Original Research Article

KINETICS OF Fe^{2+} AND VITAMIN C RETENTION IN A NOUVELLE CONTINUOUS AND SIMULTANEOUS EXTRACTION AND PASTEURIZATION SYSTEM: APPLICATION TO *Justicia Secunda* BEVERAGE.

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Kinetics of Fe2+ and Vitamin C Retention in a Novel Continuous Simultaneous Extraction and Pasteurization System: Application to *Justicia secunda* Beverage

ABSTRACT

This study evaluates the retention of Fe^{2+} and vitamin C during the processingof *Justicia secunda* drink using a Continuous Conventional Extraction followed by Pasteurization (CCEP) system in comparison to a Continuous Simultaneous Extraction and Pasteurization (CSEPA) system. In the Continuous Conventional extraction followed by Pasteurization (CCEP) system, the drink was first extracted and then pasteurized while the Continuous Simultaneous Extraction and Pasteurization (CSEPA) system integrates extraction and pasteurization into a single process. The results revealed that the average Fe^{2+} and vitamin C content of the drink produced from the CSEPA process was significantly higher compared to that from the CCEP process, withaverage Fe^{2+} and vitamin C contents being higher by 30.65% and 50.60% respectively at optimal processing temperatures. The accumulation of Fe^{2+} and vitamin C, degradation of Fe^{2+} in the CSEPA process and degradation of vitamin C in the CCEP process followed a zero order kinetic model while the degradation of vitamin C in the CSEPA process, accumulation of vitamin C and degradation of Fe^{2+} in the CCEP process followed a second order kinetic model. The results also revealed that activation energies calculated using the first order and second order equations for Fe^{2+} and Vitamin C degradations were found to be approximately 12 and 3 times higher for the CSEPA process compared to the CCEP process respectively. This study highlights the potential use of the CSEPA process over the CCEP process since the CSEPA process retains more Fe^{2+} and vitamin C, and utilizes less processing time, and energy relative to the CCEP process.

Comment [BM2]: Please, rephrase this portion and make it more explicit. Which kinetic model does vitamin C and Fe^{2+} degradation follow in CCEP and CSEPA processes respectively?

Keywords: *Justicia secunda*,pasteurization, kinetics, Vitamin C, Fe^{2+}

1. INTRODUCTION

The negative effects of a separate extraction step followed by pasteurization on the nutritional, phytochemical and sensory properties of fruit and vegetable beverages as well as the cost of processing has necessitated the exploration of alternative processing systems that can reduce or eliminate these negative impacts. Among these is our established batch simultaneous extraction and pasteurization system reported by Neba *et al*. (2020) and Neba *et al*. (2021). This new promising processing system has been used successfully to limit the degradation of Vitamin C, minimize processing times as well as reduce the overall cost of production of *Justicia secunda* drink (Neba *et al*., 2020).

Justicia secunda Vahl (Acanthaceae) is an erect perennial plant whose leaves serve as an excellent source of calcium, vitamin C, iron (N'guessan *et al*., 2010; Moswa*et al*., 2008), flavonoid and total phenols(Swiatek*et al*., 2023). It is claimed that hot water extracts of the leaves of this plant are used in traditional medicine for the treatment of anemia (Fongod*et al*., 2013;Kon*éet al*., 2012), sickle cell disease (Kitadi*et al*., 2020) and diabetes (Theiler *et al*., 2017). The beverage from this plant is usually obtained by boiling the plant in water which must be consumed in a maximum of three days after extraction to avoid deterioration. It is worth noting that studies evaluating the effect of processing conditions on the nutrient content of beverages from this plant are scarce in the scientific literature. To extend the shelf life and standardize the processing conditions of the drink from this plant, Neba *et al.* (2020) pasteurized and stabilized it with a natural stabilizer (powder ginger) using two comparative processing methods(conventional extraction followed by pasteurization (CEP) and simultaneous extraction and pasteurization (SEPA)) in a batch system at a laboratory scale. They reported that the SEPA process retained more vitamin C, and utilized less energy and processing time when compared to the CEP process. Although the two processing methods reduced the vitamin C content of the drink, the degradation was higher in the CEP because of the double heating involved in the separate extraction and pasteurization stages. Regardless of the higher retention of vitamin C in the simultaneous extraction and pasteurization process in a batch system, the effect of this process in a continuous system and on other anti-anemic chemical elements have not been carried out. Rossi (2022)and Gerstweiler*et al.* (2021) reported that continuous flow processing offers significant advantages such as higher productivity, better product quality, reduced production cost and better control than batch processing. Since vitamin C content of beverages is widely considered as an appropriate marker for monitoring quality changes during processing and storage (Yu *et al*., 2013) and the decoction is mainly consumed because of its high iron content, it has been used to monitor the Continuous Conventional Extraction followed by Pasteurization (CCEP) and Continuous Simultaneous Extraction and Pasteurization (CSEPA) processes.

The objective of this study was therefore to determine the effect of heating temperature, time, and ginger concentration on the Fe^{2+} and the vitamin C content in a Continuous Simultaneous Extraction and Pasteurization (CSEPA) system. Parallel studies were carried out in the CCEP system to form a background to the interpretation of the results.

2. MATERIALS AND METHODS

2.1. Source of samples

The first six leaves of the twig of *Justicia secunda* plant were harvested with the hands from a research farm in Bambili, Bamenda, (5° 59'N and 10° 15'E) Cameroon. Mature ginger rhizomes were harvested from Nsem, Bafut (6° 10'N and 10° 06'E). The leaves and rhizomes were each thoroughly mixed to ensure uniformity. The samples collected were then transported to the Nutrition, Food and Bioresource Laboratory of the College of Technology of The University of Bamenda.

