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RESEARCH ARTICLE

Optimization of the Production and Storage Conditions of Baobab Syrups (*Adansonia digitata* L.): Physicochemical Parameters and Kinetic Degradation

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Abstract

The objective of the study was to define the optimal conditions for the production of baobab syrups and their conservation. An aqueous extract of 9 °Brix was developed by performing a powder/ water mixture with a ratio (mass ratio) 1/6 (kg/kg). With the aqueous extract, two types of syrups (hot syrup and cold syrup) of 65 °Brix were prepared. To study the stability, syrups are pasteurized with two scales previously optimized (90 °C/10 min, 80 °C/30 min). They were stored for 120 days at different temperatures (4, 20, 30, 37 and 45 °C). The kinetics of degradation of ascorbic acid and the evolution of the reducing sugars content were examined. Activation energies, respectively, for ascorbic acid and reducing sugars, ranged from 33.559 to 44.427 kJ mol^{-1} and from 16.804 to 35.108 kJ mol^{-1}. Also, the loss of ascorbic acid and increase of the reducing sugars content were consistent with the kinetic model of the first order for coefficients between 0.884 and 0.995. The three models (Arrhenius, Eyring and Ball) used to calculate and predict these levels yielded similar results. The heat treatment, with both scales, allowed stability of syrups. In conclusion, our results indicated that the process and storage conditions in terms of preserving the nutritional quality were obtained with pasteurized cold syrup with the scale of 90 °C/10 minutes. Also, loss predictions in vitamin C with this scale was estimated at around 35% after 180 days of storage at room temperature.

Key words: *Adansonia digitata* L.; syrups; degradation; storage.

1. Introduction

Baobab (*Adansonia digitata* L.), present on the African continent, is one of the most recognizable tree. Its fruits, also called "the monkey bread" by the local populations, are commonly harvested (Soloviev *et al.,* 2004; Assogbadjo & Loo, 2011). The various parts of the baobab tree have always been used for food, medicinal, cultural and economic purposes (Sow *et al.* 2018a; Ndiaye *et al.,* 2021; Ndiaye *et al.,* 2023). Fruit production is attributed to genetic characteristics, physiological phenomena soil and climatic conditions (Sow et al., 2018b). In recent years, the authorisation of the marketing and incorporation of baobab fruit pulp into drinks by the EU (European Union) and the FDA (Food and Drug Administration) in Europe and the USA respectively increased the economic value of the species on an international scale (CEC, 2008; FDA, 2009; Sanogo *et al.,* 2015). The baobab fruit pulp is very rich in mineral elements (3.7 and 6.3%) and proteins (Cisse *et al.,* 2009). Also, this baobab pulp is a good source of essential elements (Cu, Ca, Fe, K, Mn, Zn) and vitamins B1, B2, B6 and A (Cisse *et al.,* 2009; Diop *et al.,* 2005; Kamatou *et al.,* 2011). All amino acids are found in the baobab fruit pulp, however, tyrosine, arginine and glutamic acid being the major ones and representing 20.6%, 7.6% and 6.5% of mineral content, respectively (Kamatou *et al.,* 2011; Osman, 2004). Moreover, Li *et al.* (2017) isolated in the dry pulp of baobab four (4) hydroxycinnamic acid glycosides, six (6) iridoid glycosides and three (3) phenylethanoid glycosides. However, hydroxycinnamic acids are known for their anti-carcinogenic, antimicrobial and anti-inflammatory properties (Kim *et al.,* 2012; Kylli *et al.,* 2008 ; Weng & Yen, 2012). Baobab fruit pulp is known for its richness in vitamin C, phenolic compounds, minerals and fibers (Glew *et al.,* 1997; Cisse *et al.,* 2009; Diop *et al.,* 2005; Osman, 2004; Ndiaye *et al.,* 2021). The ascorbic acid content, most often between 200 and 500 mg.100 g^{-1}, places the "monkey bread" among the fruits with higher vitamin C content (Diop *et al.,* 2005). In Africa, the fruit is generally used to produce refreshing drinks and syrups, for local consumption and sale purpose (Cisse *et al.,* 2009; Diop *et al.,* 2005). In Senegal, the traditional syrup prepared from the fruit pulp tends to degrade after a few days of storage. Loss of ascorbic acid and color alteration are then observed (Chadare *et al.,* 2009). Ascorbic acid decay depends on many factors such as dissolved oxygen content (Kennedy *et al.,* 1992 ; Lee & Coates, 1999 ; Robertson & Samaniego, 1986), pH (Lee & Coates, 1999), processing treatment used, light (Robertson & Samaniego, 1986), storage duration (Robertson & Samaniego-Esguerra, 1990) and storage temperature (Burdulu *et al.,* 2006; Polydera *et al.,* 2003). Maillard reaction (or non-enzymatic browning) resulting from the caramelization reaction of sugar as well as browning of ascorbic acid accentuates degradation during preparation and storage (Rogacheva *et al.,* 1995). Therefore, the aim of the present study was to model the colour change and vitamin C content reduction in baobab syrups during production and storage. This approach will make it possible to better preserve the organoleptic and nutritional qualities by defining optimal production and conservation conditions. Consequently, the kinetics of the degradation of ascorbic acid and the evolution of the reducing sugar content during the storage at different temperatures of the two types of pasteurized syrups were determined using three models: Arrhenius, Eyring and Ball.

