Available Online at http://www.journalajst.com

ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN: 0976-3376

Asian Journal of Science and Technology
Vol. 16, Issue, 03, pp. 13546-13554, March, 2025

RESEARCH ARTICLE

CONSERVATION TEST OF FRESH SAFOUS (DACRYOSDES EDULIS (G. DON) H.J. LAM) BY THERMAL DENATURATION OF SOFTNING ENZYMES

Feueltgaldah Christian Bopoundza[1], Rama Christ Balenkali[1], Eliane Thérèse Biassala[1,3], Bob Wilfrid Loumouamou[1,2,3], Anicet Frédéric Binaki[1,2,3] and Thomas Silou[1,3]

[1]Multidisciplinary Food and Nutrional Research Team, Regional Center of Excellence in Food and Nutrition, Faculty of Sciences and Technology, Marien Ngouabi University, Brazzaville, Congo
[2]Process Engineering Laboratory, UNESCO-ENSP Chair, Marien Ngouabi University, Brazzaville, Congo
[3]CR2IE, Chemistry and Technology Platform, Higher School of Cataract Technology (EPrES), Brazzaville, Congo

ARTICLE INFO

Article History:
Received 08th January, 2025
Received in revised form
26th January, 2025
Accepted 20th February, 2025
Published online 24th March, 2025

Keywords:

Fresh safous, Softening enzymes, Thermal denaturation, Conservation test.

ABSTRACT

Safou, an oilseed native to the Gulf of Guinea, is a highly perishable fruit, making it difficult to preserve and market. Its high perishability is attributed to the intense activity of cell wall degrading softening enzymes and its high-water content. Several alternatives have already been proposed to overcome this difficulty: storage in an aerated environment or at low temperature, pulp drying, oil extraction, processing into various food products (spreads, cookies, etc.). In spite of these efforts, the need for fresh fruit remains strong, thanks to its health benefits. The application of heat treatment in 4th range products is a good example. It has already shown good results in inhibiting the softening enzymes of several fruits, but unfortunately at temperatures harmful to saffron. Thermal denaturation of safou was carried out in boiling water for 1 min up to 10 min for whole fruit and up to 30 min for half pulp. 7 min seems to be the maximum time for effective denaturation of softening enzymes for whole fruit, and 1 min is more than sufficient for half pulp. Monitoring of the conservation of denatured half pulp in the presence of antifungal agents led to drying after 80 days, with an average water loss of 0.2%, probably facilitated by the opening and closing of the storage jars.

Citation: ***Feueltgaldah Christian Bopoundza, Rama Christ Balenkali, Eliane Thérèse Biassala, Bob Wilfrid Loumouamou, Anicet Frédéric Binaki and Thomas Silou.*** **2025.** "Conservation test of fresh safous (Dacryosdes Edulis (G. Don) H.J. Lam) by thermal denaturation of softning enzymes", *Asian Journal of Science and Technology*, 16, (03), 13546-13554.

INTRODUCTION

Safou, the fruit of the safou tree (*Dacryodes edulis*), is a rich source of fats (oil), vitamins, minerals and proteins (U. Omoti and D. Okiy, 1987; S. Kiakouama & T. Silou, 1987; T. Kinkela & J. Bezard, 1993; C. Kapseu & Tchiegang, 1996; A. Awono *et al*, 2002). Unfortunately, its conservation is a real problem for players in the sector (G. B. Noumi *et al.*, 2006), handicapping local, national and international marketing (H. Tabuna, 1993, 1999, 2002, H. Tabuna & M. Tanoe; 2009; A. Awono *et al.*, 2002) and the establishment of reserves during periods of shortage (T. Silou *et al.*, 2007). Its high perishability, attributed to the intense activity of softening enzymes that degrade the cell walls (P. N. Okolie and B. N. Obasi, 1992; C. Ella Missang *et al.*, 2001, 2004) and its high water content (J. Kengué, 2002; F. C. Bopoundza *et al.*, 2020), has already been the subject of several studies (L. C. Emebiri and M. I. Nwufo, 1990; T. Silou *et al.*, 1991, 1995, 2007; A. Noumi *et al.*, 2006; Ndindeng *et al.*, 2012; B. R. Dossou *et al.*, 2014; P. Diakabana *et al.*, 2021). Drying the pulp, which appears to be the simplest and most effective preservation technique (A. Ali *et al.*, 1997; A. Noumi *et al.*, 2006; D. Massamba *et al.*, 2012) for later consumption (H. Tabuna and Kayitavu, 2008; S. A. Ndindeng *et al.*, 2012), is not unanimously supported (H. Tabuna, 2002).

***Corresponding author:** **Feueltgaldah Christian Bopoundza**

Its transformation into certain food products ready for consumption (A. Noumi *et al.*, 2006; S. A. Ndindeng *et al.*, 2012; P. Diakabana *et al.*, 2021) has been slow to find real industrial applications. Despite all these efforts, it should be noted that the need for fresh fruit remains, thanks to its health benefits. In France, for example, the Programme National Nutrition Santé (PNNS) recommends eating "5 fruits and vegetables a day", thanks to their high micronutrient content, their protective effects against major chronic diseases and their low energy content, which is a major cause of overweight and obesity. As far as safflower is concerned, it must be recognized that it cannot be offered as a fresh fruit without any action on the enzymes that soften it. In addition, the application of heat treatment to 4th range products has been found to slow down the softening of many fruits (E. Maxie *et al.*, 1974; I. L. Eaks, 1978; M. Tsuji *et al.*, 1984; S. Lurie, 1998), albeit at temperatures detrimental to safflower, as reported by P. N. Okolie and B. N. Obasi (1992). In the same study, the same authors point out that at temperatures above 85°C, safou pulp hardens and does not soften, even when subjected to lower temperatures. Among other things, the development of the safou pulp preservation process using the DII method recently proposed by P. Diakabana *et al.* (2021) surely requires the inactivation of softening enzymes, even if the authors do not seem to be clearly attached to this fact, since this study proceeds by cooking the samples before their conservation. Also, industry players report that "safou does not soften when boiled". So, in the context of proposing innovative techniques that are simpler, more efficient and less costly, and given that proteins denature at temperatures ranging from 65 to 80°C, we tried to thermally denature the enzymes in the softening of safou with a view to preserving it as a fresh fruit.

MATERIAL AND METHODS

Plant Material: Due to the highly perishable nature of this fruit, the safous studied were purchased progressively in the Brazzaville markets as and when the need arose. Each purchase was called a lot. As a result, the safous had several origins: Boundji (Central Cuvette Department), Djambala (Plateaux Department), Kinkala (Pool Department) and Brazzaville (Brazzaville Department). The selection criteria during purchasing were:

- the dark blue or black color of the fruit, which characterizes the ripeness of safou,
- the firmness of the fruit, assessed by touch, to ensure that it has not softened,
- and the date of harvest or purchase in the production area, although less reassuring, but allows you to predict the duration of handling.

