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Effect of Osmotic Dehydration Pretreatment on Melon (Cucumis Melo) Drying Time

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Abstract

Drying has been the most widely used method of dehydration since ancient times; however, its use generates high energy costs, due to the long duration of the process. On the other hand, the exposure of foods to high temperatures for long periods of time tends to considerably affect not only their organoleptic characteristics, but also their nutritional content. An alternative to these problems is osmotic dehydration, which allows generating a partial dehydration without deteriorating the food's properties. In this way, the food begins its drying process with a reduced moisture content, thus reducing the drying time, saving energy costs and avoiding exposing the food to heat for long periods of time. The methodology consisted of evaluating the osmotic dehydration process of melon at osmotic concentrations of 45 °Bx and 60 °Bx and immersion times of 120 and 180 minutes, to be subsequently dried at 50°C until reaching a minimum humidity of 15%. The osmotic dehydration tests demonstrated the significance ($p < 0.05$) of the factors studied in water loss, weight loss and solids gain. Water losses between 48.393% and 68.204% were achieved, where drying time was reduced in a range between 23% and 46%. The treatment that generated the shortest drying time was the one that had as pretreatment conditions of 60°Bx and 180 minutes of immersion.

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Keywords

Drying Time;
Food Drying;
Melon;
Osmotic Dehydration;
Osmodehydration.

Abbreviations

OD	Osmotic dehydration, osmodeshydration
WR	Weight reduction
SG	Solid Gain
WL	Water loss
ANOVA	Analysis of variance
CRD	Completely randomized design

Introduction

The current consumer trend has focused on the consumption of minimally processed foods that maintain their nutritional value, are easy to consume and, most importantly, are safe.[1] These foods are usually exposed to peeling, cutting or chopping processes, which exposes the food tissues to the

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environment, generating nutrient losses and making them more perishable.[2] Hence, for this type of food, it is necessary to use preservation methods to extend its shelf life.

One of the most widely used preservation methods since ancient times is dehydration, which consists of removing free water from food to prevent microorganisms from taking advantage of it and deteriorating it. The most common types of dehydration are those that use heat, such as solar drying and hot air drying. These types of dehydration, although are highly efficient in extending the shelf life of foods considerably, generate high energy consumption and also generate the loss of nutrients and sensory properties due to the use of high temperatures.[3,4]

Considering the loss of nutrients and organoleptic properties from the use of drying as a preservation method, it is necessary to minimize the loss of nutrients by using a pretreatment that allows partial dehydration of the fruit and avoids long periods of exposure to heat. One of the methods that can be employed is the use of osmotic dehydration, since it has been demonstrated that this type of dehydration can reduce the moisture content of fruits and vegetables by up to 50%, concluding when the equilibrium state is reached.[5]

Osmotic dehydration is a dehydration process that makes use of the osmotic pressure generated by highly concentrated solutions, in order to generate a mass exchange, thus generating a loss of water and a minimum gain of solids.[6] During osmotic dehydration a number of factors are involved that affect the process and whose optimized use can result in higher mass transfer rates. The main process factors of major significance to the process are: the type of osmotic agent, the concentration of the osmotic solution, the process temperature, the immersion time and the agitation.

Regarding the type of osmotic agent, the most commonly used due to its accessibility is sucrose ;[7] however, the use of other types of sugar has been studied by Prosapio[8] who used various osmotic agents such as sugar, maltodextrin, maltose and fructose. The use of sugar alcohols such as erythritol and sorbitol, which even allow the retention of carotenoids, has also been used successfully.[9] The concentration and temperature of the osmotic solution have been shown to be the most important factors in the process according to various bibliographic reviews on the subject,[6,10–12] indicating that the increase in the values of these factors generates the greatest mass transfers; however, it is not advisable to use temperatures higher than 50 ºC to avoid nutrient loss. Another important factor is the immersion time, where when it is increased, better mass transfer results are obtained; however, during the first two hours of the process, the greatest losses of weight and water are generated in the process; subsequently, the mass transfer ratio decreases.[13,14]

On the other hand, this technique has allowed preserving the nutritional properties of fruits and vegetables, as well as their organoleptic properties,[15] being an ideal option to use prior to drying. Authors such as Bejarano-Martinez 16 were able to reduce the moisture content of mango pieces by up to 40% by using osmotic solutions of 65 °Brix for 60 minutes prior to drying treatment. Kaur[17] were able to reduce the water content of kiwifruit to values between 36.30 % and 55.82% in one hour of processing using syrups of 30 to 60 °Brix and temperatures between 30 and 50°C.