2.2. Preparation of Samples

The *Justicia secunda* leaves collected were sorted to separate flowers and stalk, washed repeatedly with tap water and rinsed with distilled water. The ginger rhizomes were washed with tap water to remove soil, strained, dried at 70°C in an oven, ground to powder using a commercial grinding mill. The powder was sieved using a stainless steel sieve having a pore diameter of 0.45 mm and sealed in plastic bags for further use.

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2.3. Kinetic Studies

This was carried out using a continuous simultaneous extraction and pasteurization machine constructed and tested in preliminary studies. The main parts of the developed extraction and pasteurization system include: hopper, chopper, extractor, pasteurizer, filter, storage tank, electric motors and main frame. The main frame was constructed to hold the other components and to provide support and rigidity to the equipment when in operation. The hopper was mounted at the top of the mainframe. The hopper has two shafts: the first shaft is used to rotate the leaves during washing while the second shaft which functions as a conveyor was connected to a set of pulleys powered by an electric motor mounted underneath the hopper. The hopper has an inlet pipe at the top and a perforated outlet at the bottom which receives clean water and sends out waste water. The hopper opens into the chopper containing sharp blades enclosed in a galvanized steel casing. The galvanized steel casing had two openings; one connected to the extractor and the other connected to the pasteurizer through 6.4 cm diameter pipes. An electric motor (II) which drives the chopper was mounted on the main frame beside the chopper. Beneath the electric motor (II) and mounted on the main frame, is the drink extraction unit (extractor). It consists of a stirrer, an electric heater connected to a thermocouple, an inlet pipe for the inflow of water that is linked to the casing of the chopper through PVC pipes. At the bottom of the extractor is an outlet PVC pipe which feeds the pasteurizer with the extracted drink. The pasteurizer is mounted on the main frame beneath the chopper. It consists of a stirrer, an electric heater with a thermocouple, an inlet pipe for the inflow of water and preservatives (ginger) and two inlet pipes which are linked to the extractor and the chopper through PVC pipes. At the bottom of the extractor is an outlet PVC pipe that discharges the pasteurized drink to the sieve. The filtration compartment is mounted on the main frame slightly beneath the pasteurizer and consists of a perforated stainless steel sieve and a filtrate tank. The tank has an opening on the side where a filter and a water pump are connected. The water pump conveys the drink through a pipe into the storage tank. The storage tank is the final compartment of the machine where the drink is temporarily stored before packaging. It is mounted on the main frame beside the extractor and connected through a pipe to the pump. At the bottom of the extractor is a tap where the drink is collected. Mounted on the main frame in front of the chopper is the control panel, where all the electrical components are controlled. It consists of six switches; one to switch on the machine, three to switch on/off the three motors and two to switch on/off the two heaters. It also consists of contactors which are connected to the thermocouples to control the electric heaters.

The machine was designed to operate along two different processing lines: the first was the continuous conventional extraction followed by pasteurization (CCEP) where the drink was first extracted and then pasteurized while the second was the continuous simultaneous extraction and pasteurization (CSEPA) in which extraction and pasteurization was carried out simultaneously in a single reactor.

For either process, the main switch of the machine was turned on to supply current to the machine, and then the conveyor motor, chopper motor, electric heaters, and electric pump were also turned on from the control board before the leaves were fed into the hopper. The flowsheet of the developed system used in the extraction and pasteurization process is presented on Figure 1.

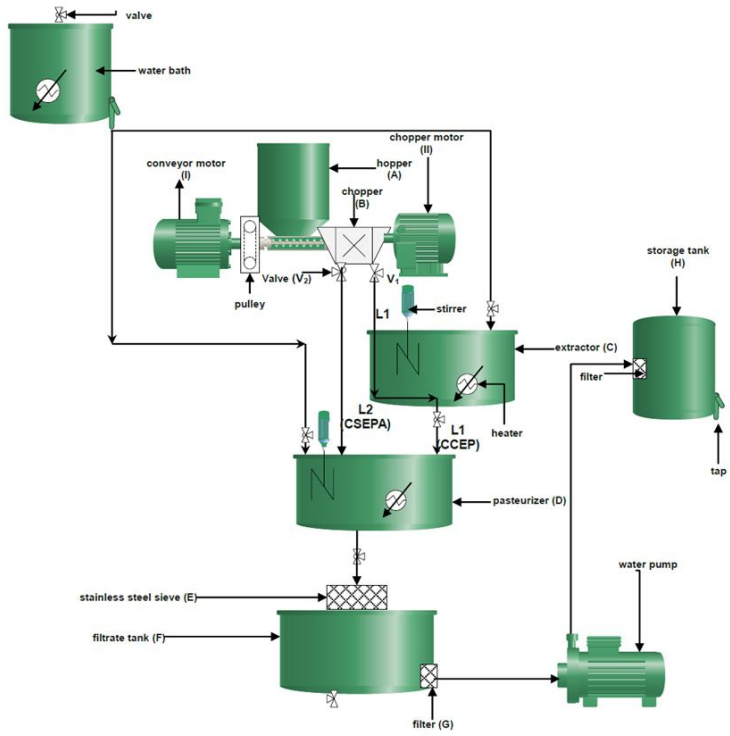

Fig.1. Flowsheet of the Developed Continuous Simultaneous Extraction and Pasteurizing system

2.3.1. Continuous Conventional Extraction Followed by Pasteurization

Fresh young leaves of *Justicia secunda* were fed at a flow rate of 1.5Kg/h into the hopper and conveyed to the chopper where the leaves were chopped into smaller sizes. The chopped leaves flowed under the force of gravity into an extractor. Water at a temperature of 70^{o}C from a water bath was added to the chopped leaves in the extractor at a flow rate of 7.5 L/h. Extraction was carried out at 70 ^{o}C for 20 min with constant stirring (1500 rpm). The mixture was then conveyed into the pasteurizer where ginger was added at a flow rate of 150 g/h to the mixture in the pasteurizer and pasteurized at 70 ^{o}C for 5, 10, 15, 20, 25 and 30 min with constant stirring. After pasteurization, the stopcock was opened and the mixture flowed under gravity into the filtration compartment where it was filtered, spent leaves discarded and the filtrate collected in the filtrate tank. The first filtrate went through two more filtration stages to remove fine particles and then pumped into storage tanks. The vitamin C and Fe^{2+} contents of the drink were then analyzed. Similar experiments were carried out at 80 ^{o}C and 90 ^{o}C. All experiments were carried out in duplicates.

