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(RESEARCH ARTICLE)



Assessment effects of post-harvest softening on the quality of safou (*Dacryodes edulis*) produced in Agboville (South-East, Côte d'Ivoire)

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Abstract

The objective of this study was to assess the impact of post-harvest softening on parameters (nutritional and anti-nutritional) of saffron pulp (*Dacryodes edulis*). Thus, the safou fruits were picked at physiological maturity and stored at room temperature (27 ± 1.2 °C) for 12 days during which five stages of softening (S0, S1, S2, S3 and S4) were defined. The softening index of *D. edulis* fruits varied from 0.86 ± 0.06 mm to 3.53 ± 0.03 mm (*edulis*) and from 0.85 ± 0.05 mm to 2.86 ± 0.04 mm (*parvicarpa*). This study reveals that the softening index is significantly different ($p < 0.05$) from one variety to another. The contents of total polyphenols decrease significantly during the post-harvest softening and vary from 13.54 ± 0.2 mg/g to 2.54 ± 0.13 mg/g (*edulis*), then from 13.31 ± 0.3 mg/g at 2.41 ± 0.1 mg/g (*parvicarpa*). The flavonoid contents decrease from 0.71 ± 0.02 mg/100 g to 0.15 ± 0.02 mg/g (*edulis*) and from 0.69 ± 0.03 mg/100g to 0.12 ± 0.02 mg/100 g (*parvicarpa*). The tannin content decreases significantly during softening but there is no significant difference between two varieties of safou at each softening stage. The inhibitory concentration of safou increases significantly to the threshold of 5% during post-harvest softening from one variety to another and no significant difference is observed. Correlation test showed that the softening stage is significantly correlated ($p < 0.05$) with the parameters studied. No significant variation in the content of total oxalates of safou is observed from one variety to another while the phytate contents decrease significantly and the values are respectively 1.46 ± 0.03 mg/100g at 0.35 ± 0.02 mg/100 g (*edulis*) and from 1.43 ± 0.01 mg/100g to 0.31 ± 0.01 mg/100g (*parvicarpa*). The post-harvest softening greatly reduced the anti-nutritional contents in the safou pulp and this led to a loss of its nutritional value.

Keywords: *Dacryodes edulis*; Safou; Softening; Antinutritional and nutritional parameters; Post-harvest

1. Introduction

In recent years, attention has focused on unconventional crops that may be of interest for local or industrial development (*Ricinodendron heudoletii*, *Irvingia gabonensis*, *Dacryodes edulis*) of populations in Africa [1,2,3]. The safoutier (*Dacryodes edulis*), produced in many countries of Central Africa and the Gulf of Guinea [4] has a strong economic potential which can contribute to the reduction of poverty of the rural population [5]. The safou is an ellipsoidal drupe, 4-8 cm long and 3-6 cm wide, depending on the variety [6]. Safou pulp, in view of its very interesting nutritional composition, would thus find its place in the food, pharmaceutical and cosmetic industries [7, 3, 8]. Indeed, several studies have shown that the leaves, pulp, and oil of safou pulp are rich in compounds with antioxidant activities [9, 10, 11].

The richness of safou in antioxidants justifies its traditional use in the treatment of diseases associated with oxidation, such as cancer, diabetes and high blood pressure [12, 13, 11]. Unfortunately, the potential of safou is not fully exploited due to its rapid softening (2 to 3 days) post-harvest (Dossou et al., 2018). Indeed, The safou generally matures on the

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tree and no softening process takes place there. Post-harvest, the safous undergo rapid softening after 2 to 3 days at room temperature, which modifies their nutritional qualities [14]. Compounds with antioxidant activity in fruits and vegetables are generally degraded during post-harvest conservation [15].

In Côte d'Ivoire (West Africa), the culture of safou (*Dacryodes edulis*) has been booming in recent years. In this context, research work is focused on the promotion and vulgarization of safou. This is how [2] characterized the varieties of safou and studied them as ingredients in the enrichment of infant flours. Subsequently, [16] optimized the extraction of total flavonoids and [3] studied the biochemical and phytochemical composition of pulp meal and safou seed. This work aims to determine the impact of post-harvest softening on nutritional and anti-nutritional parameters of safou (*Dacryodes edulis*) pulp.

