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Osmotic Dehydration of Papaya (*Carica papaya* L.): Factors of Influence, Kinetics and Mass Transfers

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Abstract— The objective of this study was to conserve papaya (*Carica papaya*) by osmotic dehydration. To do this, influencing factors, dehydration kinetics and mass transfers were determined. Papaya samples from the city of Daloa (Côte d'Ivoire) were used. A Plackett-Burmann plan was used to identify factors that significantly affect the process. In addition, the kinetics were monitored at various temperatures (30 and 60 °C) and sucrose solution concentrations (30 and 60 °Brix). The results revealed that the variety, treatment time, temperature, agitation, solute type, solute concentration and matrix form have a significant influence on the process. In addition, the maximum water loss (0.30 ± 0.03 g/g) of the papaya was obtained after 4 hours of treatment at 60 °C in an osmotic solution of sucrose concentrated at 60 °Brix. Thus, the water loss was higher when the temperature and solute concentration were high. In addition, the study of mass transfers revealed that during osmotic dehydration, the papaya loses water and becomes imbibes with sugars. This is advantage for its preservation over a relatively long period.

Index Terms— Carica papaya, osmotic dehydration, temperature, water loss, kinetics, sucrose.

1 Introduction

Originally from tropical America, papaya (*Carica papaya* L.) is widely grown in Africa with an estimated production of 1.37 million tons in 2016 [1]. In Côte d'Ivoire, its production is close to 15,951 tons with 635 exportable tons [1]. Thus, this fruit suffers from enormous post-harvest losses. These considerable losses are due in part to the rapid decay of papaya [2]. To reduce these losses, many methods of drying are requested [3]. Among them, osmotic dehydration has a number of strengths compared to traditional drying techniques namely: drying, salting and smoking. Particularly, the food is treated at a lower temperature and is protected from oxygen, which is favorable for products sensitive to oxidative and thermal degradation reactions [4], [5].

Osmotic dehydration is the partial removal of water from the food by immersing it in a hypertonic solution of sugars or salts [6]. This technique aims to achieve a significant flow of water from the fruit to the solution as well as a transfer of solute from the solution to the fruit [7], [8]. The feed can lose up to 50% of the initial water content in less than three hours [4]. In addition, many factors influence the performance of osmotic dehydration [9], [10], [5].

Concerning papaya, very little works has been done on osmotic dehydration. There is therefore a paucity of data on matter transfers, factors influence and dehydration kinetics.

The general objective of this study was to improve the preservation of papaya by osmotic dehydration. It consisted specifically to:

- determine the factors acting on the osmotic dehydration of the papaya;
- characterize the mass transfers that take place during the process of osmotic dehydration of papaya;
- determine osmotic dehydration kinetics taking into account both concentration of solute and temperature.

2 Material and Methods

2.1 Raw Material

The biological material used in the study consists of two varieties of papayas, namely: *Solo* variety and *Colombo* one. These papayas were sampled at the Lobia market (Daloa, Ivory Coast). Samples selected for dehydration were collected according to the initial characteristics summarized in Table 1. Whole papayas were washed with water and wiped. Each sample of papaya was trimmed and cut into cubes and slices of about 5 g.

TABLE 1
Initial Characteristics of the Different Papaya Varieties

Papaya Varieties	Texture	Soluble solids (°Brix)	Moisture (%)
Solo	Firm to the touch	11,2-11,6	82-84
Colombo	Firm to the touch	9-11	80-81

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2.2 Determination of the physico-chemical parameters of the papaya

The moisture content was determined following a rapid method using the moisture meter apparatus (OHAUS MB27). The soluble solids were determined using a portable refractometer (ATAGO).

2.3 Screening of factors

A Plackett-Burmann plan was used with seven factors. These included variety, treatment time, shape of matrix, agitation, temperature, solute type, and solute concentration. For each factor, a high level (+1) and a low one (-1) were retained (Table 2). According to this plan, eight trials were carried out. The factor matrix presented in Table 3 was followed and gave a table of experimentation (Table 4). In addition, trial No. 4 was randomly selected and repeated three times in order to determine experimental error. Taking into account the experimental error Se, the factor coefficients whose absolute value is greater than or equal to 2 x Se are significant. These coefficients were determined using a multiple linear regression performed on Excel 2010.

TABLE 2
LEVELS OF DIFFERENT FACTORS STUDIED

Factors	High level (+1)	Low level (-1)
Variety	Solo	Colombo
Treatment time	240 minutes	120 minutes
Shape of matrix	Cube	Slice
Agitation	Yes	None
Temperature	60 °C	30 °C
Type of solute	Saccharose	Glucose
Solute concentration	600 g/L	300 g/L

.

