Osmotic concentration of pineapple (Cayenne lisse) as a pre-treatment for convection drying

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Abstract. Osmotic dehydration as a pretreatment for convection drying is used with the purpose to get high quality dried foods. The effect of osmotic treatment at sucrose concentration of 40 °Brix and convection drying at 60 and 70 °C (air velocity of 0.8 m/s) were investigated. The quality of dehydrated pineapple was investigated by physicochemical properties, weight loss, textural characteristics, and sensorial parameters. Samples dried at 70 °C showed the fastest drying kinetics reached the required humidity at 2.5 hours. The sensory analysis allows establishing that the dehydrated pineapple at conditions of soluble solids of 40 °Brix, air temperature of the dryer at 70 °C be the best in acceptability in comparison with samples dried at 60°C. The samples were microbiologically safe for the consumer because they do not present a count of Escherichia coli and molds and yeasts.

Keywords: osmotic dehydration, drying kinetics, microbiological quality, bioactive compounds.

1. Introduction

Pineapple is considered one of the most important commercial fruit crops in the world, and a significant amount of its production is processing [1]. It is consumed as canned slices, chunks, dice, or fruit salads also in the preparation of juices, concentrates, and jams [2, 3]. This fruit is appreciated for its juiciness, taste, exceptional flavour and sugar-acid balance (12.48 °Brix – 0.93 g citric acid/100 gfw), vitamin C, vitamins of complex B, and diverse nutritional and health benefits [4-6]. Likewise, it is also rich in minerals as calcium, manganese, potassium, magnesium, iron as well as fibers [7, 8]. However of its importance and benefits tons of pineapple are lost because of the inefficient or none postharvest treatments, as well as to limited knowledge of processing technologies that allows controlling degradations produced by microorganisms or be affected by chilling injury, and others [9-11]. In this sense, there are some industrial processes which have been developed for their preservation [12]. Drying is the most common and traditional method in order to reduce water activity and weight, remove and inhibits microorganisms' growth and enzyme activity [13]. Literature reports different drying processes such as air drying by evaporation [14], freeze drying and others[15]. However, these treatments have been reported that there have different disadvantages in food such as hardening, shrinkage, poor rehydration ability, alteration of the sensory properties and cost that is necessary to remove water [14, 16].
On the other hand, some pre-treatments have also been described by its low cost and complexity with the goal to produce an intermediate moisture product [17]. Several authors have been reported that conventional drying with hot air is expensive due to the phase change of water from liquid to vapour [10, 18, 19]. In this sense, osmotic dehydration as a pre-treatment combined with drying processes allows obtaining dry food with high sensory and good techno-functional characteristics [16, 18, 20, 21]. In the present work, osmotic dehydration was applied before convective drying in order to evaluate physicochemical, sensorial, microbiological and textural characteristics.

2. Materials and Methodology

2.1. Sample preparation and processing
Pineapples (Cayenne Lisse) were purchased after 15 days of harvest from a local market (Ambato- Ecuador). The sampling for each replica was carried out applying the Codex standard 233 (1969) (N = 4000; n = 6). Rectangles of 2.5 × 2.0 × 0.5 cm were prepared, weight, pH, soluble solids, and weight loss were determined according to the methodology proposed by García Pereira, Muñiz Becerá [8] and Ortega-Rivas, Juliano [22].

2.2. Osmotic dehydration
Blanching of the samples was obtained by immersing the rectangles in water at 98 °C for 1 minute. The osmotic treatment consisted of placing the samples in a sucrose solution, starting at 30% (w/v) and stayed inside during 6 hours; after that, same samples were transferred to 35% (w/v) solution for another 6 hours and finally same samples were immersed in a 40% solution (w/v) for 6 hours more with the purpose to obtain samples with homogenous sucrose concentration, in all solutions a 0.3 % (w/w) of ascorbic acid was added. This experiment was set at a constant temperature of 40 °C. In this way, eventual differences in the food structure that could be caused by variable temperature values or osmotic strength of the osmotic dehydration process were averted [18, 21]. During the immersion, physicochemical properties such as pH, acidity and total solids were evaluated.