The characteristics of the safous studied are shown in Table 1.

Improvement of the conservation conditions for the safous studied

Once the safous studied had been attacked by molds in the open air, the conservation of the samples under a modified atmosphere was essential for a better assessment of the results. This involved monitoring the behavior of safflower pulp immersed in boiling water in the presence of essential oil, recognized for its antifungal properties (D. R. Batish *et al.*, 2008; A. Sirima *et al.*, 2020). Samples (batch 3) were introduced into closed, sufficiently airtight plastic jars in the presence of a drop of *Cymbopogon nardus* essential oil (T. Silou *et al.*, 2017). Each time the behavior of the samples was monitored, a new drop of essential oil was added before the jar was closed.

Maximum shelf life in the presence of agents: The evaluation of the maximum shelf life in the presence of *Cymbopogon nardus* essential oil was studied in order to minimize its use. The safflower pulps studied (batch 4) were placed in closed jars in the presence of *Cymbopogon nardus* essential oil. After one day, a sample was removed from the jar, placed on a plastic plate in the open air and allowed to weather; a drop of essential oil was again added to the jar, followed by the other samples. This operation was repeated every day for two weeks.

Table 1. Morphological and physical characteristics of the safous studied

Features	Length (cm)	Width (cm)	Fruit weigth (g)	Pulpe weigth (g)
Batch 1 (30 fruits)	7,45 (±0,44)	4,00 (±0,32)	67,66 (±9,90)	-
Batch 2 (45 fruits)	6,57 (±0,51)	4,03 (±0,28)	59,71 (±8,17)	43,13 (±5,65)
Batch 3 (29 fruits)	6,01 (±0,23)	4,05 (±0,22)	56,51 (±7,15)	38,28 (±5,21)
Batch 4 (34 fruits)	5,99 (±0,29)	4,01 (±0,20)	55,92 (±5,46)	37,99 (±3,95)

METHODS

Thermal denaturation of the safous studied

Reminder: In view of safous behavior towards heat (P. N. Okolie and B. N. Obasi, 1992), thermal denaturation could not be the subject of a quarantine treatment (J. D. Klein and S. Lurie, 1992). Only enzymatic denaturation at 100°C (boiling water) was considered.

Application: Safous, whole fruits (batch 1) and half-pulps (batch 2), were immersed in boiling water (J. L. Sharp, 1994) for well-defined times. 1 min, 2 min, 3 min, 4 min, 5 min, 6 min, 7 min, 8 min, 9 min and 10 min for whole fruit and up to 30 min for half pulp with 5 min withdrawal. Three samples (whole fruit or half-pulps) were removed from the boiling water at each scheduled time, and storage followed.

Monitoring the behavior of safous after immersion in boiling water: Once removed from the boiling water, the safous (whole fruits or half-pulps) were placed on plastic plates in the open air, sorted in ascending order of immersion time as a reference number, and covered with an enameled cloth to protect them from attack by small insects (Figure 1). The behavior of the fruits studied was assessed every morning at 9 a.m. and every evening at 4 p.m. The aim was to assess structural variations during storage (firmness, color, odor, etc.). In the absence of a penetrometer, fruit firmness was assessed by hand touch, and other characteristics by our sensory organs (eye, nose, etc).

Figure 1. Monitoring the conservation of safous studied in the open air

Monitoring changes in the mass of safous studied: The main objective of the study, contrary to the results obtained, was to preserve fresh safous. Thus, since monitoring was carried out under ambient conditions, away from any source of heat (sun, etc.), and since dehydration of the fruit studied was very slow, the latter remained moist for a long period and could be considered to be preserved fresh, according to the objective of the study. However, it was necessary to know how long the fruit would retain the moisture acceptable for freshness. We therefore monitored the mass of the samples studied (batch 4) on a daily basis, in order to assess daily water loss under the conditions of the experiment.

Figure 2. Behavior of safflower pulp in the presence of *Cymbopogon nardus* essential oil

Furthermore, we found that the mass of the samples increased slightly (less than 0.1%) during immersion during denaturation; thus, the initial mass for monitoring dehydration during storage was that obtained after withdrawal into boiling water, which we noted. m_1 the quantity of water lost each day (d) is obtained by the equation below.

$m_{water(l)}(d) = m_d - m_{d-1}$ Eqn.1

with:

- d: day of measurement or weighing ($d \geq 2$)
- $m_{water(l)}(d)$: mass of water lost by the pulp until the following day,
- m_d: pulp mass on the day of measurement,
- m_{d-1}: pulp mass the previous day.

The mass of water in the pulp m_{water}, determined after oven drying, is given by the formula:

$m_{water} = m_1 -_{(oven)}$ Eqn. 2

with:

- $m_{(oven)}$: mass after drying in a oven,
- m_1: pulp mass after immersion.

This makes it possible to determine the water content of pulp after immersion in boiling water:

$$\%_{water} = \frac{m_1 - m_\infty}{m_1} x100 \quad \text{Eqn. 3}$$

with m_∞mass of dehydrated pulp, and the amount of water remaining in the samples studied daily, noted $m_{water(R)}(j)$:

$m_{water(R)}(d) = m_{water(R)}(d-1) - m_{water(l)}(d)$ Eqn. 4

With$m_{water(R)}(d-1)$ the water mass of the previous day.

Then the daily water content of preserved pulp:

$$\%_{water}(d) = \frac{m_{water(R)}(d)}{m_1 - m_{water(l)}(d)} x100 \quad \text{Eqn. 5}$$

RESULTS AND DISCUSSION

Characteristics of heat-treated safous: Safous and half-pulps, after immersion in boiling water, showed a remarkable decrease in epicarp color, from dark blue or black to a slightly violet color (Figure 3), and a slight increase in mass (less than 0.1%) due to water absorption during immersion. Fruit firmness was maintained. These results confirm the studies of P. N. Okolie and B. N. Obasi (1992), according to which activity of safflower-softening enzymes was negligible at 100°C, and the speculations of industry players who claim that safflower does not soften when boiled.

a. Safous to buy **b-Heat-treated safous**

Figure 3. Color difference between mother and heat-treated safflower

Monitoring the behavior of safous after immersion in boiling water: Monitoring of storage in the open air showed very different behavior between whole fruit and half pulp. In the case of whole fruits (Table 2), safous immersed for 1 min to 3 min deteriorate from the first day, and rapidly up to the second day of storage. On the other hand, safous immersed for 4 to 7 min showed progressive spoilage, inversely proportional to immersion time, and 7 min of immersion appears to be the maximum duration for denaturation of the enzymes involved in softening safou fruits with boiling water, if we take into account the duration of the onset of spoilage. From 8 min immersion onwards, safous also spoil from the first day, but more slowly than those immersed for 1 to 3 min. Fruit spoilage in this study was characterized by a slight loss of firmness, without epicarp splitting or oil leakage, followed by the appearance of fruit shrinkage, attack by fungal microorganisms (molds) and then the sensation of a rotting odor.

