetic models is generally obtained when the diffusion capacity of the solvent, favoured by the transformation of the sample into powder and/or by an increase in temperature, merges with elution [78].

Furthermore, the poor fit of Fick's diffusion model to the experimental data obtained for storage in the shade, especially with whole fruits, can be explained by the increased resistance of the latter to dehydration, as reported in the literature [79, 80]. Whole fruits, whose biological cycle was interrupted during harvesting, appear to be more resistant to dehydration than half-pulps without their pits. This resistance to dehydration during storage is a natural behaviour of plants to combat physiological ageing, which leads to drying out, weight loss, wilting, softening, deterioration in appearance, and a reduction in the shelf life of the harvested organ [48, 49, 31]. Thus, the water released by whole fruits during storage in the shade appears to be extracted in two stages, leading to second-order kinetics, not expressed in the kinetic curves, which seem to show that the phase is at a constant rate.

Table 8. Kinetic values of the two models tested

		Peleg		Fick
		R_0 (g/j)	m_∞ (g)	D_{eff} (10^{-6} m^2/j)
Sun drying	ST1	13.33	9.29	1.73
	ST2	12.93	4.19	2.12
	ST3	10.87	4.86	1.63
	SR1	19.40	7.21	2.38
	SR2	32.20	8.82	2.75
	SR3	20.96	10.30	2.59
Smoking	FT1	12.18	9.48	4.16
	FT2	11.70	6.32	3.99
	FT3	29.23	4.89	2.77
	FB1	17.69	15.84	4.02
	FB2	20.83	5.81	3.89
	FB3	22.88	4.36	3.83
Storage in the shade	TTF1	3.46	-117.75	26.32
	TTF2	2.67	-106.01	49.72
	TTF3	4.66	-49.38	38.02
	TTH1	2.96	-5.43	1.19
	TTH2	3.90	1.12	1.33
	TTH3	4.03	3.68	1.26
	TRF1	2.83	-294.71	14.62
	TRF2	2.51	-24.39	20.47
	TRF3	2.18	-123.66	20.47
	TRH1	2.22	-2.52	1.47
	TRH2	2.15	-1.00	1.39
	TRH3	1.89	2.31	1.33

We calculated the kinetic values for both models (Table 8). These values, which vary across processes, do not appear to follow the proportionality relationships described above. The initial dehydration rate obtained by Peleg's model is proportional to mass during storage in the shade, but not to water content, as obtained with the kinetic curves, while it only shows consistent behavior for whole fruits, for which the model is less consistent with the experimental curves. This inconsistency can be explained by the longer time frames (12 hours for sun drying and 6 hours for smoking) used in the experiment compared to the instantaneous values obtained with the two models. However, the structure of the support and the position of the sample comply with the rule. The initial drying rate is higher for the rack system than for the tray system, and also greater with the endocarp at the bottom than with the endocarp at the top.

The predicted masses show large discrepancies with the final experimental masses (Tables 3, 4, and 5), except for sun drying using the rack, which generally shows discrepancies of less than 15%. These values, which are inconsistent with storage in the shade, may be due to disruption of the water desorption process caused by sample alteration.

4. Conclusion

Sun drying, smoking, and storage in the shade are among the most commonly used preservation techniques in rural areas by those involved in the safou industry. During these processes, the safou pulp dehydrates at a decreasing rate, as commonly observed during plant drying processes. These curves are curvilinear with half-pulps and linear with whole fruits, which appear to have a virtually constant rate of dehydration during storage in the shade. The drying rack (grate), which facilitates the aeration of the samples, allows for faster sun drying compared to the tray. This influence of the support on the dehydration rate was not observed during storage in the shade, probably due to poor ventilation of the samples inside the laboratory. Pulps placed with the endocarp facing downwards dehydrate more quickly during smoking than pulps positioned with the endocarp facing upwards. Beyond the influence of the structure of the drying supports and the position of the endocarp, the slopes of the dehydration curves are proportional to the mass of the samples and to the water content when the masses are similar.