2.3.2. Continuous Simultaneous Extraction and Pasteurization (CSEPA)

CSEPA experiments were carried out in a similar manner as described for CCEPA but for the fact that both extraction and pasteurization were carried out in one compartment hence the simultaneous process.

2.4. Determination of Fe^{2+} and Vitamin C Content

2.4.1. Determination of Fe^{2+} Content

The Fe^{2+} content of the *Justicia Secunda* drink was determined by the method described by Rajbhandari and Subedi (2013). Briefly, 2.5 mL of the drink samples were pipetted and transferred into 25 ml volumetric flasks. To each of the flasks, 0.25 mL, 1.25 mL, 2 mL of hydroxylamine hydrochloride, 1, 10-phenanthroline and acetic acid/sodium acetate buffer respectively were added and the mixture was allowed at room temperature for 15 min for full color development. The solution was made up to the mark with distilled water, swirled to obtain a homogenous mixture and the absorbance was measured at 510 nm using a UV-Visible spectrophotometer (UV 752(D), PEC Medical, USA).The concentration of Fe^{2+} in the *Justicia Secunda* drink was then estimated from the calibration curve.

Comment [BM5]: Please, explain how you obtain the calibration curve, stating the standard used.

2.4.2. Determination of Vitamin C

The vitamin C Content of the *Justicia Secunda* drink produced was determined by the method described by Mussa and El sharaa (2014) as reported in our studies (Neba *et al*. (2020) and Neba *et al*. (2021)). Briefly, 5mL of the drink was pipetted and transferred to a 25 mL volumetric flask. 5% metaphosphoric acid-10% acetic acid solution was added to the flask to make up 25 mL and mixture swirled to ensure uniformity. 5 mL of the solution was pipetted and transferred into another 25 mL volumetric flask and few drops of bromine water, few drops of thiourea, 1 mL of glacial acetic acid and 1mL of 2, 4- DNPH were added. The mixture was then incubated at 37 °C for 3 h in a thermostatic water bath and cooled immediately in an ice bath for half an hour. 5 mL of 85% H_2SO_4 was then added to the cooled samples and the volume completed to the mark with distilled water. The solution was swirled to obtain a homogenous mixture and the absorbance was measured at 521 nm using a UV-Visible spectrophotometer (UV 752(D), PEC Medical, USA).The concentration of vitamin C in the *Justicia Secunda* drink was then estimated from the calibration curve.

Comment [BM6]: Please, rephrase this portion clearly stating the volume of 5% metaphosphoric acid and 10% acetic acid used respectively.

Comment [BM7]: Please, explain how you obtain the calibration curve, stating the standard used.

2.5. Statistical Analysis

The results obtained from the laboratory were analyzed using SigmaPlot 10 and Microsoft Excel software 2010. The comparisons of the various components analyzed were achieved using the One-way Analysis of Variance (SigmaPlot 10) and figures plotted using SigmaPlot 10.

2.6. Modelling of Kinetic Studies

Kinetic analysis of vitamin C and Fe^{2+} degradation was done using the general reaction rate equation (equation 1) described byKadakal*et al*. (2018) and Peng *et al*. (2014).

$$-\frac{dC}{dt} = \mathbf{kC^n}, \quad \text{.....[1]}$$

where C is the quantitative value of the response (vitamin C or Fe^{2+} concentration), n, k and t represent the reaction order, rate constant and time respectively. For a first-order reaction, n=1 was substituted in equation 2 while for other orders equation 4.1 was integrated to give equation 3.

$$\boldsymbol{kt} = -\boldsymbol{ln}\frac{\boldsymbol{C}}{\boldsymbol{C_0}} \quad \text{.....[2]}$$

$$\boldsymbol{kt} = (\frac{1}{n-1})(\frac{1}{C^{n-1}} - \frac{1}{C_0^{n-1}}) \quad \text{..... [3]}$$

To determine the rate constant (K) and the coefficient of determination (R^2- value), a graph of t againstlnC for n=1 and/or t against $\frac{1}{C^{n-1}}$ for n≠1 was plotted followed by linear regression analysis on Microsoft excel. The R^2-values were estimated graphically and used to determine the best-fitted reaction order while the rate constant (k) of samples at each temperature was obtained from the slope and used in the determination of the activation energy.