2.3 Drying
Drying process was performed in a convective cross flow dryer at 60 and 70 °C during 360 minutes, in triplicates. Air velocity was fixed at 0.8 m/s and mass air flow at 1.2 kg/s. The pineapple samples were placed in a steel basket avoiding the contact between fruit pieces. At pre-established times three samples were removed (at random) from the dryer to determine moisture. Moisture content was determined gravimetrically by oven drying at 75 °C until reaching constant weight (48 h approximately). During convective drying, it is considered that only water comes out. Experimentally, the curve for convective drying is to weigh the sample at different time intervals to obtain the water content. Moisture content and diffusivity were assessed in order to evaluate the performance of drying.

| Table 1. Treatments for convective drying |
|------------------------------------------|
| Samples       | Drying temperature (°C) | Drying time (min) |
| T636          | 60                      | 360               |
| T736          | 70                      | 360               |

2.4 Physicochemical properties
The pH was determined using a potentiometer (HI 9126 HANNA, Rhode Island, U.S.A) according to AOAC 981.12. The acidity was determined by titration with 0.1N NaOH, using phenolphthalein as an indicator (AOAC 947.05). Total solids analysis was performed following the standard method NTE INEN 95. The moisture content of samples was determined according to AOAC standard method (AOAC, 2005).
2.5 Rehydration capacity
The pineapple pieces were rehydrated by immersion in distilled water at room temperature (\(\sim 18 \degree C\)) for 24 hours. The rehydration ratio (RR) was calculated by Equation 1 proposed by Gamboa-Santos, Montilla [23].

\[
RR = \frac{M_r}{M_d}
\]

Where: \(M_r\) and \(M_d\) represent weights (g) of the rehydrated and dehydrated samples respectively.

2.6 Water loss and Sugar gain
Water loss (WL) and sugar gain (SG) were calculated with the equations proposed by Le Maguer [24] and Uddin, Ainsworth [25]. WL was calculated by equation 2 and expressed as the net loss of water from the fresh pineapple sample after osmotic process based on initial sample weight, and SG was calculated by equation 3 and was defined as the net uptake of sugar by the pineapple sample based on initial sample weight.

\[
%WL = \frac{M_i - M_o}{W_i} \times 100
\]

\[
%SG = \frac{S_i - S_o}{W_i} \times 100
\]

Where: \(M_i\) = moisture content of fresh sample (g); \(M_o\) = moisture content of osmotically treated sample (g); \(S_i\) = solids content of osmotically treated sample (g); \(S_o\) = solids content of fresh sample (g); \(W_i\) = total weight of fresh sample (g).

2.7 Texture analysis
The texture analysis was carried out using a texturometer (CT3 Brookfield texture analyser, USA). TPA test (speed 2 mm/s) with TA 39 probe (2 × 20 mm cylinder stainless steel) was used. Hardness (peak load of the first compression cycle), firmness (peak load of the second compression cycle), cohesiveness (ratio of area under compression of the second cycle versus area under compression of the first cycle) and springiness (measure of how far the sample returns after being compressed to the target deformation) of the product were measured.

2.8 The content of bioactive compounds
Vitamin C, (wavelength 280 nm), total polyphenols (wavelength 760 nm) and carotenoids (wavelength 550 nm) were determined using a spectrophotometer Hach 5000.

2.9 Microbiological analysis
To analyse the microbiological quality of samples molds and yeasts analyses were performed following the AOAC official method 997.02. \(Escherichia coli\) was evaluated following the official method AOAC 991.14.

2.10 Sensory evaluation
The sensory properties of the product were evaluated using an incomplete block design with 57 semi-trained judges. Attributes as color, odor, flavor, texture, and acceptability were considered. Three tastings sessions with a hedonic scale based on 5 points were 1 is equivalent to "I do not like", and 5 is equivalent to "I like it" were used.
2.11 Statistical analysis
Statistical analysis was performed with the GraphPad Prism 5.0 program (GraphPad Software, San Diego, California, USA) with a bi-directional analysis of variance. The test of comparisons was carried out with the Tukey test with a significance level of $P \leq 0.05$.

3. Results and discussion

3.1 Osmotic dehydration
One of the experimental factors in the research was the final concentration of soluble solids (40 °Brix) in pineapple through the osmotic dehydration process (DO). The initial values of samples were pH 3.89, 13.9 °Brix and moisture 84.9%. Samples immersed in a 30 °Brix solution showed maximum rates of water reduction and solid uptake at the beginning of the process; during the immersion in 35 and 40 °Brix solution rates of water reduction and solid uptake showed a gradually reduction as the osmosis proceeds to approach practically stable values (data for solid gain SG not presented). In Figure 1 a, are shown dates from osmotic dehydrated pineapple, dates demonstrated the exchange of solutes that occurs between the sucrose solution and the samples over approximately 18 hours. Figure 1b shown dates of moisture of osmotic dehydrated pineapples, moisture reduction significantly increased with the increase of Osmotic Dehydration. A dehydrated product is considered osmotically dehydrated when it has lost between 60 and 65% of its weight. The dates of pH showed changes to the increase of the osmotic concentration, the initial pH was 3.89, after the OD process the pH was 3.81 for the final level of 40 °Brix. The soluble solids increased significantly to the fresh fruit from 13.5 to 40 °Brix.