2. Material and methods

2.1. Study and sampling equipment

Two varieties of safou (*Dacryodes edulis*) with physiological maturity, were harvested in Grand-Morié (Agboville), in the south-east of Côte d'Ivoire for study (Figure 1, Table 1). After harvest, the safou (two hundred fruits of each variety) were immediately transported to the laboratory where they were stored at room temperature (27 ± 1.2 °C) for 12 days. Five softening stages (S0, S1, S2, S3, S4) have been defined and samples are taken every three days according to the modified method of [17]:

- S0: First day of harvest;
- S1 : Safou fruits taken after 3 days of harvest and storage
- S2 : Safou fruits taken after 6 days of harvest and storage;
- S3 : Safou fruits taken after 9 days of harvest and storage;
- S4 : Safou fruits taken after 12 days of harvest and storage.
- The different varieties of safou (*Dacryodes edulis*) have been defined in the table 1 according to [2].

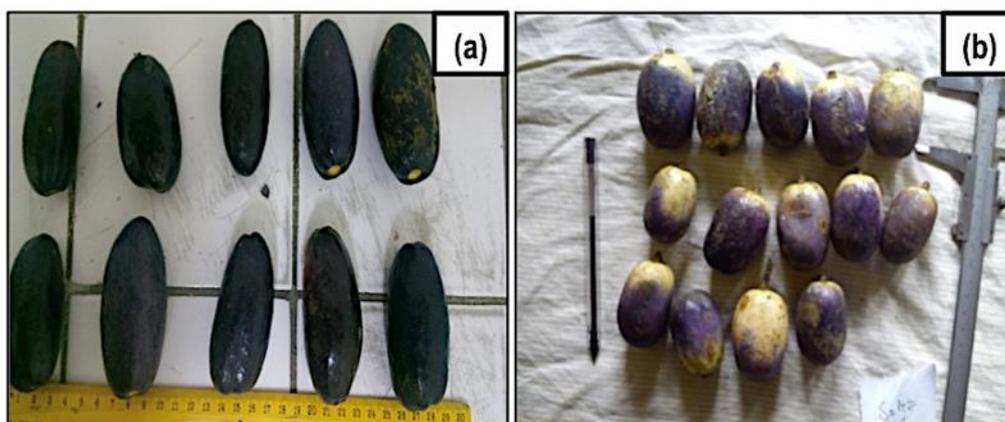


Figure 1 Mature safou fruits: *Dacryodes edulis* var. *edulis* (a) and *Dacryodes edulis* var. *parvicarpa* (b)

Table 1 Physical characteristics of two safou (*Dacryodes edulis*) varieties

Variety	Weight (g)	Thickness (mm)	Width (mm)	Pulp length (mm)
<i>edulis</i>	49.63±1.51 ^b	71.23±2.54 ^b	37.65±1.49 ^b	3.86±0.42 ^b
<i>parvicarpa</i>	27.34±1.42 ^a	38.37±1.72 ^a	33.73±2.15 ^a	2.92±0.63 ^a

Average of 50 fruits ± standard deviation. Means with different letters in the same column indicate significant differences between varieties ($p < 0.05$).

2.2. Analysis methods

2.2.1. Penetrometer measurement

The texture of the fruits expressed in softening index was measured using a penetrometer (K19500, Koehler Instrument Company, INC, United States) equipped with a 47.5 g piston. The softening index corresponds to the depth of penetration of the piston into the safou pulp. For each softening stage, five safou of each variety were studied. For each safou, twelve measurements were distributed uniformly: four measurements around the peduncle base, four measurements in the safou middle and four measurements at the end opposite peduncle base.