Temperature dependence of vitamin C and Fe^{2+} degradation was determined using the Arrhenius type equation (Equation 4).

$$k = Ae^{-\frac{E_a}{RT}}$$.....[4]

Where, k, A, R, T, $E_a$represent the reaction rate constant, frequency factor,universal gas constant, absolute temperature and activation energy of the reaction respectively. Equation 4.4 was further linearized to obtain equation 5.

$$Ink = lnA - \frac{E_a}{RT}$$.....[5]

The activation energy was obtained from the slope of the plot of lnk against 1/T

3. RESULTS AND DISCUSSIONS

3.1. Kinetic Studies

3.1.1. Continuous Conventional Extraction Followed by Pasteurization (CCEP)

Fig. 2 presents the variation of vitamin C with time at 70, 80 and 90^{o}Cduring the CCEP process. It is observed that the vitamin C content increased from 0 – 5 min, decreased after 5 min and attained relatively stable values after 10 min when pasteurization was carried out at 70 ^{o}C while at 80^{o}C and 90 ^{o}C, the vitamin C content increased during the first 5 min and then attained relatively stable values. The slight increase in the vitamin C content could be as a result of the contribution from the addition of ginger which is also a source of Vitamin C (Shalaby *et al.*, 2023; Ozola*et al.*, 2019) while the subsequent decrease is as a result of degradation during the process of pasteurization (Essodolom*et al.*, 2020; Sunetra, 2018; Zhang *et al.*, 2016; Khalil *et al.*, 2015). It was observed that the rate of degradation increases with increase in time and temperature. Similar trends were reported in a study carried out by Mazur *et al.* (2014). The rate of degradation was significantly lower when pasteurization was carried out at 70 ^{o}C compared to that at 80^{o}C ($p = 0.041 < 0.05$) and 90^{o}C ($p = 0.013 < 0.05$). No significant difference between the vitamin C contents was observed when pasteurization was carried out at 80^{o}C compared to that at 90^{o}C.

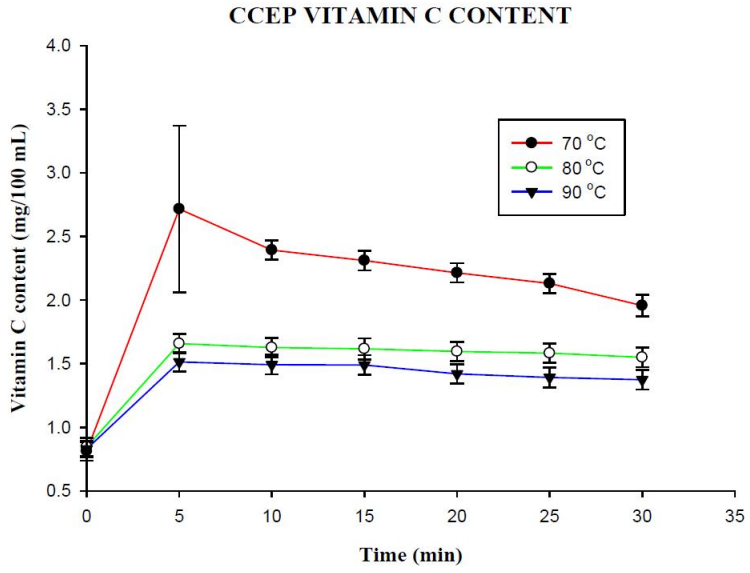

Fig. 2. Influence of Temperature on the Vitamin C Content during the CCEP Process

The results for the variation of Fe^{2+}content with time at 70, 80 and 90 ^{o}C during the CCEP process are presented in Fig. 3. The maximum Fe^{2+} content was obtained when the drink was extracted at 70 ^{o}C for 20 min and pasteurized at 70 ^{o}C for 5 min. The results revealed that there was a significant decrease when pasteurization was carried out at 80^{o}C (p = 0.002) and 90^{o}C (p = 0.000079) compared to that at 70 ^{o}C. Yang and Tsou, (2006) reported that vitamin C chelates iron and keeps the iron in the soluble form thereby increasing its availability for absorption. The decrease in vitamin C at higher temperatures and longer pasteurization time probably led to a subsequent decrease in the Fe^{2+} content of the drink. It was observed from Fig. 2 and 3 that, during the pasteurization process the vitamin C content and Fe^{2+} content were relatively stable at corresponding pasteurization temperatures and time. The decreased in the concentration of Fe^{2+} at temperatures above 80 ^{o}C could be attributed to the fact that, at higher temperatures the rate of degradation of Fe^{2+} content is higher relative to lower temperatures (Mohd-Taufek*et al.*, 2016). This is in line with a study carried out by Ouattara *et al.*, (2017) oncashew apple and pineapple juice blend.