Table 2. Fruit firmness after removal in boiling water

Immersion time (min)	Fruit number	D1		D2		D3		D4	
		M*	E**	M	E	M	E	M	E
1	1	15	25	50	100	100	100	100	100
	2	20	50	80	100	100	100	100	100
	3	50	60	75	100	100	100	100	100
2	4	25	30	60	100	100	100	100	100
	5	30	30	75	100	100	100	100	100
	6	15	50	100	100	100	100	100	100
3	7	15	25	50	90	100	100	100	100
	8	25	30	75	100	100	100	100	100
	9	20	20	20	20	100	100	100	100
4	10	0	0	10	50	100	100	100	100
	11	0	0	25	75	100	100	100	100
	12	0	0	30	80	100	100	100	100
5	13	0	0	0	75	100	100	100	100
	14	0	0	0	75	100	100	100	100
	15	0	0	0	100	100	100	100	100
6	16	0	0	0	75	100	100	100	100
	17	0	0	0	80	100	100	100	100
	18	0	0	0	75	100	100	100	100
7	19	0	0	0	0	95	100	100	100
	20	0	0	0	0	100	100	100	100
	21	10	15	25	50	100	100	100	100
8	22	25	50	60	75	100	100	100	100
	23	20	25	40	50	75	100	100	100
	24	5	15	20	20	20	100	100	100
9	25	20	50	80	100	100	100	100	100
	26	15	50	75	80	90	100	100	100
	27	5	10	15	25	25	95	100	100
10	28	8	15	25	25	25	95	100	100
	29	25	30	50	75	100	100	100	100
	30	5	10	25	30	50	75	100	100

*morning, **evening

Tainting does not appear to be due solely to the effect of softening enzymes, but rather to a combined action of softening enzymes, the high-water content of safflower and, surely, the physiological disruption of the fruit caused by heat; since the characteristics of tainting appear to be the opposite of those of softening, which does not degrade the fruit or render it unsuitable for consumption. P. N. Okolie and B. N. Obasi (1992) observed the softening of safou under the effect of heat. Safou lost their firmness; they expanded, followed by splitting of the epicarp and leakage of oil. Even at room temperature, the softening of the safou is very often followed by the leakage of oil through the split epicarp. This is not the case here. Altered safou do not seem to lose their firmness properly, and do not show any leakage of fat, despite alteration and mould attack. These results confirm the progressive denaturation of safou softening enzymes by heat through boiling water as a function of immersion time. Figure 4, which shows the evolution of the percentage of daily fruit spoilage as a function of immersion time, shows rapid and decreasing daily fruit spoilage as a function of immersion time between the 1st and 7th min of immersion, This confirms the progressive inactivation of softening enzymes in proportion to immersion time, followed by an almost similar and less rapid daily deterioration, between the different individuals, from the 8th minute of immersion, despite fluctuations, suggesting non-enzymatic activity. Half pulps, on the other hand, give a better result (Table 3). None of the pulp halves were altered up to day 3, probably due to the exposure of both sides to heat, which increases pulp contact with the heat source, their thinness, which facilitates heat transfer to the interior of the treated samples, and the absence of the core, which would absorb much of the heat, thus minimizing the denaturation process. The softening enzymes appear to be totally denatured, in this case within the first minute of immersion.

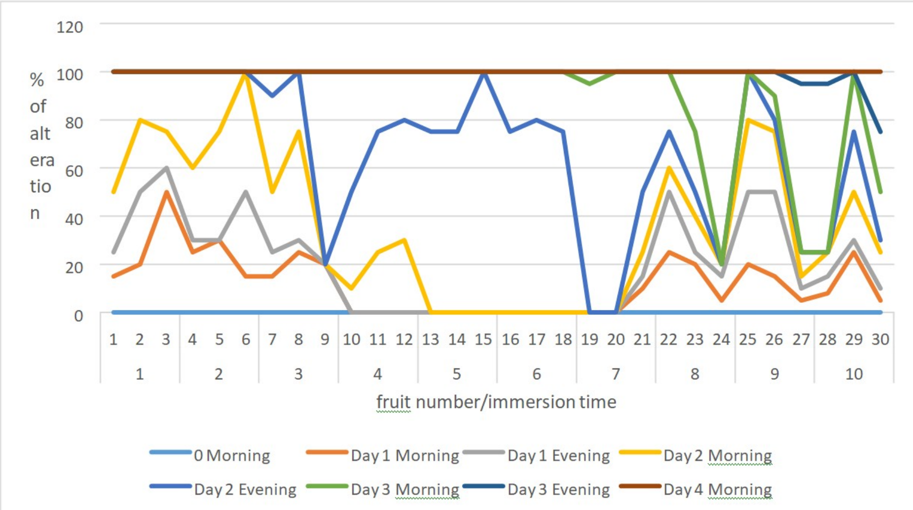

Figure 4. Daily fruit weathering trend

Table 3. Firmness of half-pulps after removal in boiling water

Immersion time (min)	Halp-pulp number	D1		D2		D3		D4		D5		Today
		M	E	M	E	M	E	M	E	M	E	
1	1	0	0	0	0	0	0	0	0	Mo*		
	2	0	0	0	0	0	0	0	0	Mo		
	3	0	0	0	0	0	0	0	0	Mo		
2	4	0	0	0	0	0	0	0	0	Mo		
	5	0	0	0	0	0	0	0	0	Mo		
	6	0	0	0	0	0	0	0	0	Mo		
3	7	0	0	0	0	0	0	Mo				
	8	0	0	0	0	0	0	Mo				
	9	0	0	0	0	0	0	Mo				
4	10	0	0	0	0	0	0	0	0	0	0	Dryer
	11	0	0	0	0	0	0	0	0	0	0	Dryer
	12	0	0	0	0	0	0	0	0	0	0	Dryer
5	13	0	0	0	0	0	0	Mo				
	14	0	0	0	0	0	0	Mo				
	15	0	0	0	0	0	0	Mo				
6	16	0	0	0	0	0	0	Mo				
	17	0	0	0	0	0	0	Mo				
	18	0	0	0	0	0	0	Mo				
7	19	0	0	0	0	0	0	Mo				
	20	0	0	0	0	0	0	Mo				
	21	0	0	0	0	0	0	Mo				
8	22	0	0	0	0	0	0	Mo				
	23	0	0	0	0	0	0	Mo				
	24	0	0	0	0	0	0	Mo				
9	25	0	0	0	0	0	0	Mo				
	26	0	0	0	0	0	0	Mo				
	27	0	0	0	0	0	0	Mo				
10	28	0	0	0	0	0	0	Mo				
	29	0	0	0	0	0	0	Mo				
	30	0	0	0	0	0	0	Mo				
15	31	0	0	0	0	0	0	0	0	0	0	Dryer
	32	0	0	0	0	0	0	0	0	0	0	Dryer
	33	0	0	0	0	0	0	0	0	0	0	Dryer
20	34	0	0	0	0	0	0	Mo				
	35	0	0	0	0	0	0	Mo				
	36	0	0	0	0	0	0	Mo				
25	37	0	0	0	0	0	0	Mo				
	38	0	0	0	0	0	0	Mo				
	39	0	0	0	0	0	0	Mo				
30	40	0	0	0	0	0	0	Mo				
	41	0	0	0	0	0	0	Mo				
	42	0	0	0	0	0	0	Mo				