2. Materials and Methods

2.1. Plant material and preparation of baobab syrups

The pulp of the baobab fruit used was purchased from "Baobab Des Saveurs" (BDS), specialized in the valorization of African raw materials. A powder/water mixture was carried out with a ratio (mass ratio) 1/6 and homogenized in order to obtain an extract whose Brix degree is equal to 9 °Brix. This mixture was prepared at room temperature. The aqueous extract of baobab obtained was filtered, using a 600 µm stainless steel sieve, and divided, into two equal volume, to produce a hot syrup (traditional syrup) and a cold syrup. The cold syrup was obtained by dissolving a previously calculated amount of sugar and by manual stirring for about 30 minutes. On the other hand, for hot syrup, the aqueous extract of baobab was heat treated (75 °C) before pouring the necessary quantity of sugar. This temperature was maintained during the dissolution phase of the sugar. The two syrups prepared had solids content of 65 °Brix. The syrups were then packaged in 30 mL glass vials and then sealed with plastic stoppers.

2.2. Pasteurization and storage

For thermal stabilization, the syrups were pasteurized under two different conditions (80 ± 0.2 °C/30 min and 90 ± 0.2 °C/10 min) previously optimized (AFTER, 2015). After heat treatment, the flasks, coated with aluminum foil, were distributed and stored at temperatures of 4, 20, 30, 37 and 45 °C for 120 days. Analyses were carried-out in triplicate after every 15 days on the pulp, extract and syrups.

2.3. Analytical methods

The physicochemical parameters (pH, titratable acidity, vitamin C, reducing sugars and soluble solids content) were monitored in order to evaluate the stability of the products. The pH was determined with a pH meter of HANNA instruments according to the standards (NF V76-122, NF EN 1132, 1994). The titratable acidity was determined according to the French standard (NF V05-101); the total soluble solids (TSS) measured with a refractometer (Atago, Tokyo, Japan); the moisture content according to AOAC (1995) and the ashes according to standards methods (NF V76-124, NF EN 1135, 1994). The water activity (a_w) was measured with an Aw-meter (rotronic HYGROPALM). The total polyphenol content was evaluated according to the method described by Georgé *et al.* (2005) with the use of a UV spectrophotometer (SPECORD 200 PLUS). The ascorbic acid content was assayed by the 2,6-dichlorophenol-indophenol (2,6-DCPIP) titration method (AOAC, 1995). The reducing sugar content was measured by the Luff-Schoorl method (AFNOR, 1982).