Sarkar[18,19] who osmotically dehydrated coconut and apricot in syrups between 40-60°Brix, before the drying process, were able to obtain nuts with high nutrient retention and better organoleptic characteristics than treatments without pretreatment, also observing that the drying time was considerably reduced, since osmotic dehydration helps to eliminate a considerable percentage of water before drying. On the other hand, Dermesonlouoglou,[20] succeeded in reducing the drying time of goji berries by 120 minutes and maintaining the bright red color of the fruit by subjecting the fruit to an osmodeshydrate pretreatment with glycerol and maltodextrin at 60°Brix. In view of the previously mentioned, the present research aims to use osmodeshydration as a pretreatment for hot air drying of melon slices, and its effect on the drying time.

Materials and Methods

The methodology of the project consisted of two parts, the first where the melon was osmodehydrated and the second stage comprising the hot air drying of the previously treated fruit. The methodology for the process was based on the research of Fabiano[21] and

Flores-Mendoza,[22] obtaining the following process flow diagram.

Preparations of samples

The melons were obtained from a supermarket in the city of Sullana (Peru). Melons were selected in good condition, with no signs of over-ripening or deterioration. The fruit was washed with abundant water in order to remove any remaining dirt from the fruit, then the fruit was submerged for 15 minutes in water with sodium hypochlorite at a concentration of 50 ppm. The peel and seeds were then removed and the fruit was cut into 5 mm slices using an industrial slicer. Fruit moisture was determined using an AND MX-50 (0.01%) moisture balance. Soluble solids (ºBrix) were measured by refractometry.

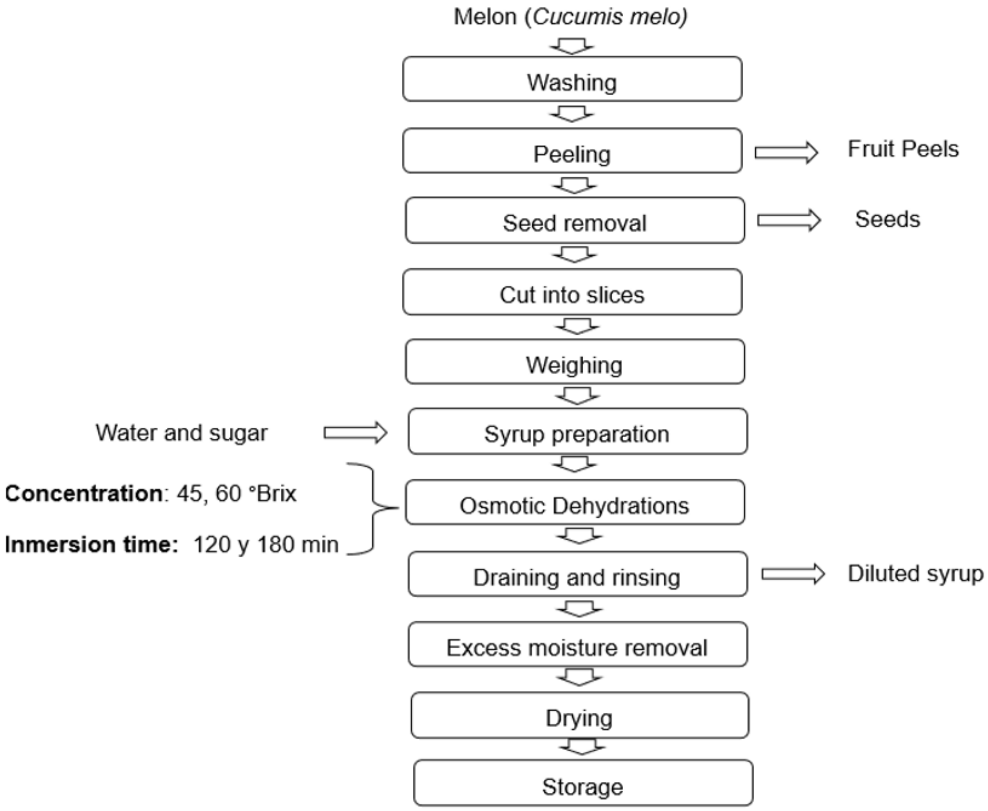

Fig. 1: Flow chart of the Osmotic Dehydration Process

Osmotic Dehydration

The osmotic dehydration process was carried out using osmotic dehydration equipment built at the Universidad Nacional de Frontera.[22] This equipment has a cylindrical stainless-steel tank, where the fruit and syrup are placed, and it also has a temperature and recirculation control system to maintain uniform concentration during the process. Process variables such as concentration and temperature can also be monitored remotely, using an intelligent flotation sensor, through the use of Bluetooth.