*Presence of mold

Alteration seems to be caused solely by the action of fungal microorganisms, the appearance of which was the reason for discontinuing conservation monitoring, followed by the smell of decay. These results confirm the conclusions drawn above. The high-water content of the fruit and its exposure to the open air are highly conducive to mold growth.

From these samples, two groups' pulps (4 min and 15 min immersion), which were not attacked by molds, eventually dried (Figure 5). These two groups of pulps, unaffected by mold and unaltered until completely dry, lead us to conclude that the alteration of safous heat-treated with boiling water is due to mold attack.

a) Internal view b) External view

Figure 5. Denatured (4 min and 15 min), unaltered, air-dried pulp halves

The structure of these dried half-pulps is very different from that of commonly dried safous. They have a very high degree of hardness, compared with commonly dried safflower, which has a soft appearance and is easy to crush by hand. The very hard character of these two groups of pulps treated with boiling water and then dried, very different to that of commonly dried safous, confirms the absence of softening enzymatic activity during monitoring of their behavior after treatment with boiling water; because commonly dried safflower pulp, whether oven-dried or dried in any type of dryer, always undergoes softening, manifested by loss of firmness, due to the action of enzymes, favored by the slow, gradual increase in heat within the pulp, followed by dehydration. The soft character of dried safou pulp, different from that obtained in the present study, is evidence of the destruction of cell membranes during softening of the pulp during drying (C. Ella Missang *et al.*, 2001, 2004; R. Nout *et al.*, 2003).

Monitoring in the presence of Cymbopogon nardus essential oil: Given the better results obtained with half-pulps, only the latter were monitored in the presence of *Cymbopogon nardus* essential oil. The results were very satisfactory. No half-pulp was altered in the presence of *Cymbopogon nardus* essential oil. They were all preserved and eventually dried. These results confirm the conclusions drawn above that spoilage of denatured safous is due to mould attack and not to the activity of softening enzymes. The high-water content of the fruit also had no effect on the spoilage of the half-pulps studied when preserved in the presence of *Cymbopogon nardus* essential oil. Also, rotting is not the cause of spoilage, but rather a consequence of it, caused by mold attack. In addition, monitoring in the presence of *Cymbopogon nardus* essential oil showed that safflower pulps treated with boiling water retained their color for over a week, which is an advantage for their proposal as a 4^{th} range fruit (R. C. Wiley, 1997). These results obtained on safou pulp show that it can be used as a 4^{th} range fruit (R. C. Wiley, 1997) by heat treatment at 100°C/1 min immersion followed by preservation in a modified atmosphere with guaranteed food value (R. Jacquot, 1954), as the moderate temperatures usually applied to fruit (R. E. Paull and N. Jung chen, 2000), although causing several fruits to slow down softening (E. Maxie *et al.*, 1974; I. L. Eaks, 1978; M. Tsuji *et al.*, 1984; S. Lurie, 1998) due to inhibition of cell wall hydrolase synthesis (H. T. Chan *et al.*, 1981; O. Yoshida *et al.*, 1984; H. Lazan *et al.*, 1989; J. D. Klein *et al.*, 1990; S. Lurie and J. D. Klein, 1991; N. Ben-Shalom *et al.*, 1993; N. Ben-Shalom *et al.*, 1996; G. O. Sozzi *et al.*, 1996; S. Lurie and A. Sabehat, 1997), are detrimental (P. N. Okolie and B. N. Obasi, 1992).

Maximum shelf life in the presence of Cymbopogon nardus essential oil: The duration of the antifungal effect is also an interesting parameter, given the cost of essential oils and the fact that long-term application can affect the taste of the food. It proved impossible to assess the effect of essential oils in jars, as they had to be opened each time to assess changes in structure. This part of the study, fundamental and guaranteeing the effectiveness of the duration of the antifungal presence in relation to the conservation of denatured safou pulp for large-scale marketing, could be the subject of further study. On the other hand, monitoring in the open air gave poor results; two weeks storage in the presence of an antifungal agent proved insufficient for the exposure of denatured safou to the open air, and monitoring for a longer period could perhaps improve the results. Nevertheless, these results confirm the conclusions drawn above:

- Boiling water denatures the enzymes that soften safou.
- The deterioration of denatured safous is due to mold attack.
- The water present in the pulp has no effect on the safous alteration.
- Preservation in the presence of an antifungal agent is satisfactory, preventing mold attack.

Monitoring changes in the mass of denatured safou pulp during storage: The daily weights of safou half-pulps denatured in boiling water for 5 and 10 minutes and preserved in the presence of *Cymbopogon nardus* essential oil in closed jars are shown in Table 4 below.

Table 4. Daily weights of denatured safou half-pulps preserved in the presence of *Cymbopogon nardus* essential oil in closed jars