Consequently, smoking, carried out according to family needs, which could predispose to cardiovascular disease, as reported in the literature on smoking fatty fish, dries the safou in two and a half days for the lower endocarp and three and a quarter days for the upper endocarp, while sun drying also takes two and a half days on the rack and four days on the tray. As the residual water content obtained is very favourable for oil extraction, sun-drying safou, which reduces processing costs thanks to the solar energy available and benefits from a range of temperatures that is very favourable for preserving the nutritional properties of dried products, could well be integrated into the process of extracting oil from safou pulp. This process, excluding the periods when the samples are stored indoors at night, is similar to drying in an oven at 50 °C, which dries the safou in 1½ days.

On the other hand, storage in the shade appears to be less advantageous. Disadvantaged by high temperatures during the experimental period, this causes the fruit to soften prematurely. Thus, it does not seem to extend the shelf life of safou.

Apart from storage in the shade, where the experimental data are less consistent with Fick's diffusion model, these two models, which fit more closely with Peleg's model, can be used to describe the dehydration mechanisms of these processes. Furthermore, and in general, the kinetic variables, which vary little for each process, do not seem to strictly follow the rules of proportionality observed in the experimental curves, except for the structure of the support and the position of the sample, which obey the rule. Furthermore, the predicted masses show large deviations from the final experimental masses, except for sun drying using a drying rack, which generally shows deviations of less than 15%.

References

[1] Omoti U, Okiy DA. Characteristics and composition of the pulp oil and cake of the African pear, Dacryodes edulis (G. Don) H.J Lam. J Sci Food Agric. 1987;38(1):67-72.

[2] Kiakouama S, Silou T. Safou or atanga: a regional fruit in the Gulf of Guinea, physico-chemical analysis. Muntu CICIBA Rev. 1987;6:137-51.

[3] Tchendji C, Severin M, Wathelet JP, Deroanne C. Composition of Dacryodes edulis fat. Rev Fr Corps Gras. 1987;28:123-5.

[4] Silou T, Goma Manouigui J, Boungou P, Ouamba JM. Study of the drying of safou pulp: Preliminary results. Tropicultura. 1991;9(2):61-8.

[5] Silou T. The safou tree (Dacryodes edulis): A little-known tree. Fruits. 1996;51(1):47-60.

[6] Kinkela T, Bezard J. Study of the structure of triacylglycerols in safou pulp oil (Dacryodes edulis). Rev Fr Corps Gras. 1993;11(12):373-82.

[7] Kapseu C, Tchiegang C. Composition of the oil from the fruits of two safou cultivars in Cameroon. Fruits. 1996;51(3):185-91.

[8] Kengue J. Safou (Dacryodes edulis). Monograph. Southampton: International Centre for Underutilised Crops; 2002.

[9] Silou T. Unconventional fats from the Congo Basin: Characterisation, biodiversity and quality. OCL. 2014;21(2):D209.

[10] Bopoundza FC, Loumouamoui BW, Ngounga Kiminou C, Binaki AF, Biassala EL, Mampouya D, et al. Morphological and Physicochemical Characterisation of Safous from Congo. Res J Appl Sci. 2020;15(10):296-304.

[11] Okorie PE. Use of Dacryodes edulis in erosion control in agriculture lands in Nigeria. In: Proceedings of the second international workshop on the valorisation of Dacyodes edulis and others non-conventional oil crops; 1997; Ngaoundéré. Yaoudé: Presses Universitaires de Yaoudé; 1998. p. 35-44.

[12] ICUC. Fruits for the future. Safou. Factsheet 3. Southampton: International Centre for Underutilised Crops, University of Southampton; 2001.

[13] Verheij EWM. Dacryodes edulis (G. Don) H.J. Lam. In: Oyen LPA, Lemmens RHMJ, editors. Plant Resources of Tropical Africa. Wageningen: PROTA; 2002.