2.4. Modeling kinetic degradation

The degradation of vitamin C and the evolution of reducing sugars of sucrose have usually been described by first order kinetics. In other words, the degradation of ascorbic acid, following a first order kinetic was corroborated by some studies (Burdulu *et al.,* 2006; Manso *et al.,* 2001; Remini *et al.,* 2015; Wibowo *et al.,* 2015; Peleg *et al.,* 2018). The influence of temperature on ascorbic acid degradation was determined by the Arrhenius equation. The latter, based on the classical approach, was considered in most studies as a reference. However, two other models (Ball and Eyring-Polanyi) were used in addition to Arrhenius one to calculate, predict and show the effect of temperature and storage time on the nutritional quality of syrups. Thus, the variation of the reaction rate as a function of temperature is described from the Arrhenius model Eq. (1).

$$K = k_{\infty} e^{-\frac{Ea}{RT}} \qquad (1)$$

Where T is the temperature expressed in Kelvin (K), k∞ is the pre-exponential factor and corresponds to the value of k at t = ∞ (t in s^{-1}), E_a is the activation energy (J. mol^{-1}) and R is the perfect gas constant (8.31 J.mol^{-1}.K^{-1}).

The Eyring-Polanyi model Eq. (2), corresponding to a theoretical model based on statistical thermodynamics, was used to determine the parameters related to the free enthalpy of activation.

$$K = \frac{K_B}{h} T . e^{-\frac{\Delta G^*}{RT}} = \frac{K_B}{h} T . e^{-\frac{\Delta H^* - T\Delta S^*}{RT}} \qquad (2)$$

Where ΔG^* is the free enthalpy of activation (J.mol^{-1}), ΔH^* is the activation enthalpy (J.mol^{-1}), ΔS^* is the activation entropy K is the Boltzmann constant (1.381.10^{-23} J.K^{-1}), h is the Planck constant (6.62.10^{-32} J.s), R is the perfect gas constant (8.31

J.mol^{-1}.K^{-1}) and T the temperature expressed in Kelvin.

The Ball model Eq. (3) widely used in the food industry to express the heat resistance of a compound was used and the parameters D_0 and z were determined.

$$D = D_0 10^{-\frac{T}{z}} \quad (3)$$

Where D_0 is the decimal reduction time at T = 0 °C in seconds, T is the temperature (in °C) and z is the temperature difference for a variation of D by a factor ten (in °C).

2.5. Statistical analysis

One-factor analyzes of variance (ANOVA) were performed to detect similarities and differences between samples. Statistical software called STATISTICA 8.0 was used and the Fisher LSD test was performed with a significance level of 0.05.

3. Results and discussion

3.1. Characteristics of aqueous extract and syrups

The physicochemical characteristics determined on the extract and the syrups were presented in **Table 1**.

Table 1 Physicochemical and biochemical characteristics of the aqueous extract, syrups.

Parameters	Units	Aqueous extract	Unpasteurized		Pasteurized			
			Cold syrup	Hot Syrup	Cold syrup		Hot Syrup	
					80 °C/30 min	90 °C/10 min	80 °C/30 min	90 °C/10 min
pH	-	3.08 (c)	3.33 (d)	3.18 (b)	3.15 (ab)	3.14 (a)	3.16 (ab)	3.16 (ab)
TSS (°Brix)	g/100g	9 (b)	65.6 (a)	65.5 (a)	65.3 (a)	65.4 (a)	65.6 (a)	65.5 (a)
Titratable acidity	mEq/L	65.64 (e)	51.91 (d)	57.07 (ab)	59.61 (bc)	60.79 (c)	55.65 (a)	56.03 (a)
Reducing sugars	g/100mL	1.62 (a)	1.15 (a)	2.98 (c)	9.57 (d)	8.85 (d)	8.69 (b)	11.35 (c)
Total sugars	g/100mL	3.18 (c)	61.30 (f)	42.30 (cd)	46.14 (d)	31.14 (a)	37.80 (bc)	34.80 (ab)
Polyphenols	g/L	29.95 (b)	18.17 (a)	16.66 (a)	16.61 (a)	17.25 (a)	16.29 (a)	16.12 (a)
Vitamin C	mg/L	174.31 (f)	121.99 (e)	106.21 (a)	103.56 (a)	115.46 (d)	87.72 (b)	98.43 (c)

On the same line, averages with the same letter are not significantly different from the 5% threshold.