2.2.2. Biochemical analyzes

The methanolic extracts were prepared according to [18]. The content of total polyphenols in the safou pulp was determined according to [19]. Tannins content in safou pulp was carried out according to [19]. The flavonoid content was determined by [21] methods. Antioxidant activity of safou pulps was determined by reducing Fe_3 to Fe_2 according to [22] method. Antioxidant activity by DPPH inhibition was made by [23] Sanchez-Moreno et al. (1998) methods. Phytates content were quantified by [24] method. Oxalates content was carried out according to [25] method using potassium permanganate.

2.3. Statistical analyzes

All the analyzes reported in this study were carried out in triplicate. Data were evaluated by analysis of variance (ANOVA) and the Duncan Multiple Range test ($p < 0.05$). The correlation between the parameters was assessed by Pearson independence test. All statistical analyzes were performed using Statistica 7.1 software (Stat Soft Inc., head office in Tulsa USA).

3. Results and discussion

3.1. Softening index

The softening index of safou (*D. edulis*) during postharvest softening are presented in Figure 2. The softening indices of varied from 0.86 ± 0.06 mm to 3.53 ± 0.03 mm (*Var. edulis*) and from 0.85 ± 0.05 mm to 2.86 ± 0.04 mm (*Var. parvicarpa*). The softening index increases significantly from S0 to S4. In addition, this study reveals that the softening index is significantly different ($p < 0.05$) from one variety to another.

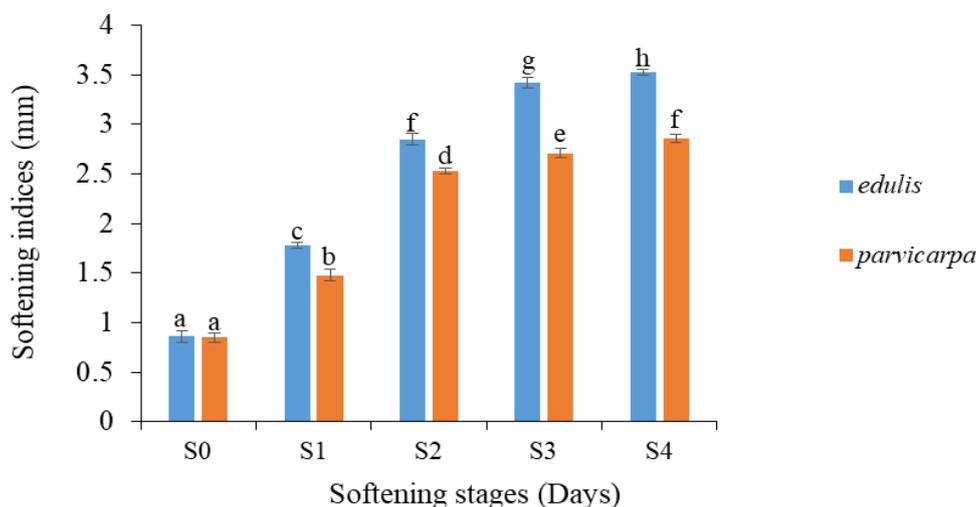


Figure 2 Changes in softening index of safou varieties during softening stages

3.2. Phenolic compounds

3.2.1. Total polyphenols

Changes of total polyphenols in safou during post-harvest softening is shown in Figure 3. Total polyphenol contents of the two varieties (safou) are not significantly different. Furthermore, these contents decrease significantly during post-harvest softening. The content varied from 13.54 ± 0.2 mg/g to 2.54 ± 0.13 mg/g (*edulis*), then from 13.31 ± 0.3 mg/g to 2.41 ± 0.1 mg/g (*parvicarpa*).