[14] Mpungi Buyungu. Contribution of safou (Dacryodes edulis) to agricultural diversification in West Africa. In: Proceedings of the 3rd International Seminar on the Development of Safou Tree and Other Unconventional Oilseeds; 2002; Yaoundé. Yaoundé: Presses Universitaires d'Afrique; 2002. p. 40-9.

[15] Emebiri LC, Nwufo MI. Effect of fruit type and storage treatments on the biodeterioration of African pear (Dacryodes edulis (G. Don) H.J. Lam). Int Biodeterior Biodegrad. 1990;26:45-50.

[16] Silou T, Bitoungui JP, Mavah G. Measurement of the natural softening of safou pulp using a penetrometer. Fruit. 1995;50:375-8.

[17] Silou T, Massamba D, Goma Maniongui J, Maloumbi MG, Biyoko SR. Post- harvest losses by natural softening of safou pulp (Dacryodes edulis) in Congo Brazzaville. J Food Eng. 2007;79:392-400.

[18] Noumi GB, Aboubakar Dandjouma AK, Kapseu C, Parmentier M. Local expertise in the food valorisation of safou fruit (Dacryodes edulis (G. Don) H.J. Lam) in Cameroon. Tropicultura. 2006;24(1):58-62.

[19] Ndindeng SA, Ambang Z, Woin N, Ngome FA, Njebu SA, Mapiemfu-Lamaré D, et al. Valorisation of Dacryodes edulis fruit (safou) through improved drying procedures, packaging and processing. Front Sci. 2012;2(6):250-5.

[20] Dossou BR, Ella Missang C, Baron A, Catherine MGC, Renard CMGC, Silou T. Factors affecting postharvest preservation of safou (Dacryodes edulis (G. Don) H.J. Lam) fruits. For Trees Livelihoods. 2012;21(1):44-55.

[21] Diabakana P, Dzondo MG, Mvili L-GS, Gampoula RH, Tamba Sompila AWG. Development of a process for preserving safou fruit pulp (Dacryodes edulis) using the dehydration-immersion impregnation (DII) method. J Food Stab. 2021;4(4):1-13.

[22] Bopoundza FC, Balenkali RC, Biassala ET, Loumouamou BW, Binaki AF, Silou T. Preservation test of fresh safous (Dacryodes edulis (G. Don) H.J. Lam) by thermal denaturation of softening enzymes. Asian J Sci Technol. 2025;16(3):13546-54.

[23] Fotouo Makouate H, Dongmo Lekagne JB. African pear (Dacryodes edulis (G.Don) H.J. Lam) Physical characteristics, Nutritional properties and postharvest management: A review. Agric Conspec Sci. 2022;87(1):1-10.

[24] Tabuna H. The marketing of safou in Brazzaville. Montpellier: CIRAD-SAR; 1993.

[25] Tabuna H. The market for non-timber forest products from Central Africa in France and Belgium: products, stakeholders, distribution channels and current outlets. Jakarta: CIFOR; 1999.

[26] Tabuna H. Strategies for developing the safou (Dacryodes edulis) market in Europe. In: Proceedings of the 3rd International Seminar on the Development of Safou and Other Non- Conventional Oilseeds. Yaoundé: Presses Universitaires d'Afrique; 2002. p. 449-63.

[27] Tabuna H, Tanoe M. Factors explaining and driving current consumption of safou (Dacryodes edulis) in Cameroon. Nairobi: World Agroforestry Centre (ICRAF); 2009.

[28] Awono A, Ndoyé O, Schreckenberg K. The marketing of Dacryodes edulis in the forest zone of Cameroon. In: Proceedings of the 3rd International Seminar on the Development of Safou Tree and Other Unconventional Oilseeds; 2002; Yaoundé. Yaoundé: Presses Universitaires d'Afrique; 2002. p. 400-17.