Syrups were prepared from the dilution of sugar in water, the concentrations used were 45 and 60 °Brix. The volume of syrup to be prepared was calculated based on the fruit: solution ratio, which was 1:4. This ratio was chosen to maintain high syrup concentrations during the process.[6,10] The process was carried out under a constant temperature of 45 °C and with duration times of 120 and 180 minutes, and each treatment was carried out in triplicate.

Once the process was finished, the syrup was drained and the osmodehydrated fruit was rinsed in order to remove the syrup from the surface of the fruit and avoid its caramelization during the drying process.

The weight of the fruit to be processed was measured, as well as the moisture content and ºBrix degrees of the fruit before and after processing, in order to calculate the weight reduction (WR), water loss (WL) and solids gain (SG). Calculations were performed according to the formulas contained in García.[23]

$$WR = \frac{(M_0 - M_f)}{M_0} x100 \quad ...(1)$$

$$WL = \frac{(M_0\, x\, H_0) - (M_f\, x\, H_f)}{M_0} x100 \quad ...(2)$$

$$SG = \frac{(M_f\, x\, S_f) - (M_0\, x\, S_0)}{M_0} x100 \quad ...(3)$$

Where M_0 is the initial weight of the melon before osmodeshydration and M_f is the weight at the end of the process. Also S_0 and S_f are the degrees ºBrix of the fruit before and after the process, other data such as H_0 which is the initial humidity and H_f the final humidity were also important data for the calculation.

Drying

After draining, rinsing and removal of excess water, the osmodehydrated fruit was placed in a hot air dryer. The drying temperature was 50 °C, prolonged until reaching a humidity of 15%, since according to Badui[24] humidity values higher than 15% generate the proliferation of fungi, so this would be the maximum limit of humidity in dried products, in order to allow a more suitable conservation of the product over time.

Statistical Analysis

For data analysis, a completely randomized design (CRD) with a 2x2 factorial arrangement will be used (Table 1), where there are two study factors with two levels each. The first factor is the concentration of the osmotic solution (45 and 60 ºBrix) and the second corresponds to the immersion time during osmotic dehydration (120 and 180 min), the response variable will be weight loss (WR), water loss (WL), solid gain (SG) and drying time to reach a humidity of less than 15%. Each treatment will be carried out in triplicate.

The experimental data were evaluated with the Shapiro-wilk normality test where a p>0.05 was obtained, indicating that the data come from a normal distribution and consequently the ANOVA analysis could be used. The ANOVA test was performed with a confidence level of 95%, and evaluating the significance level at 0.05, using IBM SPSS Statistics 26 software. Where p-values less than 0.05 indicate the existence of significance of the process factors in the results obtained for the response variables weight loss (WR), water loss (WL), solid gain (SG) and drying time.

Table 1. Completely randomized design (CRD) with a 2x2 factorial

Treatment	Concentration (°Brix)	Inmersion time (min)
T1	45	120
T2	45	180
T3	60	120
T4	60	180

Results and Discussion

Analysis of the Normality of the Data

The test allows to know whether the data found in the research are parametric or non-parametric; and according to its results, the decision to choose the test statistician is made. Table 2 contains the p-values of the Shapiro-Wilk test, which are greater than 0.05, indicating that the data obtained comply with the assumptions of normality, so it is possible to use a parametric statistical test such as analysis of variance (ANOVA).

Pretreatment of Osmotic Dehydration of Melon Weight Reduction and Water Loss

The analysis of variance (ANOVA) determined with p-values less than 0.05 that the factors concentration, immersion time and the interaction between them are significant for weight reduction and water loss in melon osmodehydration.