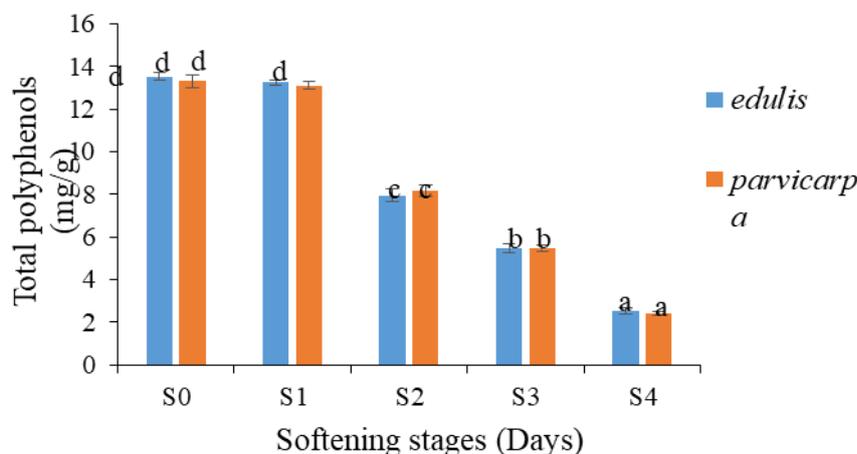


Figure 3 Changes in total Polyphenol Content of safou varieties during softening stages

3.2.2. Flavonoids

The flavonoids content in safou during the softening process are shown in figure 4. There is no significant difference between the flavonoids content in two varieties at each softening stages. Flavonoid contents varied from 0.71 ± 0.02 mg/100 g to 0.15 ± 0.02 mg/g (*edulis*) and from 0.69 ± 0.03 mg/100g to 0.12 ± 0.02 mg / 100 g (*parvicarpa*),

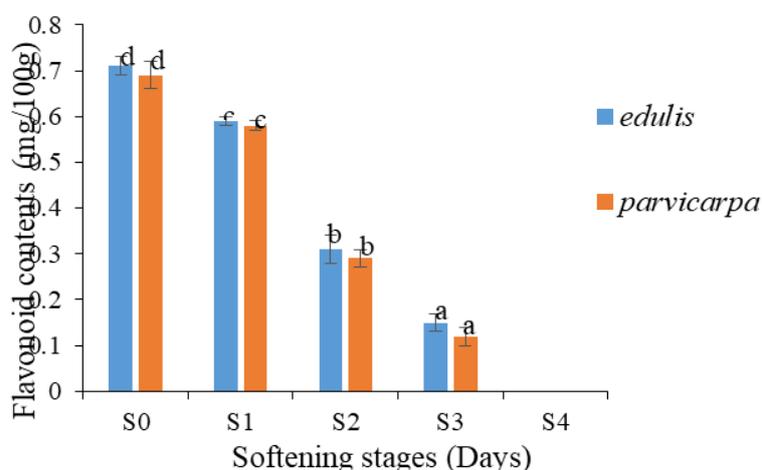


Figure 4 Changes in flavonoid content of safou varieties during softening stages

3.2.3. Tannins

Changes of tannin contents of safou varieties during softening stages is presented in figure 5. There is no significant difference between tannin contents of two varieties at each softening stage. Tannin contents decreased significantly during softening. Contents ranged from 0.66 ± 0.02 mg EAT/g to 0.13 ± 0.01 mg EAT/g (*edulis*) and from 0.67 ± 0.03 mg EAT/g to 0.14 ± 0.01 mg EAT/g (*parvicarpa*).