[29] Nwufo MI, Anyim CO. Post-harvest handling and storage of African pear (Dacryodes edulis) in south-eastern Nigeria. In: Proceedings of the second international workshop on the valorisation of Dacyodes edulis and others non-conventional oil crops; 1997; Ngaoundéré. Yaoudé: Presses Universitaires de Yaoudé; 1998. p. 217-25.

[30] Mayele Kipoy D. Morphological biodiversity and biochemistry of safou (Dacryodes edulis) from Kinshasa and Bas-Congo in the Democratic Republic of Congo [PhD thesis]. Kinshasa: University of Kinshasa; 2010.

[31] COLEACP. Conservation, processing and packaging of fruit and vegetables. Training Manual - Agricultural Production and Processing; 2021.

[32] Raponda-Walker A, Sillans R. Useful plants of Gabon: Attempt at an inventory and concordance of vernacular and scientific names of spontaneous and introduced plants, descriptions of species, properties, economic, ethnographic and artistic uses. Paris:

Paul Chevalier; 1961.

[33] Tchandjou M. Traditional use of black fruits and safous. In: Proceedings of the 3rd International Seminar on the Development of Safou Tree and Other Unconventional Oilseeds; 2002; Yaoundé. Yaoundé: Presses Universitaires d'Afrique; 2002. p. 502-7.

[34] Mbofung CMF, Njintang YN, Himedia MN. Use of safou paste (Dacryodes edulis) as an ingredient in biscuit manufacturing: sensory, physicochemical and functional characteristics. In: International Seminar on the Valorisation of Safou and Other Non-Conventional Oilseeds; 2002 Oct 3-5; Yaoundé, Cameroon.

[35] Mbofung CMF, Silou T, Mouaragadja I. Characterisation of African pear (Dacryodes edulis) and evaluation of its potential as ingredients for production of nutritious biscuits. For Trees Livelihoods. 2002;12:105-18.

[36] Kengue J. Safou (Dacryodes edulis) extension manual. Southampton: University of Southampton; 2003.

[37] Tabuna H. Sub-regional and international trade in non-timber forest food products and traditional agricultural products in Central Africa: Current situation and development strategy. FAO-ICRAF-COMIFAC report; 2007.

[38] Ferradji A, Goudjal Y, Malek A. Drying of sultana grapes using a forced convection solar dryer and a shell-type dryer. In: Proceedings of the SMSTS'08 Alger; 2008; Alger. p. 177-85.

[39] Touzi A, Merzaia-Blama A. Preservation of agri-food products by drying in Saharan regions. In: Proceedings of the SMSTS'08 Alger; 2008; Alger. p. 267-72.

[40] Mananga V, Makosso-Vheiye G, Massamba BJR, Massamba J, Kinkela T, Mbemba F, et al. Influence of smoking on the physicochemical composition and nutritional quality of fats: The case of African atherura. Ann Afr Med. 2009;3(1):337-45.

[41] Mananga V, Itoua Okouago YS, Zolatchina PA, Elenga M. Characterisation and nutritional value of smoked fish consumed in Brazzaville: the case of Protopterus dolloï, Distichodus spp. and Clarias spp. Life Earth Agric Sci. 2019;7:24-8.

[42] Bahlouli F, Tiaiba A, Slamani A. Study of different methods of drying apricots. review of traditional drying methods in the Hodna region, M'Sila province; 2014.

[43] Mwamba I, Tshimenga K, Mbabu D, Mukuna Conas, Mputu Kanyinda J-N. Drying mangoes by steaming and sun drying. Int J Innov Sci Res. 2018;37(2):216-22.

[44] Ali A, Koumpo L, Kenmegne AK, Silou T. Drying of safou pulp for its valorisation. Fruits. 1997;52(3):167-76.

[45] Silou T. Oils and Fats for the Future. A Case Study: Safou (Dacryodes edulis) from the Congo Basin Countries in Africa. New York: Nova Science Publishers, Inc; 2012.