Results indicate that the pH was significantly affected by the mode of dissolution of sucrose. These pH values were consistent with the titratable acidities measured [(51.91 to 65.64) mEq.L^{-1}] and were close to [(53-68) mEq.L^{-1}] values obtained with unsweetened nectars of [fruit/water] ratio of [1/3] reported by Cissé *et al.* (2009). However, the difference in titratable acidity between the two syrups can be explained by water evaporation during heating. As for vitamin C, a significant decrease was noted in both syrups. The vitamin C content in the aqueous extract was 174.31 mg.L^{-1}. It decreased to 122 mg.L^{-1} and 106.21 mg.L^{-1} respectively in unpasteurized cold syrup and unpasteurized hot syrup. This corresponds to a decrease of 30 % and 39 % respectively. This difference in vitamin C of 9 % between the two syrups was mainly due to the effect of cooking during the dissolution process of sucrose (Burg & Fraile, 1995; Wani *et al.,* 2016). For unpasteurized hot syrup, the content of reducing sugars increased by about 83 %. Indeed, the heat and the acidity of the medium cause the sucrose to be reversed in an equimolar mixture of glucose and fructose. On the other hand, this reducing sugar content increased by 30 % with unpasteurized cold syrup. In addition, we found that cold syrups are slightly more acid than hot syrups. The four types of pasteurized syrups showed significant differences in terms of vitamin C, reducing sugars and total sugars. Indeed, the losses of vitamin C were greater with the scale of 80 °C/30 minutes than with that of 90 °C/10 minutes. Therefore, the losses were related to the duration of the heat treatment. In addition, temperature also acts to promote vitamin C degradation (Robertson & Samaniego, 1986). This decrease can reasonably be explained by an oxidative degradation of ascorbic acid. The increase in the content of reducing sugars was more remarkable in hot syrups than in cold syrups. With the pasteurization schedule of 90 °C/10 minutes, we saw an increase of 55.5 % and 65 % respectively for cold syrups and hot syrups respectively. Similarly, we noted with the 80 °C/30 minutes scale increases of 35.4 % and 100 % respectively in cold syrups and hot syrups. This strong change in the content of reducing sugars can be explained by an inversion of sucrose during heat treatment (Wibowo *et al.,* 2015). The difference noted on syrups in terms of polyphenols can be attributed to cooking and pasteurization (Wani *et al.,* 2016) which result in large losses of polyphenols.

3.2. Degradation of vitamin C during storage

The evolution of ascorbic acid content the four types of syrups was investigated for 120 days of storage at different temperatures (4, 20, 30, 37 and 45 °C).

3.2.1. Effect of storage time

During storage, vitamin C content significantly decreased in all syrups (Figs. 1 and 2). This decrease was accentuated with the increase in storage temperature. Indeed, after 120 days of storage, the losses of ascorbic acid ranged from less than 15 % at 4 °C to more than 70 % when stored at 45 °C. This degradation follows a first order kinetic as previously reported by several studies on vitamin C (Al-Zubaidy *et al.,* 2007; Burg & Frailie, 1995; Odriozola-Serrano *et al.,* 2009; Wibowo *et al.,* 2015a; Wani *et al.,* 2016). This evolution makes it possible to model vitamin C degradation in baobab syrups.

Regardless of pasteurization scales and storage temperatures, cold syrups demonstrate lower degradation rates than those prepared under hot conditions (Table 2). These results are in agreement with those obtained on lemon juice reported by Al-Zubaidy & Khalil (2007) and Odriozola *et al.* (2009). Choosing the extreme temperatures (4 °C and 45 °C) of storage helps to show that the reaction time ($t_{1/2}$) is longer for cold syrups when compared to hot syrups (Table 2). Therefore, the cold syrups appeared to be more stable during storage. These different results showed that the production process of baobab fruit cold syrups seem to better in preserving its nutritional properties, in particular vitamin C content used here as nutrition marker. The heating during sucrose dissolution contributes to this degradation. Reports show that the oxidation of ascorbic acid was known to be proportional to temperature (Li *et al.,* 2016) and dissolved oxygen (Aka *et al.,* 2013; Li *et al.,* 2016).