Table 2. Weight reduction (WR) during osmotic dehydration of melon

Response variable	Treatment	Shapiro-Wilk		
		Statician	**Df***	**Sig.***
WR	T1	0.89	3	0.36
	T2	0.87	3	0.29
	T3	0.98	3	0.72
	T4	0.98	3	0.78
WL	T1	0.99	3	0.86
	T2	1	3	0.97
	T3	0.99	3	0.91
	T4	0.88	3	0.34
SG	T1	0.96	3	0.61
	T2	0.78	3	0.08
	T3	0.96	3	0.62
	T4	0.79	3	0.11
Drying Time	T1	0.98	3	0.78
	T2	0.99	3	0.92
	T3	0.98	3	0.78
	T4	0.99	3	0.9

*Df: degrees of freedom, Sig. Significance

Authors such as Khan 25 reached similar conclusions to those of our research when osmodehydrating Cantaloupe variety melon, the authors reported that submergence time and concentration of sucrose syrups significantly (p>0.0001) affected the final moisture content of the treated fruit.

Table 3. Weight reduction (WR) during osmotic dehydration of melon

Factor A: Concentration	Factor B: Immersion time	
	120 min	**180 min**
45 °Brix	44.05 ± 0.27	50.44 ± 0.16
60 °Brix	51.71 ± 0.20	64.98 ± 0.13

Table 3 shows the percentage of weight reduction (WR) of the four osmodeshydration treatments. The highest losses were obtained when using the 60°Bx concentration with 51.71% for 120 minutes immersion time and 64.98% in 180 minutes. The lowest losses were reported at 45°Bx with values of 44.05% for 120 minutes submergence and 50.44 for 180 minutes. Authors such as Aminzadeh[26] achieved a WR up to 48.73% in osmodehydrated melon in sucrose syrup at 60ºBrix for one hour, where the optimal treatment was the use of sucrose syrups at 50% concentration and 10% concentration of NaCl salt, with a fruit/solution ratio of 1:4 for 1 h at 45°C. In other fruits similar to melon, such as papaya,[27] weight losses up to 22.11% were obtained in an immersion time of 120 minutes in sucrose solutions at 40ºBrix and 40ºC temperature. Bozkir 28 found that pretreatment with ultrasound at 35 kHz for 30 minutes prior to OD increased weight loss in persimmon, obtaining up to approximately 38% WR in 300 hours of OD in sucrose syrups at 70 ºBrix. The use of electrical pulses has also proven to be efficient in improving mass transfer during dehydration, achieving a WR of up to 33.3% in only 60 min of process using 50 electrical pulses of 5 kV/cm as pretreatment to the osmotic dehydration of apple in 60ºBrix sucrose syrups at temperatures of 40ºC under continuous agitation.[29]

Regarding water loss (WL), Table 4 shows the percentages of water loss, where the highest losses were generated by increasing the concentration of the osmotic solution, obtaining water losses at 60°Bx of 62.78% for 120 minutes of immersion and 68.20% for 180 minutes. The lowest losses were reported at 45°Bx with values of 48.39% for 120 minutes and 58.49% for 180 minutes of immersion. Authors such as Beeu[30] achieved a WR up to 79.6% using sucrose syrups at 60ºBrix, 60ºC temperature and 300 mbar vacuum pulses and a WR of 72.1% using 50ºBrix, 30ºC temperature for 360 minutes of processing. Aminzadeh[26] in one hour of melon immersion in a sucrose solution at 60ºBrix in a 1:4 ratio obtained a WL of 55.32%. Other research has proposed the use of methods such as ultrasound to improve the efficiency of water loss in apples, using concentrated fruit syrups such as aronia at 40ºBrix, achieving a WL of up to 42% in 120 minutes of processing.[31] Kaur[17] were able to reduce the water content of kiwifruit to values between 36.30 % and 55.82% in one hour of processing using syrups of 30 to 60 °Brix and temperatures between 30 and 50°C.

Table 4. Water loss (WL) during osmotic dehydration of melon

Factor A: Concentration	Factor B: Immersion time	
	120 min	180 min
45 °Brix	48.39 ± 0.79	58.49 ± 0.48
60 °Brix	62.78 ± 1.22	68.20 ± 0.79

Figure 2 shows the interaction of the factors concentration and immersion time on the percentage of weight reduction (WR) and water loss (WL). It can be clearly observed the tendency to increase weight and water loss with increasing immersion time, it is also evident that the use of high osmotic concentrations results in higher weight losses. Other melon osmodeshydration research[32–34] also report the trend of increasing water loss with increasing osmotic concentration and processing time. These behaviors have also been studied in other fruits and compiled in reviews[6,35] where the authors emphasize the effect of concentration on water loss and weight loss in fruits, where high concentrations generate higher osmotic pressure in the food tissue, so mass transfer is accelerated, the same happens with the immersion time, where water loss stops until reaching the equilibrium state so increasing the immersion time will generate higher losses, it is important to highlight that the authors point out that during the first two hours of immersion the highest mass transfer is generated.