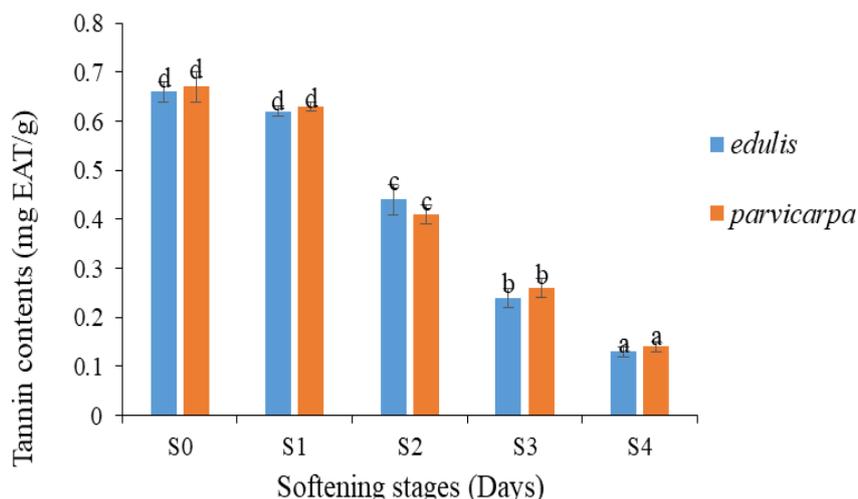


Figure 5 Changes in tannins contents of safou varieties during softening stages

3.3. Antioxidant activities

3.3.1. 2,2-Diphenyl-1-picrylhydrazole (DPPH) free radical inhibition capacity

Changes of the median inhibitory concentration during softening stages of safou varieties is presented in figure 6. Median inhibitory concentration of safou increased significantly during post-harvest softening from one variety to another. In addition, no significant difference in the median inhibitory concentration was observed. The contents varied from 0.12 ± 0.02 mg/mL to 0.32 ± 0.01 mg/mL (*edulis*) and from 0.12 ± 0.01 mg/mL to 0.31 ± 0.01 mg/mL (*parvicarpa*).

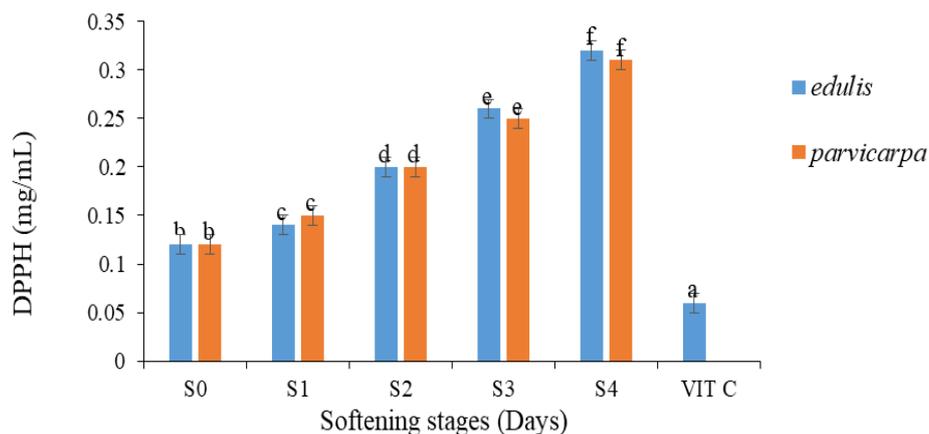


Figure 6 Changes in contents of median inhibitory concentration of safou varieties during softening stages

3.3.2. Ability to reduce Fe_3 to Fe_2

Changes in the reducing power of Fe_3 to Fe_2 during softening stages of safou varieties is presented in figure 7. The powers to reduce Fe_3 to Fe_2 in safou significantly decrease at the 5% threshold from S0 to S4. Thus, the reduction power of Fe_3 to Fe_2 of the safous is respectively 0.61 ± 0.02 (S0) to 0.15 ± 0.01 (S4) (*edulis*) and 0.6 ± 0.01 (S0) at 0.15 ± 0.02 (S4) (*parvicarpa*). These contents of reduction power of Fe_3 to Fe_2 of safou varieties are all lower than vitamin C content (0.85 ± 0.03)

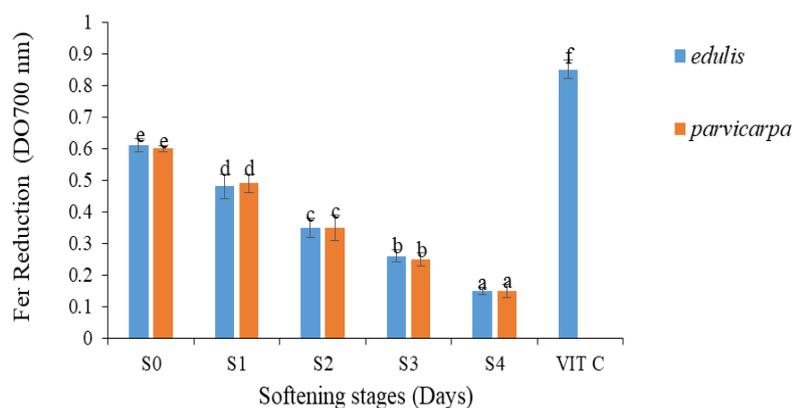


Figure 7 Powers to reduce Fe₃ to Fe₂ of safou varieties during softening stages.