3.2.2. Kinetics of degradation of vitamin C during storage

The kinetic parameters (k_∞, E_a, ΔH^*, ΔS^*, D_0 and z) of the three Arrhenius, Eyring and Ball-Bigelow models determined by the graphical method are shown in Table 3. The results were obtained with correlation coefficients between 0.87 and 0.99.

Table 2 Kinetic parameters of ascorbic acid and reducing sugars at different storage temperatures

		Ascorbic acid			Reducing sugars		
Syrup	**Temperature (°C)**	**k (s^{-1})**	**$t_{1/2}$(days)**	**D (days)**	**k (s^{-1})**	**$t_{1/2}$(days)**	**D (days)**
Cold syrup 80 °C/30min	4	1.62×10^{-8}	495	1645	3.36×10^{-8}	239	794
	20	3.94×10^{-8}	204	677	9.61×10^{-8}	84	277
	30	6.25×10^{-8}	128	428	1.44×10^{-7}	56	186
	37	9.26×10^{-8}	87	288	1.59×10^{-7}	51	168
	45	9.95×10^{-8}	81	268	1.84×10^{-7}	43	143
Cold syrup 90 °C/10min	4	9.00×10^{-4}	770	2558	3.10×10^{-3}	224	743
	20	2.40×10^{-3}	289	959	6.60×10^{-3}	105	349
	30	6.80×10^{-3}	102	339	1.20×10^{-2}	58	192
	37	9.00×10^{-3}	77	256	1.39×10^{-2}	50	166
	45	1.02×10^{-2}	68	226	1.49×10^{-2}	47	155
Hot syrup 80 °C/30min	4	1.85×10^{-8}	433	1439	7.75×10^{-8}	103	344
	20	7.99×10^{-8}	100	334	8.68×10^{-8}	92	307
	30	8.45×10^{-8}	95	315	1.24×10^{-7}	65	215
	37	1.15×10^{-7}	70	233	1.74×10^{-7}	46	154
	45	1.17×10^{-7}	69	228	1.81×10^{-7}	44	148
Hot syrup 90 °C/10min	4	1.40×10^{-3}	495	1645	2.20×10^{-3}	315	1047
	20	6.86×10^{-3}	102	339	5.50×10^{-3}	126	419
	30	7.30×10^{-3}	95	315	9.70×10^{-3}	71	237
	37	7.70×10^{-3}	90	299	1.17×10^{-2}	59	197
	45	8.90×10^{-3}	78	259	1.34×10^{-2}	52	172