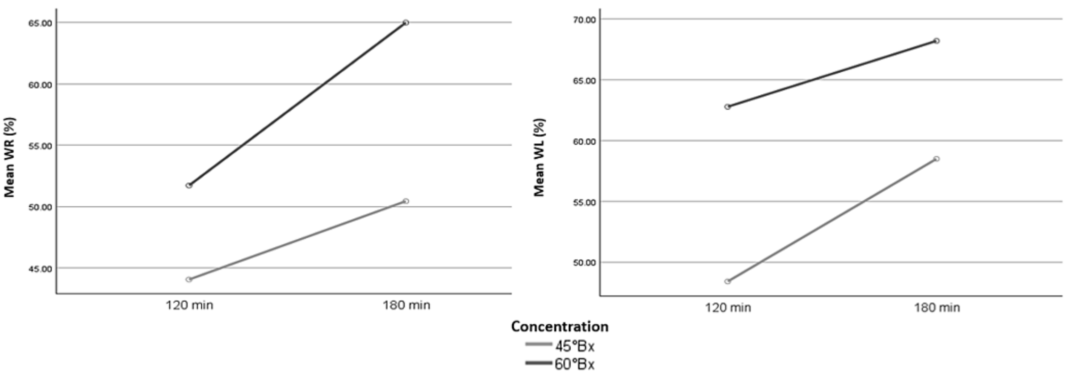

Fig. 2: Concentration-temperature interaction on WR and WL during melon osmodehydration

The weight and water loss results obtained from osmodehydration have a significant impact on the food drying industry, since it allows the removal of between 48% and 68% of water from the food in the first 3 hours of the process, thus reducing conventional drying times, avoiding the exposure of food to high temperatures for long periods of time, and reducing nutrient losses due to high drying temperatures.[25,34] Other authors such as Putri[36] and Ma[37] have used OD as a pretreatment for processes such as freeze-drying, with the aim of reducing energy costs and process times by starting the freeze-drying process with reduced moisture, in addition to preserving the nutritional and organoleptic components of the food.

Regarding solids gain, the analysis of variance (ANOVA) determined with p-values less than 0.05 that the time variable and the interaction of factors are significant in the results; however, for the concentration variable, the p-value was greater than 0.05, concluding that it is not significant for solids gain during melon osmodehydration. Ortega-Villalba,[38] in their investigation of osmodeshydration in melon, also observed that osmotic solution concentration was not significant (p>0.05) for solids gain.

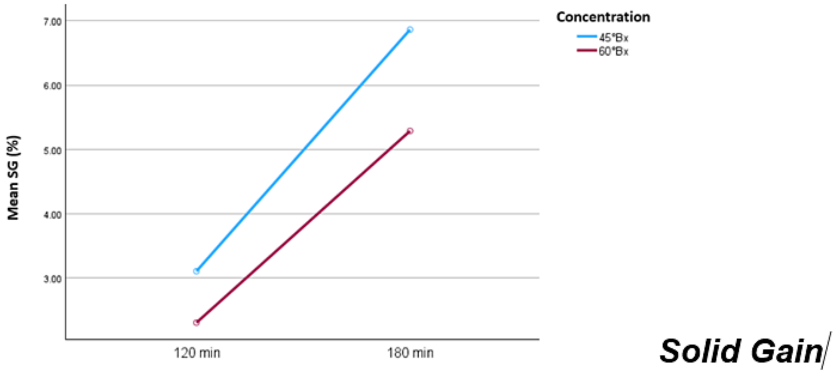

Fig. 2: Concentration-temperature interaction on WR and WL during melon osmodehydration

Table 5 shows the results of solids gain during osmotic dehydration of melon, where for the 45°Bx concentration the solids gain increases with increasing immersion time, being for 120 minutes a gain of 3.11% and for 180 minutes a gain of 5.29%. The 60°Bx concentration showed the opposite behavior, where the lowest gain of 2.31% was obtained with increasing immersion time (180 min) and a gain of 6.86% was obtained at 120 minutes.