TABLE 3
LEVELS OF DIFFERENT FACTORS STUDIED

	Factors						
Trials	X1	X2	X3	X4	X5	X6	X7
1	-1	1	1	-1	-1	1	1
2	1	-1	1	1	-1	-1	1
3	1	1	-1	1	1	-1	-1
4	-1	1	1	-1	1	1	-1
5	-1	-1	1	1	-1	1	1
6	1	-1	-1	1	1	-1	1
7	1	1	-1	-1	1	1	-1
8	-1	-1	-1	-1	-1	-1	-1

X1: Variety; X2: Treatment time; X3: Form of the matrix; X4: Agitation; X5: Temperature; X6: Type of solute; X7: Solute concentration

2.4 Kinetics of osmotic dehydration of papaya

Preparation of osmotic solutions

Osmotic solutions (glucose and sucrose) were prepared at concentrations of 30 and 60 °Brix. To facilitate dissolution of the solute, the solutions were placed in a water bath at 80 °C with gentle stirring. After dissolution, the Brix degree of the cooled solutions was measured using a refractometer [11].

Conduct of osmotic dehydration

Osmotic dehydration of papaya *Solo* samples was conducted in glass jars at a fruit/solute ratio of 1/20 (w/v). Each jar, containing a 5 g fruit sample and 100 mL of the osmotic solution, is sealed, then kept in a water bath with mechanical stirring at constant temperature. Preliminary tests were made to set the optimum treatment time at 4 h.

Measurement and calculation of water loss (PE).

The influence of the operating parameters was monitored through the determination of the water loss. After one hour of treatment, each papaya sample was removed from the jar, placed on blotting paper and weighed. This operation continued at regular intervals of one hour of time during 4 hours. The loss of water (PE) at time t is given by the following formula [12]:

$$PE(t)=[Me(0)-Me(t)]/M \quad (1)$$

Me (0): Mass of water in the sample before treatment;
Me (t): Mass of water in the sample after treatment at time t;
M: Mass of the sample before treatment.

2.5 Evaluation of mass transfers

Considering the different transfers that take place during the osmotic dehydration process, it is possible to perform the mass balance affecting the product as a result of the movements of water and sugar.

Water balance

The water mass of the sample at time t, [Me (t)] corresponds to the difference between the initial mass of water, [Me (t0)] and the mass of water lost from time t0 to time t, [PE (t) × Mp (t0)]. The quantity of water of the sample at time t was determined according to the following formula [12]:

$$Me(t) = [H (t0) \times Mp (t0)] - [PE (t) \times Mp (t0)] \quad (2)$$

Me (t): Mass of water in the sample at time t;
H (t0): Water content of the sample at the initial time;
Mp (t0): Mass of the sample at time t0;
PE (t): Loss of water at time t, relative to the initial mass of the product.

Sugar Balance

The mass of sugar in the sample at time t, S (t) corresponds to the cumulation of the initial sugar mass, S (t0) and the mass of sugar impregnated from time t0 to instant t, [GS (t) × Mp (t0)]. The following formula was used to calculate the sugar mass [12]:

$$S(t) = S (t0) + [GS (t) \times Mp (t0)] \quad (3)$$

TABLE 4
EXPERIMENTAL DESIGN

Trials	Varieties	Treatment Time (min)	Matrix shape	Agitation	Temperature (°C)	Solute	Solute concentration
1	Colombo	240	Cube	None	30	Saccharose	600 g/L
2	Solo	120	Cube	Yes	30	Glucose	600 g/L
3	Solo	240	Slice	Yes	60	Glucose	300 g/L
4	Colombo	240	Cube	None	60	Saccharose	300 g/L
5	Colombo	120	cube	Yes	30	Saccharose	600 g/L
6	Solo	120	Slice	Yes	60	Glucose	600 g/L
7	Solo	240	Slice	None	60	Saccharose	300 g/L
8	Colombo	120	Slice	None	30	Glucose	300 g/L

S (t): Mass of sugar in the sample at time t;
S (t0): Mass of sugar in the sample at the initial moment t0;
GS (t): Solute gain at time t;
Mp (t0): Mass of the sample at the initial moment.