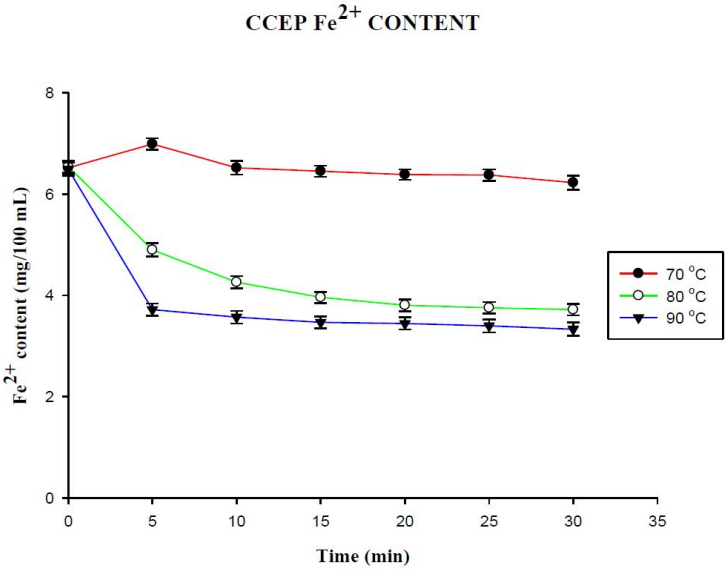

Fig. 3. Influence of Temperature on the Fe^{2+}Content during the CCEP Process

3.1.2. Continuous Simultaneous Extraction and Pasteurization (CSEPA)

Fig. 4 presents the variation of vitamin C content with time at 70, 80 and 90 ^{o}C during the CSEPA process. At 70, 80and 90 ^{o}C, the vitamin C content increased from 0 – 3.05mg/100 mL then decreased to 2.79 mg/100 mL, increased from 0 – 1.90 mg/100 mL then decreased to 1.43 mg/100 mL and increased from 0 – 2.50mg/100 mL then decreased to 1.79 mg/100 mL respectively. The highestvitamin C content was obtained when the drink was simultaneously extracted and pasteurized at 70^{o}C for 20 min. As observed for Fe^{2+}, Vitamin C content increased with time and attained peak values of 3.05, 1.90 and 2.50 mg/100ml after about 20, 10 and 8 minute of processing at , 70, 80 and 90 ^{o}C respectively. Peak vitamin C content decreased significantly (P<0.05) with temperature as expected since vitamin C is water-soluble and heat liable. There is a great tendency for it to be leached out from the leaves but at the same time degraded during the simultaneous extraction and pasteurization process. An increased in pasteurization time resulted to a decreased in the vitamin C content of the drink. At constant temperature and prolonged pasteurization, the drink is exposed to heat for a longer period of time, hence an increased in the rate of vitamin C degradation. This decreased in vitamin C at longer pasteurization time has also been reported by Duong *et al.* (2023), Neba*et al.* (2020) and Diengdoh*et al.* (2015).

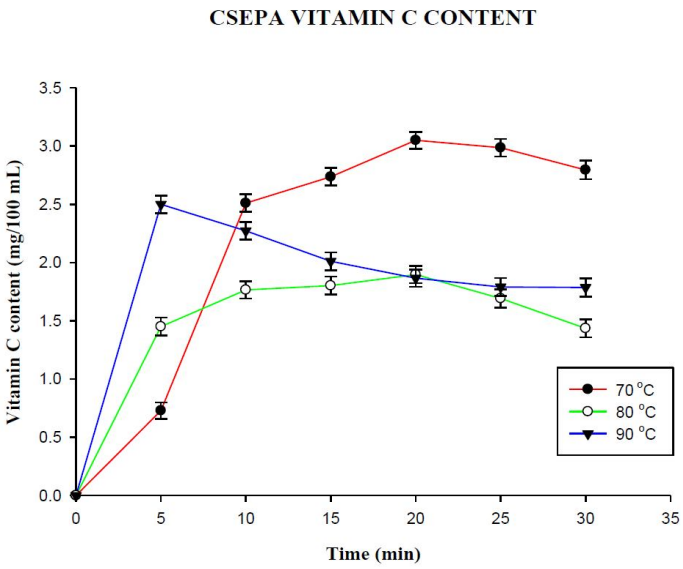

Fig. 4. Influence of Temperature on the Vitamin C Content during the CSEPA Process

Fig. 5 presents the variation of Fe^{2+} content with time at temperatures of 70, 80°C and 90 °C. At 70, the Fe^{2+} content increased steadily from 0 – 7 mg/100 mL in the first 20 min, at 80°C from 0 – 5 mg/100 mL in the first 10 min and at 90°C an increase in Fe^{2+} was observed only in the first 5 min from 0 – 4.86 mg/100mL. The maximum Fe^{2+} content was obtained when the drink was simultaneously extracted and pasteurized at 70°C for 20 min. That is, in the CSEPA process, Fe^{2+} increased significantly with time to attain maximum values after 20, 10 and 5 min at 70, 80 and 90°C and then remained fairly constant. Final Fe^{2+} content was significantly higher at 70 compared to values obtained at 80 and 90°C. Since Fe^{2+} is water-soluble, there is a great tendency for it to be leached out from the leaves during the simultaneous extraction and pasteurization process. It has also been reported that at higher temperatures and in the presence of water, Fe^{2+} is easily leached out from the leaves of vegetables (Sharma and Sharma, 2022).With increasing temperature and time, the amount of Fe^{2} that leaches out from the leaves into the water increases, thus a subsequent increase in the concentration of Fe^{2+} in the drink. This is in line with studies carried out by Joshua *et al.* (2012) and Yakubo*et al.* (2012). As in the CCEP process, increase in temperature led to a significant decrease in the final Fe^{2+} content.