Table 5. Solid gain (SG) during osmotic dehydration of melon

Factor A: Concentration	Factor B: Immersion time	
	120 min	180 min
45 °Brix	3.11 ± 0.250	6.86 ± 0.84
60 °Brix	2.31 ± 0.396	5.29 ± 0.65

Figure 3 shows the interaction of the factors: concentration and immersion time on the percentage of solids gain of osmotically dehydrated melon. Similar to the results for weight and water loss, for the same concentration, the tendency of water loss increases with increasing immersion time, and the use of high osmotic concentrations results in higher water losses. Acevedo Correa[32] found that increasing concentration did not significantly influence melon osmodeshydration during the first hour and a half of immersion for the 40°Bx and 50°Bx concentrations with gains between 0.09 and

0. 1 g solids/g initial mass, however, the difference became more noticeable after the second hour of immersion with values of approximately 0.12 and 0.19 g solids/g initial mass for the 40°Bx and 50°Bx concentrations, respectively. It should also be noted that these higher gains were also influenced by the use of high temperatures (40°C and 50°C). Authors such as Beeu[30] were able to obtain maximum solids gain of 1.7% in 360 minutes of melon immersion in 60ºBrix syrup at 45 ºC, while applying vacuum pulses during the process they achieved a gain of up to 7.9%. Other authors[27] who also worked with melon obtained an SG of 6.59% in 1 hour of processing using sucrose syrup at 60ºBrix. In papaya, an SG of 5.24% was achieved in 120 minutes of immersion in 60ºBrix syrup at 50ºC.

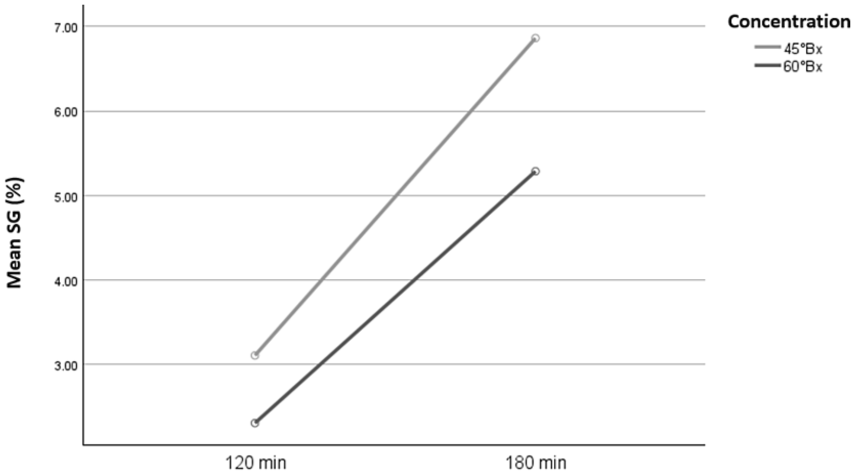

Fig. 3: Concentration-temperature interaction on SG during melon osmodehydration

Table 6. Osmodehydrated melon drying time

Factor A: Concentration	Factor B: Immersion time	
	120 min	180 min
45 °Brix	1200 ± 2.52	1020 ± 7.51
60 °Brix	1018 ± 5.03	840 ± 11.02

Osmodehydrated Melon Drying

The ANOVA results for osmodehydrated melon drying determined that with p-values less than 0.05 the factors concentration, immersion time were significant for drying time, while the interaction was not significant ($p>0.05$). Khan[25] also studied the effect of osmodeshydration on the drying of Cantaloupe melon variety, the fruit was immersed in 25, 35 and 45 °Bx syrups for times of 1, 2 and 3h, the pretreated samples were oven dried at 60°C. The authors reached similar conclusions to the present work, since they also found that sucrose concentration and immersion time significantly affected ($p>0.0001$) the moisture content of the samples, reducing considerably the drying time; however, the combination of the effects was not significant ($p>0.4197$), in their results they were able to reduce the drying time of melon by up to 10 hours. Table 6 shows the results of melon drying time with osmodeshydration pretreatment. It is concluded that for the osmodeshydration pretreatments carried out at the same concentration, extending the immersion time generated greater water losses, thus, the drying time tends to be reduced. The treatment carried out at 45°Bx and 120 minutes resulted in the longest drying time among the treatments with a duration of 1200 minutes, while at 60°Bx and 180 minutes OD generated the shortest drying time with 840 minutes.