	Sample weigh (g)					
Heating time	5 min			10 min		
Day	1	2	3	1	2	3
1	15,424	17,121	15,298	20,202	20,282	16,883
2	15,387	17,045	15,121	19,600	19,698	16,397
3	15,329	17,004	15,06	19,300	19,535	16,225
4	15,298	16,874	14,826	19,247	19,445	16,185
5	15,262	16,847	14,751	19,201	19,376	16,108
6	15,251	16,812	14,536	19,124	19,299	16,044
7	15,166	16,582	14,344	18,978	19,266	15,841
8	15,022	16,525	14,386	18,878	19,204	15,658
9	15,398	16,5668	14,271	18,735	19,170	15,538
10	15,150	16,400	14,271	18,614	18,933	15,354
11	14,028	16,218	14,004	18,267	18,818	15,168
12	14,930	16,035	13,842	18,010	18,796	14,968
13	14,777	16,074	13,664	17,813	18,730	14,857
14	14,654	16,003	13,400	17,668	18,541	14,857
15	14,586	15,900	13,118	17,527	18,502	14,627
16	14,264	15,730	12,958	17,200	18,239	14,025
18	14,248	15,701	12,733	17,051	18,502	13,817
20	14,199	15,563	12,559	17,038	18,067	13,750
22	14,077	15,311	12,254	16,804	17,979	13,376
24	13,851	15,111	12,075	16,501	17,842	13,130
26	13,688	14,924	11,842	16,284	17,742	12,886
28	13,641	14,752	11,608	16,089	17,434	12,701
30	13,127	14,159	11,041	15,547	17,241	12,085
35	12,552	13,743	10,464	14,253	17,192	11,045
40	12,134	13,451	10,097	14,112	16,145	10,204
45	11,8016	13,139	9,502	14,024	15,352	9,756
50	11,624	12,852	9,054	13,808	14,756	8,924
55	11,475	12,652	8,587	13,685	14,185	8,485
60	11,284	12,476	7,951	13,485	13,902	7,852
65	11,124	12,113	7,228	13,253	13,757	7,504
70	10,954	12,924	7,039	13,112	13,356	7,354
75	10,670	11,802	6,921	12,124	12,041	6,598

These daily masses, represented graphically in Figure 6, decrease steadily, albeit with slight fluctuations, with almost similar slopes. No stabilization is observed until the seventy-fifth day, except for sample 1, which is heated for 10 minutes and appears to stabilize after the thirtieth day. Heating time does not appear to influence the rate of water removal from denatured and preserved half-pulps. It remains, although almost similar between the different samples, proportional to the water content (Table 6) as reported in the literature for undenatured safous (T. Silou, 1991; A. Ali *et al.*, 1997; D. Massamba *et al.*, 2012; A. F. Binaki *et al.*, 2024). Daily water loss appears to be highly variable within each individual and between individuals (Table 5 and Figure 7); however, this variability is minimized by the small quantities of water evacuated during storage, leading to almost constant decreases in mass (Figure 6).

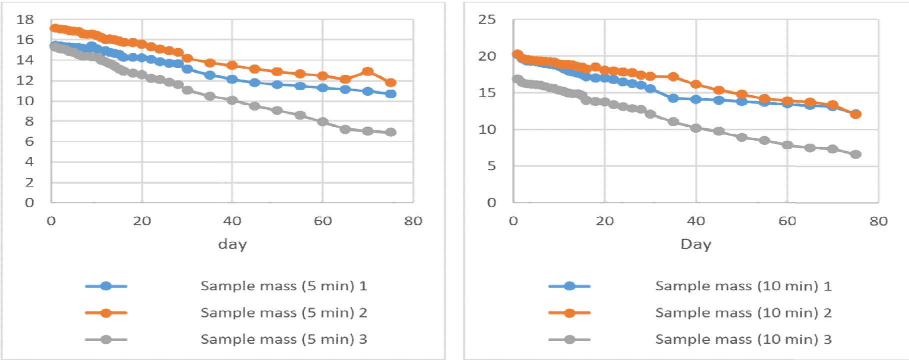

Figure 6. Mass trends for denatured samples preserved in the presence of lemongrass essential oil (*Cymbopogon nardus*)

Table 5. Daily water loss of samples

	$m_{water}(l)$ (g)					
Heating time	5 min heating			10 min heating		
Day	1	2	3	1	2	3
1	0	0	0	0	0	0
2	0,037	0,076	0,177	0,602	0,584	0,486
3	0,019	0,041	0,061	0,300	0,163	0,172
4	0,023	0,130	0,234	0,053	0,090	0,040
5	0,083	0,040	0,075	0,046	0,069	0,077
6	0,051	0,025	0,215	0,770	0,770	0,064
7	0,045	0,230	0,192	0,146	0,033	0,203
8	0,016	0,057	0,029	0,100	0,062	0,183
9	0,070	0,039	0,115	0,143	0,034	0,120
10	0,015	0,068	0,130	0,121	0,237	0,184
11	0,037	0,182	0,067	0,347	0,115	0,186
12	0,198	0,183	0,232	0,257	0,022	0,200
13	0,053	0,051	0,178	0,197	0,066	0,111
14	0,123	0,054	0,264	0,145	0,189	0,100
15	0,068	0,130	0,282	0,141	0,039	0,130
16	0,322	0,170	0,230	0,327	0,263	0,600
18	0,016	0,029	0,225	0,149	0,137	0,208
20	0,049	0,136	0,174	0,013	0,035	0,067
22	0,122	0,252	0,305	0,234	0,088	0,374
24	0,226	0,200	0,179	0,303	0,137	0,246
26	0,163	0,187	0,197	0,217	0,100	0,244
28	0,047	0,172	0,234	0,195	0,308	0,185
30	0,514	0,593	0,567	0,542	0,102	0,616
35	0,575	0,416	0,577	1,294	0,049	1,040
40	0,418	0,292	0,367	0,141	1,047	0,841
45	0,318	0,312	0,595	0,088	0,793	0,448
50	0,192	0,287	0,448	0,216	0,596	0,832
55	0,149	0,200	0,467	0,123	0,571	0,439
60	0,191	0,176	0,636	0,200	0,283	0,633
65	0,160	0,363	0,723	0,232	0,145	0,348
70	0,170	0,189	0,189	0,141	0,401	0,150
75	0,284	0,122	0,118	0,988	1,315	0,756

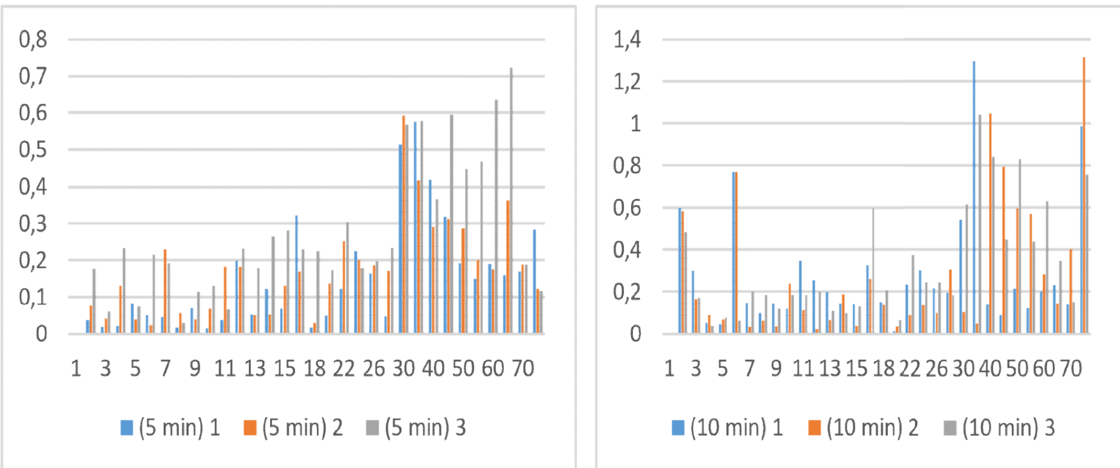

Figure 7. Daily water loss of denatured samples preserved in the presence of *Cymbopogon nardus* essential oil