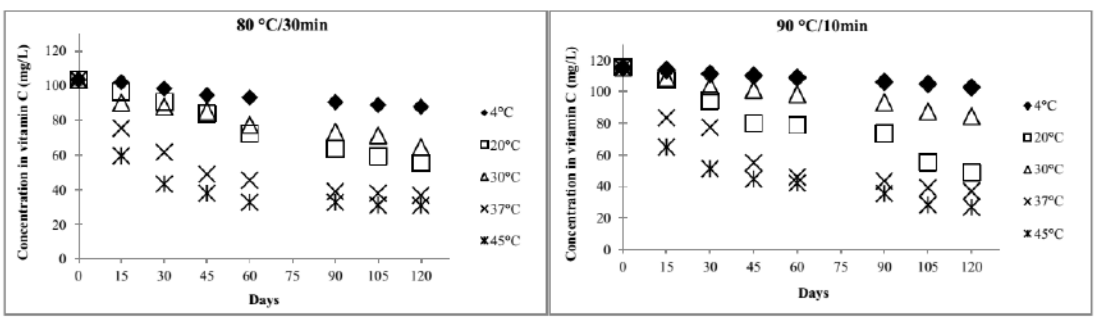

Fig. 1. Degradation of vitamin C in cold syrups as a function of time

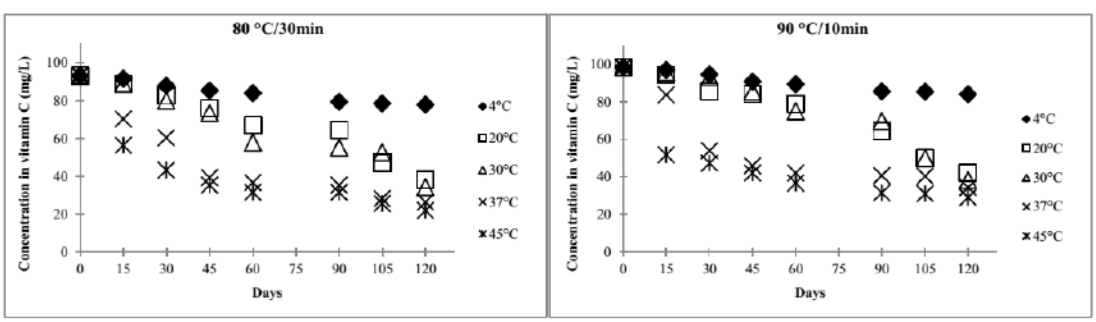

Fig. 2. Degradation of vitamin C in hot syrups as a function of time

Results confirmed that the degradation of vitamin C follows a first order kinetic and it depends on the temperature. Activation energies ranged from 33.559 to 44.427 $kJ.mol^{-1}$ in cold syrups and from 35.223 to 34.739 $kJ.mol^{-1}$ in hot syrups. These activation energies obtained were lower than the one reported for orange juice estimated at 115.5 $kJ.mol^{-1}$ (Johnson *et al.,* 1995). The activation energy (E_a) value of pasteurized cold syrups at 90 °C/10 minutes was higher than that of hot pasteurized syrups at 80 °C/30 minutes. To initiate the degradation of ascorbic acid in pasteurized syrups at 90 °C/10 minutes, more energy needs to be supplied. Thus, this syrup seems less sensitive to temperature variation, the activation energy increasing with temperature. The values found in the literature varied from 42.066 to 68.5 $kJ.mol^{-1}$ for storage temperatures between 0 and 45 °C (Al-Zubaidy & Khalil, 2007; Polydera *et al.,* 2005). The kinetic parameters ΔH*, D_0 followed the same logic as the activation energy. The enthalpy of activation (ΔH*) oscillated between 31.105 and 41.973 $kJ.mol^{-1}$ with cold syrups. With hot syrups, the activation enthalpy varied between 32.769 and 32.285 $kJ.mol^{-1}$. Also, the activation entropy (ΔS*) evolved between -281.49 and -246.47 $J.mol^{-1}.K^{-1}$ for cold syrups. However, for hot syrups, the activation entropy varies between -276 and -273.33 $J.mol^{-1}.K^{-1}$.

The pasteurized cold syrup with the 90 °C/10 minutes scale remained more stable despite the losses recorded during storage. After storage for 180 days, predictions showed that all hot syrups stored at 4 °C would lose between 24 % and 29 % of vitamin C compared to 15 % for pasteurized cold syrups under similar conditions. This loss was accentuated by storage temperature. Consequently, predictions indicate very high losses (between 94 and 98 %) for syrups stored at 45 °C. In conclusion, these results confirm the high sensitivity of vitamin C to heat. In addition, the results obtained with these three models are consistent with those obtained during the follow-up study. According to this concordance, it appears that the degradation of vitamin C followed the kinetics order. Thus, these models can be used to calculate and make predictions of losses during storage at different temperatures.

Table 3 Kinetic parameters of the various models describing the degradation of vitamin C in cold syrups and hot syrups

		Arrhenius model			Eyring model			Ball model		
		K∞	E_a	R²	ΔH*	ΔS*	R²	D_0	z	R²
Cold syrups	80°C/30min	3.26×10^{-2}	33559.10	0.9271	31105.16	-281.49	0.9165	$1.80.10^{8}$	49.75	0.9336
	90°C/10min	2.20	44427.75	0.8847	41973.81	-246.47	0.8729	$1.16.10^{8}$	37.45	0.8958
Hot syrups	80°C/30min	8.69×10^{-2}	35223.60	0.9659	32769.65	-273.33	0.9604	$1.38.10^{8}$	47.85	0.9528
	90°C/10min	6.31×10^{-2}	34739.12	0.9501	32285.18	-276.00	0.9421	$1.53.10^{8}$	48.54	0.9342