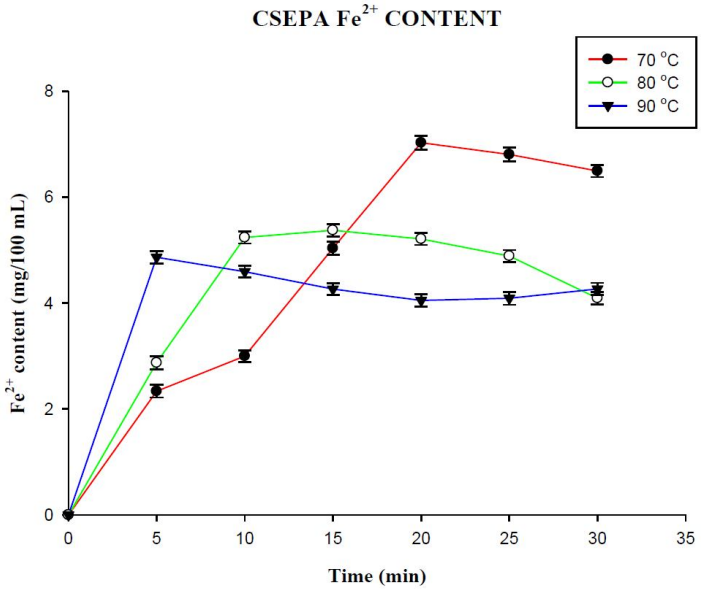

Fig. 5. Influence of Temperature on the Fe^{2+} Content for the CSEPA Process

3.1.3. Modeling of the CCEP and CSEPA Kinetics

The CSEPA and CCEP processes were modeled using the zero, first and second-order reaction equations. The data for each temperature was divided into two phases corresponding to the vitamin C or Fe^{2+} accumulation and degradation in the aqueous medium respectively. Table 1 presents the results of the R^2-values and the rate constants for the parameters measured for the CSEPA and CCEP processes. High R^2-values estimated graphically permitted us to use the selected equations to determine the order of the reactions; because it has been reported that the higher the R^2 -value (the closer the R^2-value is to 1) the better the reaction order tested is suited (Joglekar and May, 1987). From the R^2 - values of Table 1, it can be observed that, the accumulation of Fe^{2+} and vitamin C, degradation of Fe^2 in the CSEPA process and degradation of vitamin C in the CCEP process followed a zero order kinetic model while the degradation of vitamin C in the CSEPA process, accumulation of vitamin C and degradation of Fe^{2+} in the CCEP process followed a second order kinetic model. This is similar to a study carried out by Abbasi and Niakousari (2006) but contrary to studies carried out by Jirasatida and Noipanta, (2015) and Zhang *et al.* (2016). R^2-values for the accumulation of Fe^{2+} in the CCEP process revealed that none of the reaction orders could be determined from the models at all temperatures. Generally, it was difficult to model either iron accumulation or degradation at 90°C with the selected models.

Table 1: R^2 -values degradation and accumulation rate constants (k) for Fe^{2+} and Vitamin C for both processes

			Zero-order		First order		Second order	
		Temp / °C	k-value	R^2	k-value	R^2	k-value	R^2
CSEPA	Fe^{2+} accumulation	70	-0.3351	0.9796	-0.0934	0.9632	0.0011	0.0027
		80	-0.3698	0.8943	-0.1129	0.8571	0.008	0.1321
		90	-0.4594	0.706	-0.0859	0.53	0.0143	0.702
	Fe^{2+}	70	0.0533	0.9908	0.0079	0.9886	0.0012	0.9862

	Degradation	80	0.0834	0.8921	0.0176	0.8715	0.0038	0.8504
		90	0.0166	0.3723	-0.0031	0.0031	-0.00006	0.0032
CCEP	**Fe^{2+} accumulation**	70	-0.0001	0.000005	-0.0001	0.000005	-0.000003	0.000006
		80	-	-	-	-	-	-
		90	-	-	-	-	-	-
	Fe^{2+} degradation	70	0.0132	0.9189	0.0132	0.9189	0.0003	0.9132
		80	0.0801	0.7147	0.0167	0.7697	0.0036	0.8204
		90	0.0732	0.4786	0.02	0.5481	0.0036	0.5634
CSEPA	**Vitamin C accumulation**	70	-0.1621	0.8966	-0.0711	0.7346	-0.007	0.0116
		80	-0.0829	0.6867	-0.0299	0.8106	0.0184	0.2928
		90	-0.2272	0.6756	-0.082	0.6638	0.044	0.8176
	Vitamin C degradation	70	0.0254	0.9225	0.0087	0.9178	0.003	0.9132
		80	0.0463	0.9958	0.028	0.9893	0.017	0.9801
		90	0.0238	0.852	0.0119	0.8691	0.006	0.8849
CCEP	**Vitamin C accumulation**	70	-0.158	0.6015	-0.108	0.6629	-0.0813	0.7042
		80	-0.078	0.7199	-0.0654	0.7281	-0.0567	0.7346
		90	-0.0662	0.7257	-0.0587	0.7318	-0.0535	0.7367
	Vitamin C degradation	70	0.021	0.9744	0.0097	0.9641	0.0048	0.9519
		80	0.0037	0.962	0.0024	0.9594	0.0015	0.9567
		90	0.0067	0.926	0.0047	0.9286	0.0033	0.9312

Activation Energies

Table 2 presents the activation energies of Fe^{2+} and vitamin C calculated in the accumulation and degradation phases of both the CSEPA and CCEP processes. These activation energies represent the minimum amount of energy required for each reaction to begin. In most of the phases, the activation energies were found to be lower in the CSEPA process indicating that the CCEP process is more energy intensive relative to the CSEPA process. Activation energies calculated using the first order and second order equations for Fe^{2+} degradation were found to be approximately 12 and 3 times higher for the CSEPA process compared to the CCEP process respectively.This indicates that the degradation of Fe^{2+} in the *Justicia secunda* drink was slower in the CSEPA process compared to CCEP process.

Table 2: Activation energies and Arrhenius constants for the CSEPA and CCEP Processes

		Zero-order			First order			Second order		
		E_a(KJ/mol)	A	R^2	E_a (KJ/mol)	A	R^2	E_a (KJ/mol)	A	R^2
CSEPA	**Fe^{2+} accumulation**	-	-	-	-	-	-	133.52	2.88653E+17	0.9184
	Fe^{2+} Degradation		6.77633E-11	0.4735	249.12	3.82869E+35	0.859	346.14	2.81041E+49	0.8631
CCEP	**Fe^{2+} accumulation**	-	-	-	-	-	-		-	-
	Fe^{2+} degradation	89.64	7.31966E+11	0.7254	21.55	25.31760491	0.9964	129.91	2.64227E+16	0.764
CSEPA	**Vitamin C**	-	-	-	-	-	-		4.75032E-26	0.5689

	accumulation								
	Vitamin C degradation	0.011891874	0.0052	17.21	5.025374608	0.0754	37.25	2197.773321	0.1697
CCEP	**Vitamin C degradation**	9.57371E-12	0.4352		105476633.2	0.2836		115959.9324	0.0836

3.1.4. Comparison between CCEP and CSEPA

Fig. 6 a-c and d-f compare the Vitamin C and Fe^{2+} contents obtained during the CCEP and CSEPA processes at 70, 80 and 90 ^{o}C respectively. It can be seen that for both parameters and at most of the temperatures degradation was significantly higher for the CCEP compared to the CSEPA process as reported in our earlier works for the batch process (1). The higher degradation of Vitamin C and Fe^{2+} in the CCEP process is attributed to the double heating that occurred during the separate extraction and pasteurization stages compared to CSEPA where these processes are carried out in a single stage.