As stabilization was not achieved until the seventy-fifth day, by which time the samples had already lost almost a third of their mass, and given that the water content of safou pulp varies between 40% and 70% of the fresh matter (T. Silou *et al.*, 1991; H. Ene-Obong *et al.*, 2019; F. C. Bopoundza *et al.*, 2020; A. F. Binaki *et al.*, 2024), we continued to dehydrate the half-pulps in an oven to determine the amount of water remaining in the pulps. The results obtained (Table 6) showed that the mass of preserved samples was close to stabilization. The residual water masses obtained, ranging from 0.55 to 1.18 g, corresponding practically to a water loss margin of 5 days, show us that effective dehydration of the preserved half-pulps should be reached 80 days later, corresponding to the maximum duration of water loss from denatured safou pulps, preserved in closed jars, with daily openings.

determined the average daily water losses of the samples studied (Table 8), which are respectively 0.067, 0.076 and 0.112 g for samples 1, 2 and 3 denatured for 5 min, and 0.116, 0.116 and 0.138 for samples 1, 2 and 3 denatured for 10 min. The average percentage of water released daily in relation to the water content of each sample is close to 0.20%, except for samples 1 and 2 denatured for 10 min, which are identically worth 0.25% (Table 7). Since daily water loss is virtually constant during storage under the conditions of experiment (Fig. 6), and since the preserved pulp is completely dry after 80 days, we can conclude that the pulp has lost three quarters of its water after 20 days of storage, half after 40 days and a quarter after 60 days. However, it should be noted that organoleptic assessment of the freshness of denatured and preserved safflower pulp cannot be based on simple mathematical calculation, but rather on panel tasting.

Table 6. Weight and moisture content of preserved half-pulps after oven drying

Heating time	5 min			10 min		
Half-pulp number	1	2	3	1	2	3
m(oven) (g)	10,059	11,052	6,371	10,943	11,014	5,831
$m(water)_r$ (g)	0,611	0,750	0,550	1,181	1,027	0,767
%water	32,69	35,48	58,39	46,27	46,20	65,77

Table 7. Average daily water loss for samples studied

Heating time	5 min				10 min			
Sample	1	2	3	average	1	2	3	average
Discharged water mass (g/j)	0,067	0,076	0,112	0,080	0,116	0,116	0,138	0,123
% water evacuated	0,20	0,21	0,19	0,20	0,25	0,25	0,21	0,24

Table 8. Daily water content of preserved pulp

	Water content (%)					
Heating time	5 min			10 min		
Day	1	2	3	1	2	3
1	34,78	35,45	58,35	45,53	42,282	62,58
2	34,87	35,61	59,04	46,92	44,03	64,34
3	34,59	35,09	57,43	43,14	42,37	60,32
4	34,47	35,03	57,68	41,168	41,36	58,83
5	34,46	34,08	55,54	40,89	40,84	56,58
6	33,85	33,91	55,56	42,18	39,86	56,07
7	33,5	34,17	54,05	37,03	34,61	56,16
8	33,15	32,4	52,22	36,22	34,5	54,87
9	33,15	32,11	52,32	35,58	34,14	53,58
10	32,58	31,94	51,62	34,83	34,32	53,06
11	32,53	31,78	50,55	34,62	32,93	51,96
12	32,63	30,68	50,66	32,72	31,58	50,7
13	31,04	29,31	48,95	31,34	32,18	49,43
14	30,83	29,02	48,04	30,27	32,06	48,74
15	29,92	28,83	46,34	29,54	30,87	48,23
16	29,98	28,13	44,31	29,11	31,03	48,82
18	27,29	26,9	42,77	27,22	29,53	44,08
20	27,25	26,9	41,13	26,3	28,7	42,47
22	27,06	26,28	40,33	25,53	28,6	42,86
24	26,44	25,66	39,6	25,44	29,23	40,28
26	24,59	23,51	37,67	23,82	27,5	38,79
28	24,66	22,38	36,46	22,71	27,29	37,2
30	25,12	21,91	35,69	22,12	25,49	37,04
35	21,76	18,13	31,87	20,13	24,91	34,15
40	17,7	15,53	27,55	12,51	23,66	27,24
45	14,82	13,81	25,48	11,79	17,98	21,47
50	12,61	11,93	21,23	10,78	13,77	19,2
55	11,59	10,18	18,23	9,66	10,73	13,68
60	10,37	8,98	15,28	9,08	7,72	11,14
65	9,375	8,03	10,98	8,09	6,26	7,12
70	8,12	5,81	5,81	6,9	5,61	4,95
75	7,13	1,14	4,54	6,4	3,77	4,21

This dehydration time for the denatured pulps studied, surely shortened by the daily opening and closing of the storage jars imposed by the experiment, each time disturbing the storage environment through contact with the ambient environment, could be improved if storage were carried out without opening the jars, a condition guaranteeing relative moisture balance between the stored pulps and the inside of the jars. However, based on the conditions of the experiment, and taking into account the 80 days considered to be the maximum storage time for fresh denatured pulp, we have

Table 8 shows the daily water content of the samples studied during preservation.

CONCLUSION

Thermal denaturation of the softening enzymes in safou can help to preserve it, and in particular its use as a 4th range fruit. Stone-free pulps seem to respond better to thermal denaturation, with treatment at 100°C and as early as 1st min immersion, thanks to the two sides exposed to the heat and the absence of the stone, which would absorb much of this heat; this means that whole fruits, whose positive effects seem to be apparent at the same temperature but after 7 min immersion, are more fragile to attack by fungal microorganisms. The non-softening of fruit or half-pulp after enzyme denaturation confirms earlier findings that softening enzymes are the main contributors to the softening of safflower pulp. The high-water content of the pulp does not appear to be a handicap to its preservation when kept in the presence of antifungal agents. Monitoring in the presence of *Cymbopogon nardus* essential oil enabled fresh, denatured safflower pulps to be preserved, characterized by low and virtually constant water loss in all samples. This loss of water, which calls into question the objective of this study, leads to the drying of the samples, which have a very high hardness compared with that of commonly dried safflower, after almost 80 days; a period surely shortened by the opening-closing of the preserving jars, thus disturbing the relative humidity balance of the preserving medium each time, the opposite of which could minimize these losses. Thus, improvements in experimental conditions, with weekly, monthly or quarterly monitoring, could yield better results in terms of the use of antifungals, modified atmosphere packaging and shelf life.