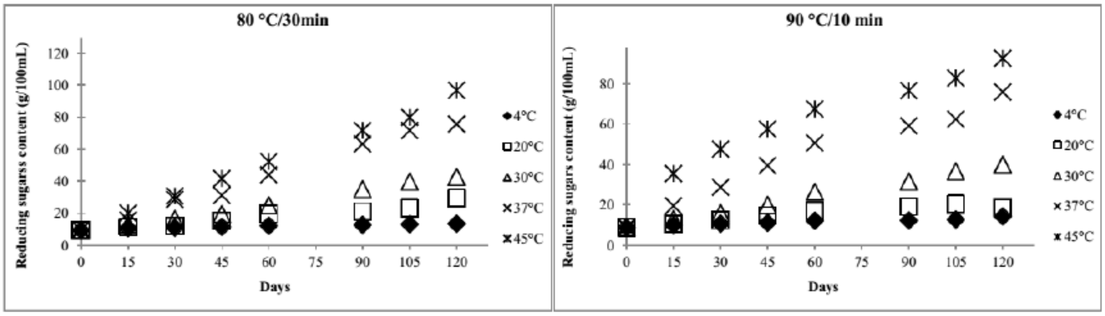

Fig. 3. Evolution of the reducing sugar content of cold syrups during storage

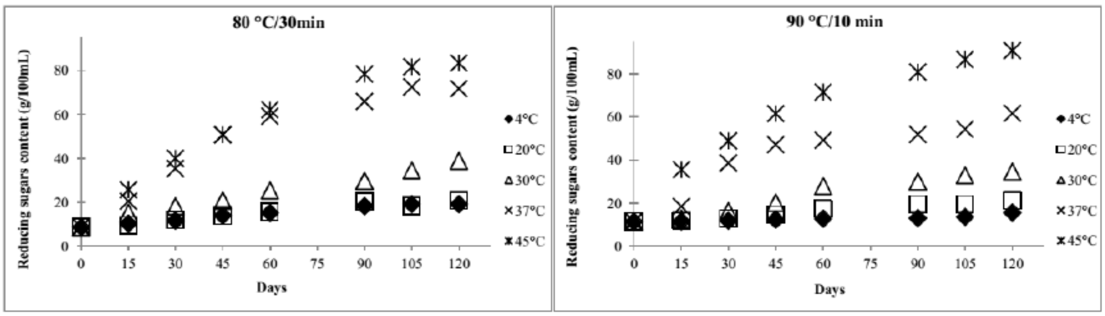

Fig. 4. Evolution of the reducing sugar content of hot syrups during storage

3.3. Evolution of the reducing sugar content during storage

3.3.1. Effect of storage temperature

During storage, an increase of the reducing sugars content was noted in all syrups as a function of the storage temperature (Figs. 3 and 4). Indeed, after 120 days of storage, the reducing sugars contents were elevated by 40 % and 100 % respectively for storage temperatures of 4 °C and 45 °C. Moreover, these results confirm that the increase in reducing sugars of the syrups follows a first order reaction and are consistent with previous reports (Wibowo *et al.,* 2015b).

Therefore, modelization of the increase in reducing sugars content in baobab syrups appears of interest. With the two pasteurization scales, the hot syrups have higher rates of reduction in reducing sugars than cold syrups (Table 2). These results agree with those obtained on mango juice (Wibowo *et al.,* 2015b).

Also, by selecting the extreme temperatures (4 °C and 45 °C) of storage, the highest $t_{1/2}$ values are recorded on the hot syrups of the 90 °C/10 minutes scale. These results clearly indicate that the organoleptic quality of the hot syrups (90 °C/10 minutes scale) seems to be of better quality. Indeed, the hot syrup was more stable during storage. In acidic media, high temperatures favor the hydrolysis of sucrose in reducing sugars (Wibowo *et al.,* 2015b).