Global balance

The overall balance, at time t, of matter movements affecting the product is the result of sucrose gain, water loss and solute loss, hence the formula [12]:

$$Mp(t) = Mp(t0) + [GS(t) \times Mp(t0)] - [PE(t) \times Mp(t0)] \quad (4)$$

Mp (t): Mass of the sample at time t;
Mp (t0): Mass of the sample at time t0;
GS (t): Solute gain at time t;
PE (t): Loss of water at initial time

2.6 Stastical analyses

The collected data were subjected to statistical analyses. For this purpose, one-way analyzes of variance were performed to assess the existence of differences between the samples studied. When the difference is significant, a multiple comparison test (TUKEY HSD) is performed to separate the samples. In addition, a multiple linear regression was conducted to identify the factors that significantly influence the osmotic dehydration of papaya.

3 RESULTS

3.1 Factors influence on osmotic dehydration process

All factors including variety, time of treatment, temperature, solute type, solute concentration, matrix form and agitation significantly ($p<0.05$) influenced the osmotic dehydration of the papaya (Table 5).

3.2. Influence of temperature on papaya osmotic dehydration kinetics

At concentration of the 60 °Brix of saccharose osmotic solution, the water loss of the papaya samples was greater in the solutions maintained at 60 °C than the samples immersed at a temperature of 30 °C (Figure 1a). The same is true for the samples in an osmotic solution with a concentration of 30 °Brix (Figure 1b).

TABLE 5
RESULTS OF FACTORS SCREENING

	Coefficients	Significance
Constante	0,251125	Significant
X1 (Variety)	0,179625	Significant
X2 (Time)	-0,029625	Significant
X3 (matrix shape)	-0,113625	Significant
X4 (Agitation)	0,068375	Significant
X5 (Temperature)	0,009625	Significant
X6 (Type of solute)	-0,118375	Significant
X7 (Concentration of solute)	0,081875	Significant

Coefficients whose absolute value is greater than or equal to 2Se (0.003) are significant.

3.2. Influence of solute concentration on papaya osmotic dehydration kinetics

At a temperature of 60 °C, the water loss of the papaya samples in the 60 °Brix osmotic solution was greater than that of the samples immersed in a 30 °Brix solution (Figure 2a). Similar results were obtained at a temperature of 30 °C (Figure 2b).

3.3. Comparison of different water losses at different temperatures and concentrations

Papaya slices immersed at high-temperature in high-concentration of saccharose osmotic solutions lose much more water than samples immersed in the less concentrated solutions at lower temperatures (Figure 3). The results also indicated that when the concentration is high, regardless of the temperature level, the water loss is high.

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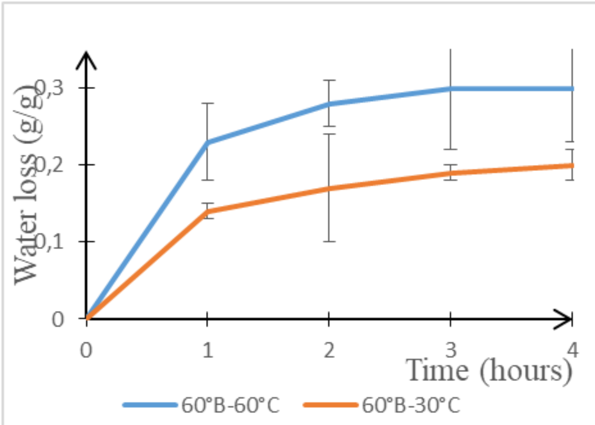
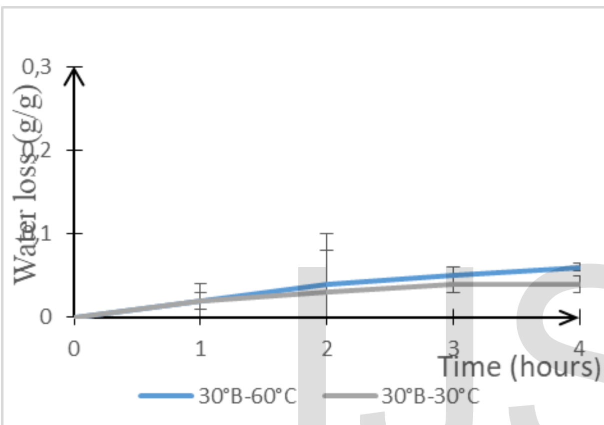
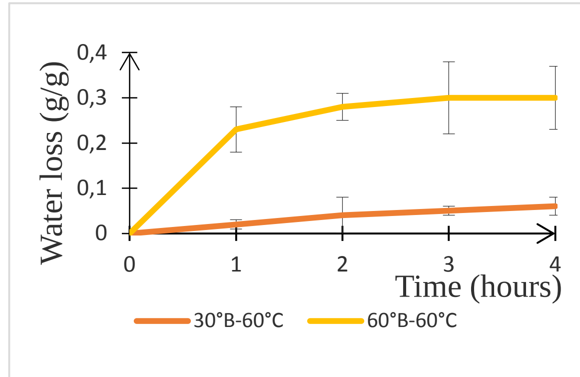