[46] Massamba D, Matouba E, Elenga G, Goma Maniongui J, Silou T. Mathematical Modelling of Microwave Drying of Safou Pulp. Pak J Nutr. 2012;11(6):553-60.

[47] Dossou BR, Ella Missang C, Karou SD, Ameyapoh Y. Relationship between texture and cell-wall components of safou (Dacryodes edulis (G. Don) H.J. Lam) fruits at different storage conditions. J Appl Biosci. 2018;125:12566-80.

[48] Tano K, Kamenan A, Arul J. Respiration and transpiration characteristics of selected fresh fruits and vegetables. Agron Afr. 2005;17(2):103-15.

[49] Bovi GG, Herppich WB. Keeping fruits and vegetables fresh by limiting respiration and transpiration. Front Young Minds. 2021;9:576906.

[50] Silou T, Rocquelin, Mouaragadja IG, Gallon G. Contribution of the characterisation of safous (Dacryodes edulis) of Central Africa III. Chemical composition and nutritional characteristics of safou from Cameroon, Congo-Brazzaville, Congo-Kinshasa and Gabon. Riv Ital Sostanze Grasse. 2002;79:177-82.

[51] Ondo Azi AS, Ella Missang C, Silou T. Classification of Dacryodes edulis (G. Dom) H.J. Lam by using morphological and physical characteristics of the fruits: statistical approach. For Trees Livelihoods. 2009;19(2):99-109.

[52] Krisher O, Kroll K. Drying techniques. 2nd ed. Orsay: CETIAT; 1963.

[53] Awotona EO, Alade AO, Adebanjo SA, Duduyemi O, Afolabi TJ. Estimating moisture absorption kinetics of sword beans during soaking using Midilli model. Eng Technol Res J. 2020;5(2):76-80.

[54] Yildirima A. Kinetics and thermodynamic properties of parboiled burgos wheat (Triticum durum) in Turkey during drying. Appl Ecol Environ Res. 2018;16(1):495-510.

[55] Charmongkolpradit S, Luampon R. Study of Thin Layer Drying Model for Cassava Pulp. Energy Procedia. 2017;138:354-9.

[56] Fang S, Wang L-P, Wu T. Mathematical modelling and effect of blanching pretreatment on the drying kinetics of Chinese yam. Chem Ind Chem Eng Q. 2015;21(4):511-8.

[57] Khawas P, Dash KK, Das AJ, Deka SC. Drying Characteristics and Assessment of Physicochemical and Microstructural Properties of Dried Culinary Banana Slices. Int J Food Eng. 2015.

[58] Porniammongkol O, Duangkhamchan W, Inchuen S. Evaluation of thin-layer drying models for Jerusalem artichoke (Helianthus tuberosus L.) tubers in different drying methods. Suranaree J Sci Technol. 2014;21(1):47-58.

[59] Binaki AC, Bopoundza FC, Loumouamou BW, Nguié Gueko S, Biassala ET, Silou T. Modelling the kinetics of moisture desorption from safou pulp (Dacryodes edulis (G. Don) H. J. Lam) before the oil extraction step. Open J Appl Sci. 2024;14:2050-64.

[60] Crank J. The mathematics of diffusion. 2nd ed. Oxford: Clarendon Press; 1975.

[61] Peleg M. An empirical model for the description of moisture sorption curves. J Food Sci. 1988;53(4):1216-7.

[62] Bonazzi C, Bimbenet J-J. Drying of food products: principles. Engineering techniques. Agri-food. 2003;2(F3000):F3000-1.

[63] Youcef-Ali N, Moummi JY, Desmons A, Abène H, Messaoudi M, Le Ray. Numerical and experimental study of dryer in forced convection. Int J Energy Res. 2001;25(6):537-53.

[64] Toğrul IT, Pehlivan D. Mathematical modelling of solar drying of apricots in thin layers. J Food Eng. 2002;55:209-16.