3.4. Correlation between softening level, softening index, phenolic compounds and antioxidant activities of safou pulp

Correlation test shows that the softening stage is significantly correlated ($p < 0.05$) with the parameters studied (Tables 3 and 4).

Table 3 Linear correlation matrix between softening level, phenolic compounds and antioxidant activities of safou (*edulis* variety)

Edulis variety							
	N.R.	P.T.	T	F	DPPH	FRAP	I.R.
N.R.	1.00						
P.T.	-0.981	1.00					
T	-0.983	0.991	1.00				
F	-0.975	0.992	0.996	1.00			
DPPH	0.988	-0.991	-0.995	-0.997	1.00		
FRAP	-0.997	0.977	0.972	0.963	-0.977	1.00	
I.R.	0.964	-0.947	-0.938	-0.915	0.928	-0.976	1.00

.N.R.: Softening level; P.T.: Total polyphenol; T: Tannin; F: Flavonoid; I.R.: Softening index * Significant values in bold.

Table 4 Linear correlation matrix between softening level, phenolic compounds and antioxidant activity of safou (*parvicarpa* variety)

Parvicarpa variety							
	N.R.	P.T.	T	F	DPPH	FRAP	I.R.
N.R.	1,00						
P.T.	-0.9808	1.00					
T	-0.9851	0.9985	1.00				
F	-0.9728	0.9810	0.9731	1.00			
DPPH	0.9939	-0.9896	-0.9895	-0.9897	1.00		
FRAP	-0.9980	0.9824	0.9874	0.9656	-0.9887	1.00	
I.R.	0.9459	-0.9299	-0.9399	-0.8801	0.9160	-0.9637	1.00

N.R.: Softening level; P.T.: Total polyphenol; T: Tannin; F: Flavonoid; I.R.: Softening index * Significant values in bold.

3.5. Anti-nutritional factors

3.5.1. Total oxalates

Changes of total oxalate content during post-harvest softening of safou varieties are presented in figure 8. No significant variation in total oxalate content of the safou is observed from one variety to another. The contents varied from 4.63 ± 0.21 mg/g to 0.84 ± 0.1 mg/100 g (*edulis*) and from 4.61 ± 0.22 mg/g to 0.79 ± 0.23 mg/g (*parvicarpa*).

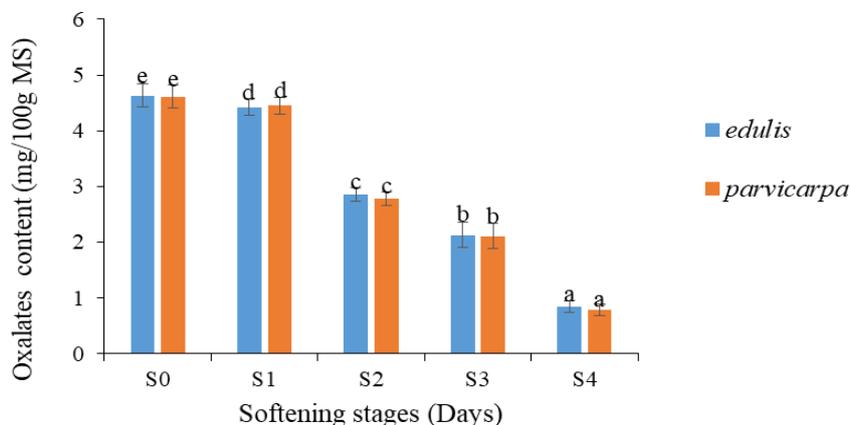


Figure 8 Changes in oxalates contents of safou varieties during softening stages

3.5.2. Phytates

Changes of phytates contents during softening stages of safou varieties are presented in figure 9. No significant difference between the phytate contents of safou varieties. The phytate contents decrease significantly during softening stages. The contents are respectively 1.46 ± 0.03 mg/100g to 0.35 ± 0.02 mg/100g (*edulis*) and 1.43 ± 0.01 mg/100g to 0.31 ± 0.01 mg/100g (*parvicarpa*).