a) Saccharose osmotic solution at 60 °Brix

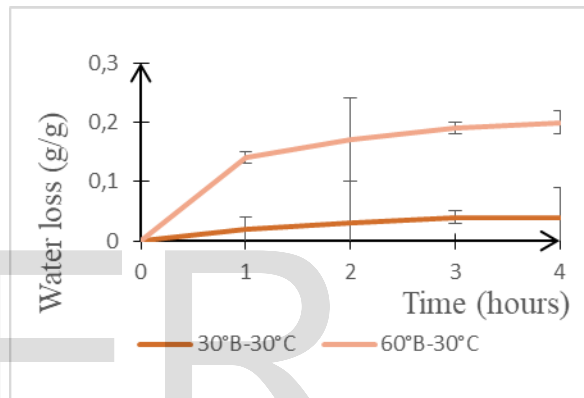


b) Saccharose osmotic solution at 30 °Brix

Fig. 1. Kinetics of the water loss of the papaya in osmotic solution at different concentrations of saccharose.



a) Saccharose osmotic solution at 60 °C



b) Saccharose osmotic solution at 30 °C

Fig. 2. Kinetics of the water loss of the papaya in saccharose osmotic solution at different tempuratures.

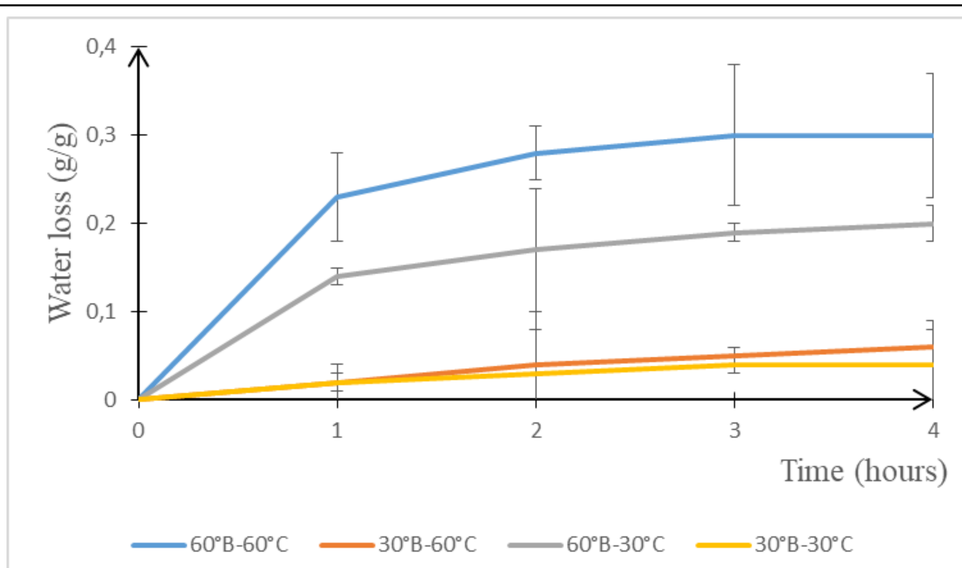


Fig. 3. Kinetics of the water loss of the papaya in saccharose osmotic solution at different concentrations and temperatures.

3.4. Balance of mass transfer

The calculation of the balance gave the results presented in Table 6. These results indicated a smaller amount of water quantity (2.90 ± 0.2 g) in the papaya samples at the end of the osmotic dehydration operation for high concentrations (60 °Brix) and temperatures (60 °C). In addition, for these high concentrations and high temperatures, the papaya samples recorded the highest sugar balances (3.4 ± 0.13 g). On the contrary, the sugar balances were the lowest (1.97 ± 0.04 g) when the temperature and the concentration of the osmotic solution were the lowest, respectively 30 °C and 30 °Brix.

TABLE 6
MATTER BALANCES DURING THE OSMOTIC DEHYDRATION OF PAPAYA

	Treatment conditions			
	30 °C – 60 °Brix	30 °C – 30 °Brix	60 °C – 60 °Brix	60 °C – 30 °Brix
Water balance (g)	3,07 ± 0,07^{b}	3,87 ± 0,09^{c}	2,90 ± 0,2^{a}	4,06 ± 0,65^{c}
Sugar balance (g)	2,43 ± 0,03^{c}	1,97 ± 0,04^{d}	3,4 ± 0,13^{a}	3,22 ± 0,33^{b}
Global balance (g)	6,36 ± 0,09^{c}	6,70 ± 0,11^{b}	6,89 ± 0,17^{b}	7,81 ± 0,87^{a}

Values with different alphabetic letters on the same line are statistically different (p<0.05).