[65] Ferradji A. Solar drying of figs: Heat balance and desorption isotherm. Renew Energy Rev. 2011;14(4):3-4.

[66] Tetang Fakone A, Edoun M, Kuitche A, Kengue C. Modelling of drying kinetics of fresh carrots (Dacus carota). Int J Innov Appl Stud. 2013;4(2):375-81.

[67] Boy V, Khalifa WB, Lemée Y, Drévillon L, Lendormi T, Lanoiselle J-L. Intensification of drying by intermittent impact air jets. The case of apples and mangoes. In: 17th edition of the French Society of Process Engineering Congress; 2019 Oct; Nantes, France.

[68] Noumi GB, Njouokam YM, Njiné CB, Ngameni E, Kapseu C. Effects of drying on the yield and quality of oil extracted from safou pulp. Tropicultura. 2011;29(3):138-42.

[69] Dissa AO, Bathiebo J, Kam S, Savadogo PW, Desmorieux H, Koulidiati J. Modelling and experimental validation of thin layer indirect solar drying of mango slices. Renew Energy. 2009;34(1):1000-8.

[70] Danjouma AKA, Kouebou CPA, Kameni A, Tchiegang C, Yezouma C, Desmorieux H. Study of some conditions for the production and preservation of dried tomatoes. Cah Agric. 2007.

[71] Benseddik A, Azzi A, Allaf K. Modelling of pumpkin desorption isotherms for solar drying. In: Proceedings of the SIENR’14 GhardaïA; 2014; GhardaïA. p. 173-82.

[72] Bouverat-Bernier JP. Optimisation of drying conditions for peppermint leaves. Herba Gallica. 1990;1:83-95.

[73] Odile B-B. Study of the effects of heat treatment on the quality (flavour and colour) of several aromatic plants: Basil, Ocimum basilicum L.; Mint, Mentha piperita; Parsley, Petroselinum sativum Hoffm; Tarragon, Artemesia dracunculus L [PhD thesis]. Paris: University of Paris VII; 1991.

[74] Okoli PN, Obassi BN. Implication of cell wall degrading enzymes in the heat- induced softening of the African pear (Dacryodes edulis (G. Don) H.J Lam). J Sci Food Agric. 1992;59:59-63.

[75] Ella Missang C, Baron A, Drilleau JF. Enzymatic maceration of apple parenchyma tissue. II. Effect of the degree of ripeness on the kinetic behaviour. Food Biotechnol. 2001;15(2):135-45.

[76] Ella Missang C, Baron A, Renard CMGC. Cell wall-degrading enzymes and changes in cell wall polysaccharides during ripening and storage of bush butter (Dacryodes edulis (G. DOM) H.J. Lam) fruit. J Hortic Sci Biotechnol. 2004;79(5):797-805.

[77] Bassiloua JB, Bimvoukoulou R, Bopoundza FC, Andzanga LM, Makomo H, Silou T. Modelling the sequential extraction of water and oil essential from Cymbopogon citratus acclimatised in the Plateau des Cataractes. Empir Diffus Desorpt Models. Int J Nutr Food Sci. 2025;14(4):226-36.

[78] Bopoundza FC, Binaki AF, Biassala ET, Loumouamou BW, Nguié Ngueko S, Siassa Massamba JA, et al. Modelling of the extraction kinetics of oil from safou pulp (Dacryodes edulis (G. Don) H.J. Lam) by heating in hexane with stirring. Int J Appl Sci Biotechnol. 2024;12(4):224-34.

[79] Lara I, Heredia A, Dominguez E. Shelf life potential and the fruit cuticle: The unexpected player. Front Plant Sci. 2019;10:770.

[80] Linke M, Hoffmann TG, Sonawane AD, Rux G, Mahajan PV. Method for measuring the transpiration resistance of fruit and vegetables. MethodsX. 2024;13:103058.