REFERENCES

A. Awono, O. Ndoyé & K. Schreckenberg 2002. La commercialisation de *Dacryodes edulis* dans la zone forestière du Cameroun, Actes du 3ème Séminaire international sur la valorisation du safoutier et autres oléagineux non conventionnels, Presses Universitaires d'Afrique, pp. 400-417.

A. F. Binaki, F. C. Bopoundza, B. W. Loumouamou, G. S. Nguié, E. T. Biassala, T. Silou (2024), Modeling the kinetics of moisture desorption from safou pulp (*Dacryodes edulis* (G. Don) H. J. Lam) before the oil Extraction step, Open Journal of Applied Sciences, Vol. 14, pp. 2050-2064. DOI: 10.4236/ ojapps. 2024.14813

A. Sirima, A. Sereme, D. Sereme, K koïta, T. A. Nana, & M. Sawadogo. (2020), Effets de quatre huiles essentielles sur la croissance mycélienne radicale d'un isolat de *Alternaria* sp. au Burkina Faso, *International Journal of Biological and Chemical Sciences,* Vol. 14, No. 3, pp. 762-771

Ali, A. Koumpo, L. A. K. Kenmegne, & T. Silou 1997. Séchage de la pulpe de safou pour sa valorisation, *Fruits,* Vol. 52, No. 3, pp. 167 – 176

B. R. Dossou; C. Ella Missang, A. Baron, M. G. C. Catherine, M. G. C. Renaed and T. Silou. (2012), Factors affecting postharvest preservation of safou (*Dacryodes edulis* (G. Don) H.J. Lam) fruits forests, Trees and Livelihoods, Vol. 21, No. 1, pp. 44-55

C. Ella Missang, A. Baron and J. F. Drilleau (2001), Enzymatic maceration of apple parenchyma tissu. II. Effect of the degree of ripeness on the kinetic behavior, *Food Biotechnology,* Vol. 15, No. 2, pp. 135-145

C. Ella Missang, A. Baron, and C.M.G.C. Renard (2004), 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 ; The Journal of Horticultural Science and Biotechnology, Vol. 79, No. 5, pp. 797-805

C. Kapseu, & Tchiegang (1996), Composition de l'huile des fruits de deux cultivars de safou au Cameroun, *Fruits,* Vol. 51, No. 3, pp. 185-191

D. Massamba, E. Matouba, G. Elenga, J Goma Maniongui, and T. Silou (2012), Mathematical Modeling of Microwave Drying of safou pulp, *Pakistan Journal of Nutrition*, Vol. 11, No. 6, pp. 553-560

D. R. Batish, H. Pal Sing, Kumar A. Kohli, and S.Shalinder Kaur (2008), Eucalyptus essential oil as a natural pesticide, *Forest Ecology and Management,* Vol. 256, pp. 2166-2174

E. Maxie, G. Mitchell, N. Sommer, G. Snyder, and H. Rae (1974), Effects of elevated temperature on ripening of « Bartlett » pear, *J. Am. Soc. Hort. Sci.,* Vol. 99, pp. 344-349

F. C. Bopoundza, B. W. Loumouamou, C. Ngounga Kiminou, A. F. Binaki, E. T. Biassala, D. Mampouya, and T. Silou (2020), Morphological and Physicochemical Characterization of Safous from Congo, Research Journal of Applied Science, Vol. 15, No. 10, pp. 296-304

G. B. Noumi, A. K. Aboubakar Dandjouma, C. Kapseu, & M. Parmentier (2006), Le savoir-faire local dans la valorisation alimentaire des fruits du safoutier (*Dacryodes edulis* (G. Don) H.J. Lam), au Cameroun, Tropiculture, Vol. 24, No. 1, pp. 58 – 62

G. Noat, J. Nari, A.-M. Moustacas, & M. Borel (1991), Propriétés des parois cellulaires végétales et interactions matrice-enzymes, Bulletin de la Société Botanique de France. Actualités Botaniques, Vol. 138:3-4, pp. 263-277

G. O.Sozzi, O. Cascone, and A. A. Fraschina (1996), Effect of high temperature stress on endo-β-mannase and α- and β-galactosidase activities during tomato fruit ripening, Postharvest Biology and technology, Vol. 9, pp. 49-63

H. Ene-Obong, G. Igile, A. Ekpo, E. Ekbung, and M. Agbo (2019), Variations in the nitrients and bioactive compounds of different accessions of the West Africa pear (Dacryodes edulis) ; Implication of dietary intake assessment and health, Journal of Food Composition and Analysis, Vol. 79, pp. 80-85

H. T. Chan, Jr., S. Y. T. Tram, and S. T. Seo (1981), Papaya polygalacturonase and its role in thermally injured ripening fruit, Journal of food Science, Vol. 46, pp. 190-197

H. Tabuna (1993), La commercialisation du safou à Brazzaville Montpellier, France, CIRAD-SAR, rapport interne, Vol. 82, No. 93, pp. 28

H. Tabuna (1999), Le marché des produits forestiers non ligneux de l'Afrique centrale eu France et en Belgique: produits, acteurs, circuits de distribution et débouchés actuels, Jakarta: CIFOR

H. Tabuna (2002), Stratégies de développement du marché du safou (*Dacryodes edulis*) en Europe, Actes du 3ème Séminaire international sur la valorisation du safoutier et autres oléagineux non-conventionnels, Presses Universitaires d'Afrique, pp. 449-463

H. Tabuna, I. Kayitavu (2008), Diagnostic technique et stratégie de développement des unités de transformation des aliments traditionnels en Afrique Centrale, ICRAF, Yaoundé, 99p

H. Tabuna, M. Tanoe (2009), Facteurs explicatifs et dévéloppement de la consommation actuelle du safou (*Dacryodes edulis*) au Cameroun, World Agroforestry Centre (ICRAF), 62p

H. Lazan, Z. M. Ali, K. S. Liang, and K. L. Yee (1989), Plygalacturonase activity and variation in ripening of papaya fruit with tissue depth and heat treatement, Physiologia Plantarum, Vol. 77, pp. 93-98

I. L. Eaks (1978), Ripening, respiration and ethylene production of « Hass » avocado fruits at 20 °C to 40 °C, J. Am. Soc. Hort. Sci., Vol. 103, pp. 576-578

J. D. Klein, and S. Lurie (1990), Prestorage heat treatement as a means of improving poststorage quality of apples,J. Am. Soc. Hort. Sci., Vol. 105, pp. 1327-1334

J. D. Klein, and S. Lurie (1992), Heat treatment for improved postharvest quality of horticultural crops, Hort Technology, Vol. 2, pp. 316-320

J. Kengue (2002), Safou (*Dacryodes edulis*). Monographie centre international de cultures sous utilisé, Southampton. 150p.