4 DISCUSSIONS

The present study was conducted in order to conserve of papaya by osmotic dehydration. To do this, it was necessary to determine firstly, the factors influencing the osmotic dehydration of the papaya. The results showed that variety, time, temperature, solute type, solute concentration, matrix form, and agitation significantly influenced the osmotic dehydration of the papaya. The influence of the shape of the samples has been reported [13]. Indeed, the majority of plant products are cut into cubes or spheres before osmotic dehydration. This facilitates the transfer of matter through direct contact between the cells and the solution. Concerning the influence of concentration, Raoult-Wack [14] has stated that the difference in solute concentration between the product to be dehydrated and the solution is the driving force of mass transfer in osmotic dehydration. He added that the loss of water is greater when the gap is initially high. In addition, any increase in sugar concentration resulted mainly in an increase in water transfer rates [15]. Regarding the type of solute, the study conducted showed its influence on osmotic dehydration. A similar result was obtained by [16]. According to these authors, the composition of solutions (type, solute molecular mass) used in osmotic dehydration was a key factor in the process. The influence of temperature on this process is due to the fact that water transfers are favored by high temperatures [17]. Also, the results showed an influence of treatment time of osmotic dehydration. Indeed, many authors have reported that water loss, mass reduction, and solids gain increase with treatment time [9], [13]. In this study the water loss was higher after 4 h of treatment. Many other factors have influenced the osmotic dehydration process, including the variety of products and operating conditions as agitation [14].

As a prelude to papaya conservation, the kinetics of osmotic dehydration were determined as a function of temperature and solute concentration. For this purpose, the various transfers that took place in the papaya were determined. The results revealed that water loss differed from one temperature to another as well as from one concentration to another. In addition, during osmotic dehydration, the product loses water and at the same time imbibes sugars. The shelf life of such products is therefore improved. During this dehydration, mass transfers were highlighted. There are water loss and sugar gain in the papaya samples. Thus, higher was the temperature, greater the water loss. Authors have already reported the effect of high temperatures on osmotic dehydration [18]. This evolution would certainly be due to a difference in the osmotic gradient between the fresh fruit (hypotonic) and the osmotic solution (hypertonic). Indeed, the increase in temperature causes a large flow of water from the fruit to the reaction medium, which naturally results in a loss of water in the immersed product [12], [18], [19].

In addition, water losses were greater when the solute concentration was higher. Similar results have been observed [20]. These authors reported in their study on the influence of osmotic agents on the dehydration of papaya that the increase in solute concentration contributed significantly to the water loss of the papaya. In the present study, water loss was greatest at high temperature and high solute concentration. These factors, namely the concentration of the solution and the temperature, have been widely discussed in previous studies [5], [21]. The temperature and solute concentration were considered as those that contributed effectively to the osmotic dehydration of food. In addition, some authors showed the positive dependence of water loss on temperature and sucrose concentration during osmotic dehydration of banana [23]. These results are in agreement with the principles of osmosis, which states that the diffusivity of water strongly depends on the temperature, the pressure and the composition of the reaction medium [23]. A rapid evolution of water loss during the first hours of immersion has been recorded in the present study. These results are in agreement with those reported by [19].

The water loss and the imbibed sugar during the osmotic dehydration of papaya are benefits for the conservation of derivative products.

5 CONCLUSION

The present study was conducted for the purpose of improving the conservation of papaya (*Carica papaya*) by osmotic dehydration. This study showed that factors such as variety, time of treatment, temperature, concentration and type of solute, agitation, and matrix shape significantly influenced the osmotic dehydration of the papaya. In addition, the maximum water loss (0.30 ± 0.03 g/g) of the papaya was obtained after 4 hours of treatment at a temperature of 60 °C and in a solution of concentrated sucrose at 60 °Brix. Besides, the water loss was higher when the temperature and concentration were high. Moreover, the study of mass transfers has clearly indicated that during osmotic dehydration, the papaya loses water and at the same time imbibes sugars. This is therefore an asset for the conservation of such product for a relatively long period. Thus, the use of osmotic dehydration allows better control of the quality of finished products. The osmotic dehydration process contribute to a diversification of the characteristics of the products obtained and to the development of new products.

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