![Figure 1](image1.png)

**Figure 1.** a) Changes in solid soluble solids during osmotic treatment and b) Moisture of osmotic dehydration of Pineapple.

3.2 Drying kinetics
Figure 2 shows the variation of moisture content for pineapples dried at 60 °C and 70 °C. From an average moisture content of 84.9 %, samples were dehydrated for 6 hours, the moisture content of 13.3 % at 60 °C and 5.9 % at 70 °C were established. This behaviour suggests that samples treated at 70 °C had a higher drying rate than those of 60 °C due to the higher drying air temperature. The increase of drying temperature influences the speed of drying of the samples, this effect could favour the transfer
of mass and water loss in the samples. SG value for treatment T636 was 12.32% and for T736 was 12.52, there are no significant differences (P>0.05). WL was 2.52% and 4.98% for treatments T636 and T736 respectively. The values of sugar gain and water loss are directly related to the final concentration of soluble solids and air temperature in the dryer; these results are in concordance with Uddin, Ainsworth [25]. In general, the convective drying process depends on the changes that occur in the properties of the drying air stream [26]. The drying rate of 70 ºC was faster up, around 2.5 hours of elapsed drying time to get samples with the moisture content in safe ranges to avoid the development of molds and yeast. Subsequently, the drying rate became slow as the drying progressed until 6 hours which was the set of drying time. On the contrary, the drying rate of 60 ºC needs around six hours to get safe moisture values. Similar results were observed for the drying of pineapples as reported by Daud and Simate [21] and Ramallo and Mascheroni [6]; drying of Goji Berry as reported by Dermesonlouoglou, Chalkia [27]; drying of golden apples as reported by Menges and Ertekin [28]. During the drying process, the period of decreasing speed that is controlled by diffusion can be observed. For each treatment, the effective diffusivities were calculated using the diffusional model based on the second Fick Law. The sugar concentration and the temperature influence the coefficient during the drying process. The results showed a variation between $3.92 \times 10^{-10}$ to $7.28 \times 10^{-10}$ m$^2$/s.

![Figure 2. Variation of moisture content for pineapples dried at 60 ºC and 70 ºC](image)

3.3 Sensory evaluation
From the sensory evaluation (Figure 3), it was possible to establish that at a 95% level of confidence there are significant differences between treatments (p<0.05). The sensory profile of treatments showed that the treatment T736 obtained the highest acceptability. Likewise, color, olor, flavor, texture, and acceptability parameters had the highest values.
3.4 Rehydration capacity
For all treatments, the rehydration capacity (RC) value is in a range of 1.54 to 1.60 except for the control sample whose value was 1.38. The RC values are low in comparison with dates reported by Sette, Salvatori [29] and Daud and Simate [21] for other fruits such as raspberries, apples and cherries. These low values could be attributable to the formation of a protector at a structural level before dehydration. The rehydration time should be as short as possible to obtain rehydrated products of pleasant texture [30].

3.5 Texture
Textural parameters such as hardness, cohesiveness, elasticity index, and firmness are shown in Table 4. Treatment T736 had the highest values of hardness and firmness. The drying with hot air at 70 C caused the evaporation of water and caused the hardening of the samples. Likewise, when samples lose water, the highest values of firmness are more evident because there is no humidity to produce the sensation of elasticity and juiciness in samples.

Table 2. Textural parameters of rectangular pineapple slices

| Treatments | Hardness (N) | Cohesiveness (N) | Elasticity index (N) | Firmness (N) |
|------------|--------------|------------------|---------------------|--------------|
| T636       | 1.50 ± 0.03^a | 0.56 ± 0.02^a   | 0.50 ± 0.14^a       | 1.18 ± 0.10^a |
| T736       | 2.12 ± 0.04^b | 0.62 ± 0.11^b   | 0.59 ± 0.12^b       | 1.84 ± 0.03^b |

Results are the mean ± standard deviation. One-way ANOVA: different letters (a,b,..) in the same column indicate significant differences between samples (P ≤ 0.05).

3.6 Microbiological analysis
The microbiological analysis establishes that the pineapple complies with the provisions of the CPEINEN-CODEX CAC/RCP 5 for dehydrated fruits. All the products meet with the normative that request the absence of harmful microorganisms to public health.