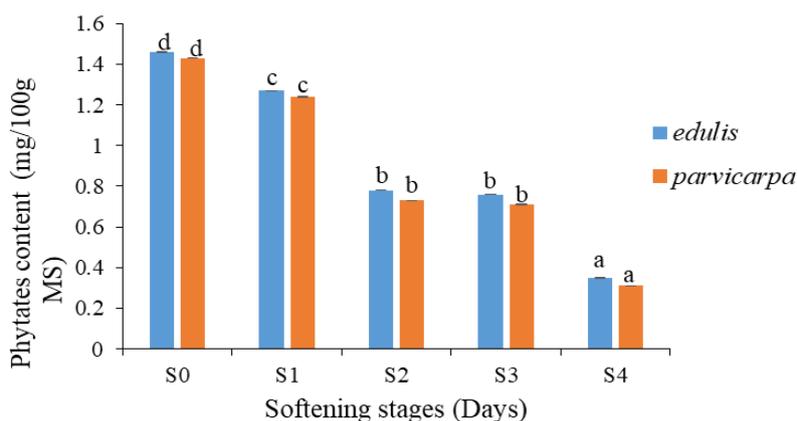


Figure 9 Changes in phytates contents of safou varieties during softening stages

4. Discussion

Firmness is an important parameter for determining the quality of fresh fruits and vegetables [26]. The softening index (0.86 mm Var. *edulis*, 0.85 mm Var. *parvicarpa*) taken on the first day of harvest is similar to that of [14] which was 0.85 mm. Third day of harvest, a decrease (1.78 mm Var. *edulis*, 1.48 mm Var. *parvicarpa*) in firmness is observed. This is consistent with studies did by [6,27] who reported that post-harvest softening occurs on the third day of storage. This loss of firmness is progressive up to the softening stage (S4). Indeed, according to [14], the softening of safou is due to the progressive and significant degradation of the cell wall carbohydrates during ripening, leading to its disassembly [28]. Thus, softening would be associated with degradation of pectin during the ripening phase [29]. Therefore, the changes undergone by the cell wall polysaccharides during the post-harvest storage would influence the safou texture

[22]. The change in safou firmness would therefore be associated with the phenomenon of ripening during which the fruits undergo profound biochemical changes. The safou softening index of *edulis* variety is higher than *parvicarpa* variety. These results are consistent with those of [30] who reported that the softening speed of safou depend of their size.

Polyphenols play an important role in human health by preventing degenerative pathologies such as cancer, cardiovascular disease or osteoporosis [31]. Polyphenol contents of safou at softening stage S0 (13.54 mg/g (*edulis*), 13.31 mg/g (*parvicarpa*) are close to those (12.10 mg/g) reported by [10] in Nigeria and higher than those obtained from baobab pulp (*Andasonia digitata*) whose content is 10.84 mg/g [32]. Polyphenol contents decreased during postharvest softening and this was observed by [15] during the storage of *Solanum anguivi* berries. Indeed, at the softening stage S1 (third day after harvest), a non-significant decrease ($p > 0.05$) in polyphenol content is observed. This suggests that the polyphenol content of safous studied remains constant from S0 to S1. From stage S1, the polyphenol content decreases significantly up to the softening stage S4. This reduction in polyphenol content could be attributed to phenolic oxidation which characterizes the advanced stages of fruits ripening [33].