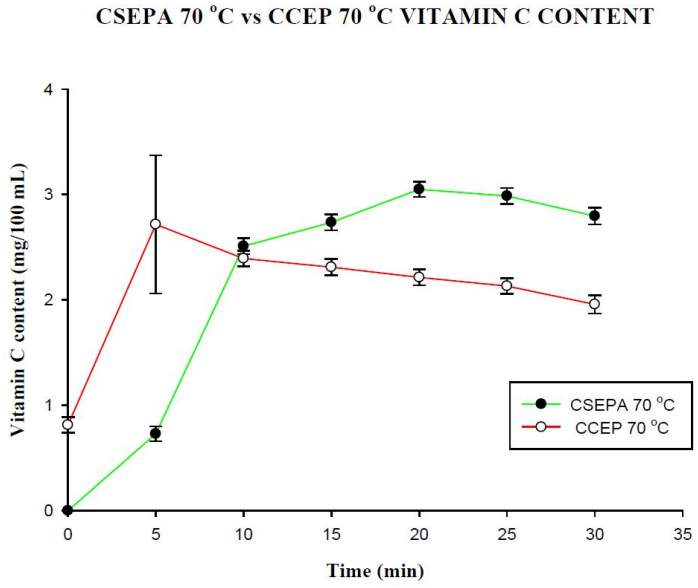

Fig. 6a. Comparison of vitamin C content for CSEPA and CCEP at 70 ^{o}C

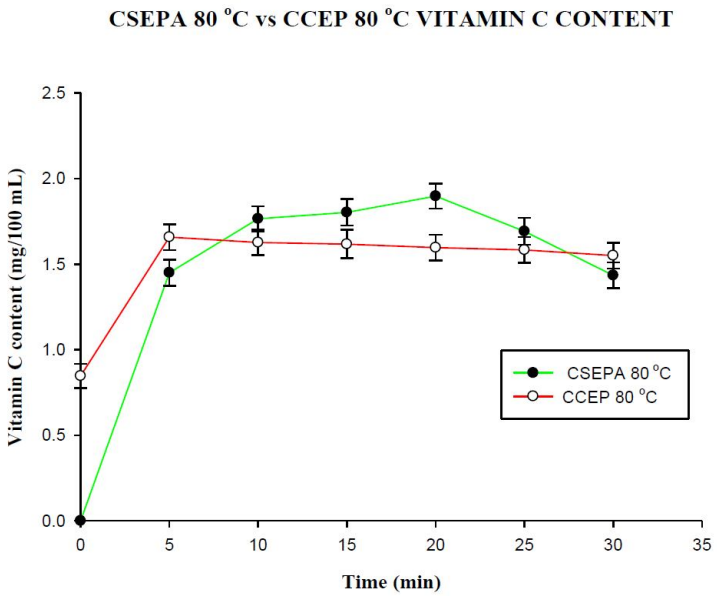

Fig. 6b. Comparison of vitamin C content for CSEPA and CCEP at 80 °C

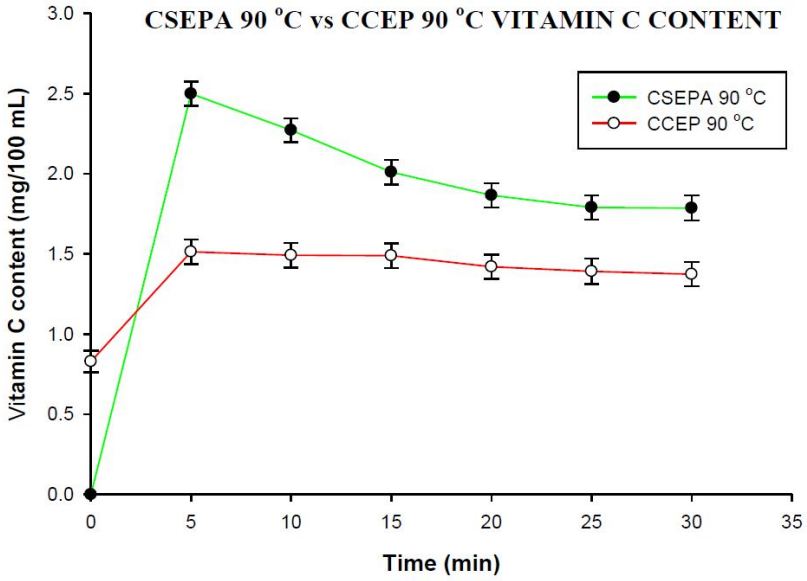

Fig. 6c. Comparison of vitamin C content for CSEPA and CCEP at 90 °C

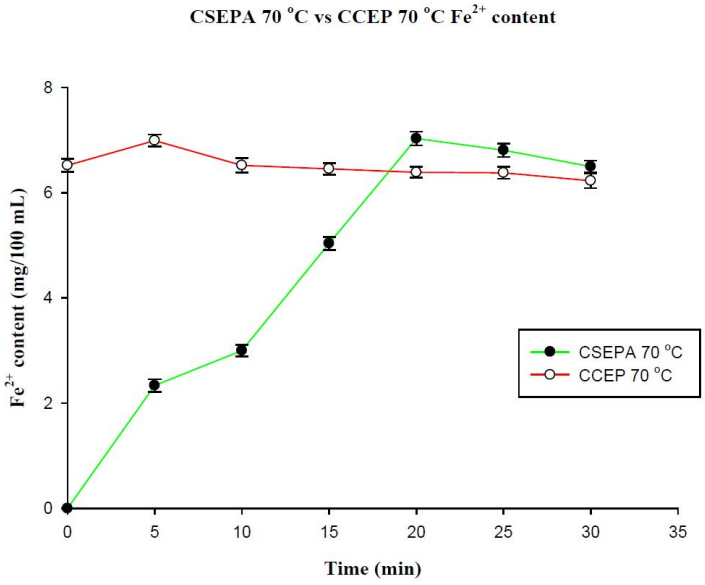

Fig. 6d. Comparison ofFe^{2+} content for CSEPA and CCEP at 70 °C

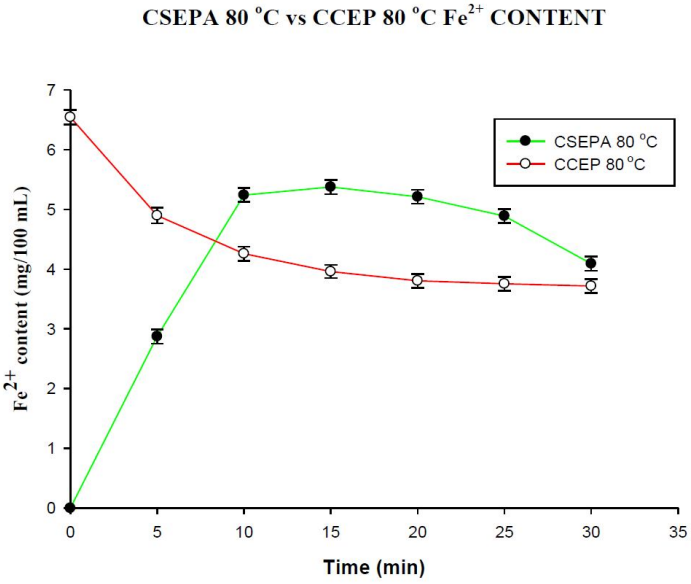

Fig. 6e. Comparison of Fe^{2+}content for CSEPA and CCEP at 80 ^{o}C

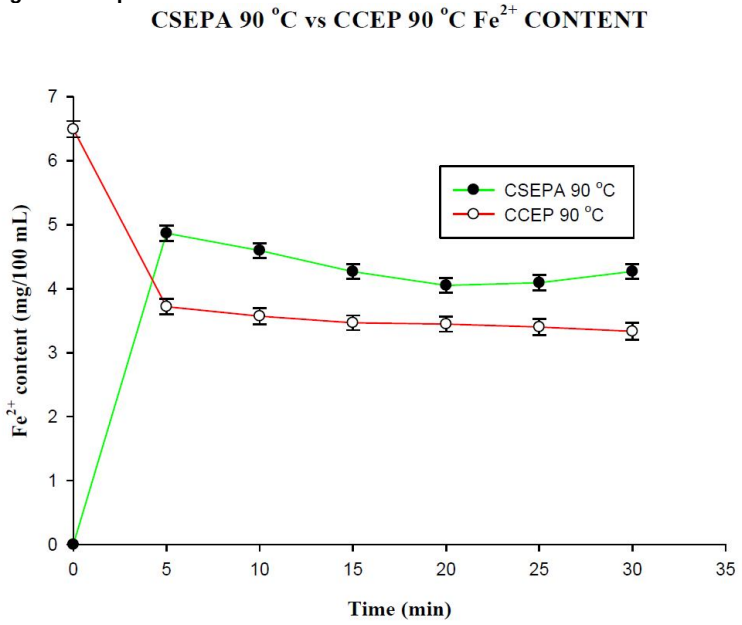

Fig. 6f. Comparison ofFe^{2+} content for CSEPA and CCEP at 90 ^{o}C

The results obtained from the study revealed the following advantages of the CSEPA compared to the CCEP process:

1. The processing time for the CSEPA process was reduced by 20 % (processing time of 20 minutes for the CSEPA and 25 minutes for the CCEP) compared to the CCEP process.

2. The average Fe^{2+} content for CSEPA was 0.1, 35.61, and 30.65 % higher compared to CCEP at 70, 80 and 90 ^{o}C respectively
3. The average vitamin C content for CSEPA was 38.01, 18.75 and 50.60 % higher compared to CCEPat 70, 80 and 90 ^{o}C respectively

4. Activation energies calculated using the first order and second order equations for Fe^{2+} and Vitamin Cdegradations were found to be approximately 12 and 3 times higher for the CSEPA process compared to the CCEP process respectively. This indicates that the degradation of Fe^{2+} in the *Justicia secunda* drink was slower in the CSEPA process compared to CCEP process.

4. CONCLUSION

Based on the methodology used and the results obtain from the study, it is concluded that, the processing time for the Continuous Simultaneous Extraction and Pasteurization (CSEPA) process was reduced by 20 % compared to the Continuous Conventional Extraction followed by Pasteurization (CCEP) process. The average Fe^{2+} content retention for CSEPA was 0.1, 35.61, and 30.65 % higher compared to CCEP at 70, 80 and 90 ^{o}C respectively. The average vitamin C retention for CSEPA was 38.01, 18.75 and 50.60 % higher compared to CCEPat 70, 80 and 90 ^{o}C respectively. Furthermore, activation energies calculated using the first order and second order equations for Fe^{2+} and Vitamin Cdegradation were found to be approximately 12 and 3 times higher for the CSEPA process compared to the CCEP process respectively indicating that the degradation of Fe^{2+} and Vitamin C in the *Justicia secunda* drink was slower in the CSEPA process compared to CCEP process. These results confirm the

conclusions we made in our previous publications that simultaneous extraction and pasteurization is more beneficial than carrying out a separate extraction and pasteurization process hence should be adopted for juice processing.

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