3.7 Analysis of the content of bioactive compounds in the product
The conditions of osmotic dehydration and convective drying produce changes in the bioactive compounds of the fruit. Vitamin C content in fresh fruit was 88.63 mg/100 g, while 83 mg/100 g was determined in the final product. The low content of vitamin C could be attributed to the use of ascorbic
acid (0.3% w/w) that was added into the osmotic solution. Likewise, the use of concentrated solutions (≥ 40%, w/w), in the osmotic concentration process could reduce the loss of soluble components (Ex: ascorbic acid), probably due to the sugar barrier effect [31, 32]. In osmotic dehydration, the natural cell membrane acts as a semi-permeable membrane and is only partially selective to different solids. This means that besides water removal from the product, some solute solids could increase into the product. Therefore, osmotic dehydration is considered to be simultaneous water and solute counter-diffusion process as was reported by Saputra [31], likewise, in drying processes, more water is removed from samples, and the content of solids increase gradually. On the other hand, total polyphenols showed a reduction from 20.28 mg/100 g to 2.19 mg/100 g in the final product; this reduction would be attributed to the thermal drying which affects the presence and stability of bioactive compounds such as polyphenols due to their sensitivity towards heat [33]. Finally, carotenoids show a significant difference between fresh fruit (115 µg/100 g) and the final product (5.06 µg/100 g). During processing, carotenoid denaturation increases due to heat, light and high oxygen tension values. The reduction of the carotenoid content could also be explained because the polyene chains, which are in all the carotenoid, undergo destabilization, and therefore make them prone to suffer alterations by oxidation or isomerization causing changes in their primary structure [34-36].

4. Conclusion
The dehydrated pineapples showed different drying kinetics. Sugar gain values were up to 12%, and moisture loss ranged from 2.52 to 4.98 % of their dry weight. The optimum drying conditions were established at an air temperature in the dryer of 70 °C for a time of 300 min with an air velocity of 0.8 m/s. The physical and chemical changes that were observed during the treatment were the loss of mass, colour change and thermal degradation of the bioactive compounds.