Flavonoids are compounds with remarkable antioxidant activity [34]. The flavonoid content of safou at the softening stage S0 is 0.71 ± 0.02 mg/g (*edulis*) and 0.69 ± 0.03 mg/g (*parvicarpa*). These contents are close to those reported by [7] 0.67 ± 0.27 mg/g for mature safou in Nigeria. The flavonoid content decreased during postharvest softening. This decrease was reported by [9] in a comparative study of fresh and softened safou. In fact, from the softening stage S0, the flavonoid content decreased significantly up to the softening stage S4. This gradual reduction in flavonoid content is said to be due to the action of polyphenol oxidases, peroxidases and catalases which degrade phenolic compounds during enzymatic browning [35]. Indeed, loss of purple coloration due to the presence of flavonols and anthocyanins in favor of the brown color in safou during post-harvest softening would be due to the enzymes responsible for the phenomenon of enzymatic browning [36].

Tannins have beneficial health effects, although they are associated with a decrease in the nutritional value of proteins [37]. The tannin content of safou studied of softening stage S0 is 0.66 ± 0.02 mgEAT/g (*edulis*) and 0.67 ± 0.03 mg EAT/g (*parvicarpa*). These contents are similar to those reported by [4] for safou (*edulis* variety) where the content was 0.68 ± 0.05 mg EAT/g. During post-harvest softening, the tannin content decreased. This was observed by Dan (2014) during the storage of *Solanum anguivi* berries. It would be attributed to the activation of protein and lipid syntheses during ripening. These biochemical reactions degrade the tannins responsible for astringency [15]. Furthermore, the weakening of cell walls leading to the oxidation of phenolic compounds would also explain this reduction in tannins [38].

The antioxidant activity of safou at softening stage S0 is 0.12 ± 0.02 mg/ml (*edulis*) and 0.12 ± 0.01 mg/ml (*parvicarpa*) by DPPH method and 0.61 ± 0.02 (*edulis*) and 0.6 ± 0.01 (*parvicarpa*) by FRAP method. These values are similar to those reported by [4] on safou (*edulis* variety) which is 0.12 ± 0.02 mg/mL (DPPH) and 0.6 ± 0.03 mg/mL (FRAP). Antioxidant activity of safou decreased during postharvest softening. This decrease in antioxidant activity was reported by [39] in tomatoes studies (*Lycopersicon esculentum*). It would be associated with a decrease in phenolic compounds during post-harvest softening [40].

4.1. Effects of post-harvest softening on anti-nutritional factors

Oxalates form insoluble complexes with calcium, magnesium, iron and zinc, which reduces the absorption of these mineral elements [41]. Total oxalate content of safou is 4.63 ± 0.21 mg/g (*edulis*) and 4.61 ± 0.22 mg/g (*parvicarpa*) at softening stage S0. These contents are comparable to those (4.97 mg/g) reported by [7]. This content decreases during post-harvest softening. Reduction in total oxalate content was reported by [15] during the storage of *Solanum anguivi* berries. Indeed, during ripening the total oxalates content is reduced due to the increase in water content in fruits and vegetables [42].

A phytate intake of 4.00 to 9.00 mg/100 g reduces iron absorption in humans [43]. Phytate content of safou studied from softening stage S0 is 1.46 ± 0.03 mg/100g (*edulis*), 1.43 ± 0.01 mg/100g (*parvicarpa*). These results are corroborated by those reported by [44] in Nigeria which are 1.59 mg/100g (*edulis*) and 1.05 mg/100g (*parvicarpa*). The decrease of phytate content during postharvest softening was reported by [15]. This would be caused by phytases activation during biochemical and physiological changes that take place in plant during ripening [45].

5. Conclusion

This study assessed the impact of post-harvest softening on the nutritional and anti-nutritional parameters of the two varieties of safou (*Dacryodes edulis*). The study showed that antioxidant activity and anti-nutritional factors in safou varied little until the first softening stage (third day after harvest). Then, these parameters are gradually reduced until the end of the experiment. On the other hand, post-harvest softening significantly reduces the content of anti-nutritional compounds (phytates and oxalates). However, this phenomenon leads to a loss of the nutritional value of safou by promoting the degradation of phenolic compounds and the loss of antioxidant power.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

Authors have declared that no competing interests exist.

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