3.3.2. Kinetics of the appearance of reducing sugars during storage

The kinetic parameters (k_∞, Ea, ΔH^*, ΔS^*, D_0 and z) of the three models (Arrhenius, Eyring and Ball-Bigelow) were presented in Table 4. These kinetic parameters were obtained with correlation coefficients ranging between 0.85 and 0.99. In other words, these results confirm that the increase in reducing sugars (from the sucrose inversion) in the syrups follows a first order

Table 4 Kinetic parameters of the various models describing the evolution of reducing sugars in cold syrups and hot syrups

		Arrhenius model			Eyring model			Ball model		
		K_∞	E_a	R^2	ΔH^*	ΔS^*	R^2	D_0	z	R^2
Cold syrups	**80°C/30min**	1.46×10^{-1}	35108.09	0.9333	32646.67	-269.05	0.9229	7.62×10^{7}	48.54	0.9114
	90°C/10min	4.99×10^{-2}	32327.56	0.9954	29866.14	-277.98	0.9954	6.66×10^{7}	52.36	0.9881
Hot syrups	**80°C/30min**	1.03×10^{-4}	16804.48	0.8923	14343.06	-329.33	0.8593	3.59×10^{7}	99.01	0.9070
	90°C/10min	5.86×10^{-2}	33551.63	0.9743	31090.20	-276.64	0.9697	9.65×10^{7}	50.51	0.9607

reaction. After 120 days of storage, an increase in the reducing sugar content was noted in all the syrups stored at different temperatures. Thus, it oscillated between 8 and 19 g.100 mL^{-1} in syrups stored at 4 °C, whereas in syrups stored at 45 °C, it was between 8 and 80 g.100 mL^{-1}. The activation energies (E_a) of the cold syrups were higher than those of the hot syrups. Therefore, the energy required to initiate the sucrose inversion reaction was greater in cold syrups than in hot syrups. Indeed, the syrups pasteurized at 90 °C/10 minutes have higher activation energies (35.108 $kJ.mol^{-1}$) than the other syrups. Also, it seems that this scale tends to make the degradation of reducing sugars, from the cold syrup, slower. The enthalpy of activation (ΔH*) varied from 29.866 to 32.646 $kJ.mol^{-1}$ and from 14.343 to 31.090 $kJ.mol^{-1}$ respectively for cold syrups and hot syrups. The highest "z" value was 99 °C with the pasteurized hot syrup with the 80 °C/30 minutes scale. In addition, the lowest z value (48 °C) was noted with the pasteurized cold syrup with the same scale. These results attest of the influence of production process and storage temperature on the organoleptic quality of the syrups. Ultimately, the increase in reducing sugar content appears to be related to the degradation of sucrose.

Furthermore, from the color point of view, result showed that the syrups stored at 45 °C are very different from those stored at 4 °C. This change in color, which increases with storage temperature, can be attributed to non-enzymatic browning reactions. The Maillard reaction occurs when reducing sugars (free carbonyl function) are in the presence of proteins, peptides or amino acids (free amine function). It was influenced by reaction factors (water activity, pH of the reaction medium, temperature and duration of heating) and reactants (nature of the reducing sugars, nature of the amino acid and the ratio

Ose/Amino acid) (Ajandouz & Puigserver, 1999). In the literature, it was mentioned that browning would increase with storage time (Wibowo *et al.*, 2015b). Several studies showed a correlation between ascorbic acid degradation and the development of brown pigments (Manso *et al.*, 2001; Choi *et al.*, 2002).

4. Conclusion

In this study, the influence of syrup production process, pasteurization, temperature and shelf life on the degradation of ascorbic acid and on the content of reducing sugars were evaluated. Their degradations are well described by first order kinetics. The effect of temperature and shelf life on nutritional quality (vitamin C) was demonstrated with the different models used (Arrhenius, Eyring and Ball). The initial characterization of the syrups before and after the pasteurization showed the impact of the heat treatment on the organoleptic and nutritional quality. The study also showed that storage temperature is an essential factor in the degradation of nutritional quality. These results suggest the production of pasteurized cold syrup with the scale of 90 °C for 10 minutes and storage at a temperature of 4 °C to preserve the nutritional and organoleptic characteristics. Thus, further studies will be needed to define new pasteurization scales and to evaluate the health effect of baobab pulp syrups for the benefit of small and medium-sized enterprises and consumers.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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