References
[1] Prosapio V, Norton I 2017 Influence of osmotic dehydration pre-treatment on oven drying and freeze drying performance LWT-Food Science and Technology 80 401-8
[2] Salvi M, Rajput J 1995 Pineapple Food Science and Technology-New York-Marcel Dekker 171
[3] Mahesh U, Mishra S, Mishra H 2017 Standardization of Honey and Sugar Solution of Osmotic Dehydration of Pineapple (Ananas comosus L.) Fruit Slices Int J Curr Microbiol App Sci 6(7) 2364-70
[4] Zahoor I, Khan M 2017 Mass Transfer Kinetics of Osmotic Dehydration of Pineapple J Food Process Technol 8 653
[5] Bartolomé AP, Rupérez P, Fúster C 1995 Pineapple fruit: morphological characteristics, chemical composition and sensory analysis of Red Spanish and Smooth Cayenne cultivars Food Chemistry 53(1) 75-9
[6] Ramallo LA, Mascheroni RH 2012 Quality evaluation of pineapple fruit during drying process Food and Bioproducts Processing 90(2) 275-83
[7] da Silva WP, e Silva CMDPS, Lins MAA, Gomes JP 2014 Osmotic dehydration of pineapple (Ananas comosus) pieces in cubical shape described by diffusion models LWT - Food Science and Technology 55(1) 1-8
[8] García Pereira A, Muñiz Becerá S, Hernández Gómez A, González LM, Fernández Valdés D 2013 Análisis comparativo de la cinética de deshidratación Osmótica y por Flujo de Aire Caliente de la Piña (Ananas Comosus, variedad Cayena lisa) Revista Ciencias Técnicas Agropecuarias 22(1) 62-9
[9] Ahmed J, Lobo MG, Ozadali F. Tropical and subtropical fruits: postharvest physiology, processing and packaging: John Wiley & Sons; 2012.
[10] Horuz E, Maskan M 2015 Hot air and microwave drying of pomegranate (Punica granatum L.) arils Journal of Food Science and Technology 52(1) 285-93
[11] Campos CDM, Sato ACK, Tonon RV, Hubinger MD, Cunha RLd 2012 Effect of process variables on the osmotic dehydration of star-fruit slices  *Food Science and Technology* 32(2) 357-65
[12] Omolola AO, Jideani AIO, Kapila PF 2017 Quality properties of fruits as affected by drying operation  *Critical Reviews in Food Science and Nutrition* 57(1) 95-108
[13] Bruijn J, Rivas F, Rodriguez Y, Loyola C, Flores A, Melin P, et al. 2016 Effect of Vacuum Microwave Drying on the Quality and Storage Stability of Strawberries  *Journal of Food Processing and Preservation* 40(5) 1104-15
[14] Ratti C 2001 Hot air and freeze-drying of high-value foods: a review  *Journal of food engineering* 49(4) 311-9
[15] Karam MC, Petit J, Zimmer D, Djantou EB, Scher J 2016 Effects of drying and grinding in production of fruit and vegetable powders: A review  *Journal of Food Engineering* 188 32-49
[16] Chou S, Chua K, Mujumdar A, Tan M, Tan S 2017 Study on the osmotic pre-treatment and infrared radiation on drying kinetics and colour changes during drying of agricultural products  *ASEAN Journal on Science and Technology for Development* 18(1) 29-43
[17] Ahmed I, Qazi IM, Jamal S 2016 Developments in osmotic dehydration technique for the preservation of fruits and vegetables  *Innovative Food Science & Emerging Technologies* 34 29-43
[18] Lombard G, Oliveira J, Fito P, Andrés A 2008 Osmotic dehydration of pineapple as a pre-treatment for further drying  *Journal of food engineering* 85(2) 277-84
[19] Andrés A, Bilbao C, Fito P 2004 Drying kinetics of apple cylinders under combined hot air–microwave dehydration  *Journal of Food Engineering* 63(1) 71-8
[20] Torreggiani D 1993 Osmotic dehydration in fruit and vegetable processing  *Food Research International* 26(1) 59-68
[21] Daud LEI, Simate IN 2017 Drying Kinetics of Sliced Pineapples in a Solar Conduction Dryer  *Energy and Environment Research* 7(2) 14
[22] Ortega-Rivas E, Juliano P, Yan H. Food powders: physical properties, processing, and functionality: Springer Science & Business Media; 2006.
[23] Gamboa-Santos J, Montilla A, Soria AC, Villamiel M 2012 Effects of conventional and ultrasound blanching on enzyme inactivation and carbohydrate content of carrots  *European Food Research and Technology* 234(6) 1071-9
[24] Le Maguer M 1988 Osmotic Dehydration: Review and future RAOULT-WACK, AL, S. GUILBERT and G. RIOS. 1989. Osmotic dehydration: study of mass transfer in terms of engineering properties  *Drying* 88 487
[25] Uddin MB, Ainsworth P, İbanoğlu Ş 2004 Evaluation of mass exchange during osmotic dehydration of carrots using response surface methodology  *Journal of Food Engineering* 65(4) 473-7
[26] Monzón CIC. Influencia del método de secado en parámetros de calidad relacionados con la estructura y el color de manzana y fresa deshidratadas 2008.
[27] Dermesonlougliou E, Chalkia A, Taoukis P 2018 Application of osmotic dehydration to improve the quality of dried goji berry  *Journal of Food Engineering* 232 36-43
[28] Menges HO, Ertekin C 2006 Mathematical modeling of thin layer drying of Golden apples  *Journal of Food Engineering* 77(1) 119-25
[29] Sette P, Salvatori D, Schebor C 2016 Physical and mechanical properties of raspberries subjected to osmotic dehydration and further dehydration by air- and freeze-drying  *Food and Bioproducts Processing* 100 156-71
[30] Mendoza R 2003 Isotermas de sorción y velocidad de rehidratación en frutas de carica papaya L.: deshidratadas con diferentes métodos  *Argentina: Universidad Nacional de Misiones*
[31] Saputra D 2001 Osmotic dehydration of pineapple  *Drying Technology* 19(2) 415-25
[32] Montoya JEZ, Quintero GC 1999 Osmotic dehydration of fruits and vegetables Revista Facultad Nacional de Agronomía 52(1) 451-66

[33] Saxena A, Maity T, Raju P, Bawa A 2012 Degradation kinetics of colour and total carotenoids in jackfruit (Artocarpus heterophyllus) bulb slices during hot air drying Food and Bioprocess Technology 5(2) 672-9

[34] Takyi EE 2000 2 Bioavailability of Carotenoids from Vegetables versus Supplements Vegetables, Fruits, and Herbs in Health Promotion 19

[35] García L, Armesto D, Correa D 2015 Osmotic Dehydration: A revision

[36] Chan JR HT, Kuo MT-H, Cavaletto CG, Nakayama T, Brekke JE 1975 Papaya puree and concentrate: Changes in ascorbic acid, carotenoids and sensory quality during processing Journal of Food Science 40(4) 701-3