On the other hand, treatments A 45°Bx-180 min and 60°Bx-120 min did not show significant differences between their drying times.

Figure 4 shows the melon drying curve for the control treatment and the osmodehydrated pretreatments. It is observed that the control test without OD pretreatment generated the longest drying time with 1,560 minutes of drying, due to the fact that the drying of these samples was carried out with their initial moisture content of 91.2%, while the samples treated with OD were dried with lower moisture percentages, which generated a reduction in drying time for these samples. The reduction in drying time using osmotic dehydration as pretreatment was reduced in a range between 23% and 46%. The treatment that generated the shortest drying time was the one carried out at 60°Bx and 180 minutes of immersion. On the other hand, the authors Teles 34 studied the effect of osmotic dehydration of melon at three concentrations (45°, 55° and 65° Brix), at temperatures of 65°C and under vacuum conditions (600 mmHg) for a period of 5h of immersion, the hot air drying tests were carried out at temperatures of 65°C, terminating the process until reaching a humidity of 30%. The melon control test without pretreatment had a drying time of 1,750 min, while the samples pretreated with osmodeshydration obtained drying times of 630, 540 and 450 min for concentrations of 45°, 55° and 65° Brix, respectively. Osmodeshydration was able to reduce drying time by up to 18 h compared to fruit dried with hot air alone.

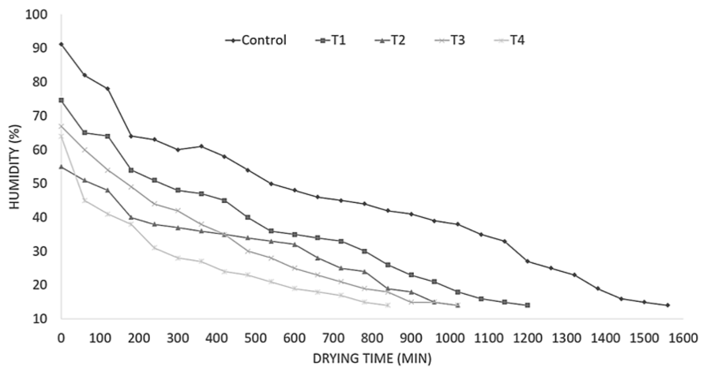

Fig. 4: Drying curve of melon slices

Conclusion

Melon (Cucumis melo) slices were osmotically dehydrated evaluating the effect of two concentrations of syrups (45°Bx and 60°Bx) and two immersion times (120 min and 180 min), weight and water losses were obtained up to 64.983% and 68.204% respectively, being the factors and their interaction significant ($p<0.05$) for the process. In addition, maximum solids gains of 6.862% (45 °Bx - 120 min) and a minimum of 2.305% (60 °Bx - 120 min) were obtained. It was possible to determine the effect of osmotic dehydration pretreatment on the drying of melon slices, drying times of 1200, 1020,1018 and 840 minutes were obtained for treatments T1, T2, T3 and T4, respectively. The drying time was reduced in a range between 23% and 46%. The treatment that generated the shortest drying time was the one carried out at 60°Bx and 180 minutes of immersion. Therefore, it is concluded that osmotic dehydration promises to be a very interesting pretreatment for dehydrated fruit industries, since the fruits would have a considerably reduced moisture content when entering the drying process, allowing a shorter drying time and less exposure to heat, avoiding variations in the nutritional content and sensory characteristics of the final product. However, it is proposed to generate a future research regarding the costs involved in both processes, because although the drying time reduces energy costs, during the osmodehydration, syrup elaboration costs are incurred. On the other hand, the syrups obtained after osmotic dehydration can be reconstituted and used for a second process; however, research is also needed on the maximum number of times the syrup can be reused and if this has an impact on the efficiency of the osmodehydration process.

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The manuscript includes all data produced during the course of this research, for further information please contact the corresponding author.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement
This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration
This research does not involve any clinical trials.

Author Contributions
- **Carlessi Steinar Valdiviezo-Seminario:** Conceptualization, research, review, methodology
- **Manuel Jesús Sánchez-Chero:** Research, writing
- **Lesly Carolina Flores-Mendoza:** Research, data analysis, writing and translation.

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