J. L. Sharp (1994), Hot water immersion. In: Sharp J. L., Hallman G. J. (Eds), Quarantine treatments for pests of food plants, westview press, Boulder, CO, USA, pp. 133-147

L. C. Emebiri, and M. I. Nwufo (1990), Effect of fruit type and storage treatments on the biodeterioration of African pear (*Dacryodes edulis* (G. Don) H. J. Lam), International Biodeterioration & Biodegradation, Vol. (26), pp. 45-50

M. Tsuji, H. Harakawa, Y. Komiyama (1984), Changes in shelf life and quality of plum fruit during storage at high temperature, *J. Jpn. Soc. Hort. Sci.,* Vol. 52, pp. 469-473

N. Ben-Shalom, J. Hanzon, J. D. Klein, and S. Lurie (1993), A postharvest heat treatement inhibits cell wall degradation in aplles during storage, *Phytochemistry,* Vol. 34, pp. 955-958

N. Ben-Shalom, J. Hanzon, R. Pinto, and S. Lurie (1996), Cell wall changes and partial prevention of fruit sotning in pre-storage heat treated « Anna » apples, *Journal Sci. Food Agric.,* Vol. 72, pp. 231-234

O. Yoshida, H. Nakagawa, N. Ogura, and T. Sato (1984), Effect of heat treatement on the developpement of polygalacturonase activity in tomato fruit during ripening, *Plant Cell Physiol,* Vol. 25; pp. 505-509

P. Diabakana, M. G. Dzondo, L. G. S. Mvili, R. H. Gampoula, & A. W. G. Tamba Sompila (2021), Mise au point d'un procédé de conservation de la pulpe de fruit de safou (*Dacryodes edulis*) par la méthode de déshydratation-imprégnation par immersion (DII), *Journal of Food Stability,* Vol. 4, No. 4, pp. 1-13

P. N. Okoli, and B. N. Obassi (1992), Implication of cell wall degradind enzymes in the Heat-induced softening of the african pear (*Dacryodes edulis* (G. Don) H.J Lam), *J Sci Food Agric,* Vol. 59, pp. 59-63

R. C. Wiley (1997), Preservation methods of minimally processed refrigeration foods and vegetables. In: Minimally processed refrigerated fruit and vegetables, New York: Chapman an Hall, pp. 66-134

R. E. Paull, and N. Jung Chen (2000), Heat treatement and fruit ripening, Postharvest Biology and Technology, Vol. 21, pp. 21-37

R. Jacquot (1954), Traitement thermique et valeur alimentaire. Annales de zootechnie, Vol. 3, No. 3, pp. 189-214, hal-00886608

R. Nout, J.D. Hounouigan, & T. Van Boekel (2003), Quelques facteurs de détérioration des aliments. In: Les aliments: Transformation, conservation et qualité. Backhus Publishers, CTA Wageningen, The Netherlands, pp. 15-51.

S. A. Ndindeng, Z. Ambang, N. Woin, F. A. Ngome, S. A. Njebu, D. Mapiemfu-Lamaré, W. N. Leke, J. M. A. Etoa, G. L. Chi, and V. T. Mbah (2012), Valorisation of *Dacryodes edulis* fruit (safou) through improved drying procedures, packaging and processing, Frontiers in Science,Vol. 2, No. 6, pp. 250-255

S. Kiakouama, & T. Silou (1987), Le safou ou atanga : fruit à vocation régionale dans le golfe de Guinée, analyse physico-chimique, Muntu, Revue du CICIBA Vol. 6, pp. 137 – 151

S. Lurie (1998), Postharvest heat treatement of horticultural crops, *Horticultural Reviews*, Vol.: 22, pp. 91-121

S. Lurie, and A. Sabehat (1997), Prestorage temperature manipulation to reduce chilling injury in tomatoes. *Postharvest Biology and technology*, Vol. 11, pp. 57-62

S. Lurie, J. D. Klein (1991), Acquisition of low temperature tolerance in tomatoes by exposure to high temperature stress, *J*. Am. Soc. Hort. Sci., Vol. 116, pp. 1007-1012

T. Kinkela, et J. Bezard (1993), Etude de la structure des triglycérides de l'huile de la pulpe de safou (*Dacryodes edulis*), Rev. Fr. Corps Gras, Vol. 40, pp. 373-382

T. Silou (1996), Le safoutier (*Dacryodes edulis*): Un arbre mal connu, Fruits, Vol. 51, No. 1, pp. 47-60

T. Silou, & E. Avouompo (1997), Perspectives de production de l'huile de safou, Bulletin Africain Bioressources, Energie, Développement, Environnement., Vol. 8, pp. 7-13

T. Silou, D. Massamba, J. Goma Maniongui, M. G. Maloumbi, and S. R. Biyoko (2007), Post harves losses by naturel oftening of safou pulp (*Dacryodes edulis*) in Congo Brazzaville, Journal of Food Engineering, Vol. 79, pp. 392-400

T. Silou, J. Goma Manouigui, P. Boungou, & J. M. Ouamba (1991), Etude du séchage de la pulpe de safou : Résultats préliminaires. Tropicultura, Vol. 9, No. 2, pp. 61-68

T. Silou, J. P. Bitoungui, &G. Mavah (1995), Mesure du ramollissement naturel de la pulpe de safou par pénétromètre, Fruit, Vol. 50, pp. 375-378

T. Silou, R. Kama-Niamayoua, D. Mampouya, T. Kinkela, &L. Hernalesteren (2000 b), Contribution à la caracterisation des safous (*Dacryodes edulis*) d'Afrique centrale, importance de la culture et caracteristiques morphologiques des fruits de safoutiers dans le district de Boko au Congo Brazzaville, Bulletin africain RABEDE, Vol. 12, pp. 21 – 29

T. Silou, R. Bikanga, S. Nsikabaka, J. Nombault, C. Mavoungou, G. Figuérédo, and J. C. Chalchat. (2017), Plantes aromatiques du Plateau des Cataractes (Bassin du Congo). Caractérisation du chémotype de l'huile essentielle de Cybompogon nardus (L.) Rendle acclimaté au Congo-Brazzaville, *Biotecnol. Agron. Soc. Environ.,* Vol. 21; No. 2, pp. 105-116

U. Omoti, and D. Okiy (1987), Characteristics and composition of the pulp oil and cake of the African pear, *Dacryodes edulis* (G. Don) H. J Lam, *Journal of the Science of Food and Agriculture*, Vol. 38, No. 1, pp. 67-72

****