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Optimization of the Drying of *Artocarpus Altilis* "Tree Bread" using Combined Methods of Osmodeshydration and Hot Air

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To extend the shelf life and make efficient use of the fruit requires industrial processing, transforming the fresh fruit into a dehydrated product. Therefore, the objective of this research was to determine the optimal technological process for the dehydration of tree bread (*Artocarpus altilis*) by combined methods, osmodeshidratado (OD) and hot air drying (HAD) showing its effect on the kinetics of OD, sensory and physicochemical characteristics. The Taguchi design was used with 8 treatments that were formulated through the following factors: OD concentration (40-60°Brix), OD temperature (20-40°C), OD time (1-8hr), HAD temperature (45-65°C) and HAD time (1-2hr), at 5% significance. The products with the lowest %H, which were obtained from the treatments with the best results in the first stage, were sensorially evaluated using a hedonic scale (1-7) and Friedman's nonparametric test. The results indicated that at a concentration of 60 ºBrix, time 8 hr and temperature 65 ºC in OD and at a time of 2 hr in HAD, obtaining a product with 16.2% moisture, with better sensory and physicochemical results with 76.5% carbohydrates, 8% protein, 1.7 % fat, 1.0 % ash, 0.9 % crude fiber and total energy of 353.3 Kcal. Therefore, the study demonstrated that the combined OD and HAD methods reduce heat stress, stabilize sensory parameters and maintain the nutritional value of arbor bread.

1. Introduction

The fruit of Artocarpus altilis known as "tree bread" due to its bread-like appearance, is considered a very consumed food in the world, for being a natural source of carbohydrates that such content is compared to rice, potato or corn, it is also rich in protein, fiber, vitamins (A, B and C) and minerals (calcium, magnesium, phosphorus, iron and potassium), low in fat and cholesterol, so its nutritional contribution is beneficial and necessary for human nutrition (Fitrya et al., 2024). However, in the world there are several food products that are not being industrially processed, tree bread being one of them (de Araújo et al., 2022). In Peru this exotic fruit is only used in the gastronomy of certain regions, mostly in the tropical regions, which is destined to self-consumption and as cattle feed, due to the lack of diffusion, so it is not fully exploited this great source of energy, which consequently affects the economy of producers in those regions. Also, another problem arises, according to Guo et al. (2021) there is a high dependence on foods with high energy source for the daily diet of children and the elderly such as rice, potato or corn, which are crops that have high production costs and use agrochemical inputs that negatively affect the environment, being a necessary alternative the use of new resources that contain nutritional, nutritional and functional properties for health and with pleasant taste as the consumption of tree bread whose cultivation in tropical areas is done organically (Mehta et al., 2023).
However, to efficiently take advantage of this fruit requires industrial processing, transforming the fresh fruit into a dehydrated product, since the conventional dehydration process can result in the loss of nutrients and undesirable changes in the texture as well as in the flavor of the final product (de Souza et al., 2022). Drying is an outstanding alternative that prevents microbial contamination, improves storage stability, minimizes packaging requirements and presents better availability and mobilization of the product to different locations (Li et al., 2023). In this regard, hot air drying is the most common method and its independent use can generate a

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risk because high temperatures and prolonged drying periods are factors that affect the degradation of the nutritional composition, organoleptic properties, texture and color of the final product (Araújo y da Silva, 2023). In view of this fact, other methods are used for pre-drying that reduce the time and prevent the adverse effect of hot air drying (Nudar et al., 2023). Several studies have shown that there are methods that, when combined with hot air, maintain the nutritional quality and shelf life extension of the fruit, among these pretreatment methods, the most applicable is osmotic dehydration or osmotic dehydration (OD) (Khuwijitjaru et al., 2022). The OD consists of submerging the fruit in hypertonic solutions, for which different agents can be used such as sucrose, corn syrup, glucose, sorbitol or other agents, which causes the product to lose water and gain soluble solids, this occurs through two types of flow, the first through the diffusion of water from the fruit to the osmotic solution and the second flow is the diffusion of solutes from the osmotic solution to the interior of the fruit, which leads to a partial elimination of water, maintains the nutritional value, reduces heat stress, stabilizes sensory parameters and prolongs the shelf life of food products (Li et al., 2023).
Likewise, the intensity of the OD in the fruit depends on different factors such as the concentration of the osmotic solution, temperature, time and the structure of the fruit (Pavkov et al., 2021). Each of these factors presents different levels and their capacity differs in the response of the sensory and physicochemical characteristics of the dehydrated product (Sharifi et al., 2020). For these reasons, the objective of this research was to determine the optimal technological process for the dehydration of tree bread by combined methods, OD and HAD showing its effect on the kinetics of OD, sensory and physicochemical characteristics.

2. Materials and Methods

This research was conducted during the months of August 2022 and May 2023, in Huacho, Lima, Peru.

2.1 Preparation of raw materials

The treatments developed in the present investigation were established based on the combined methods of OD and HAD for the determination of the final moisture content: the concentration of the osmotic solution (OD Concentration) with minimum and maximum levels of 40 and 60 ºBrix, the second factor was temperature (OD Temperature) with minimum and maximum levels of 20 and 40 ºC and the third factor was time (OD Time) with minimum and maximum levels of 1 and 8 hours respectively in od. Likewise, in HAD, two factors were taken into consideration, one is temperature (HAD Temperature) with minimum and maximum levels of 45 and 65 ºC, the second variable was time (HAD Time) with minimum and maximum levels of 1 and 2 hours respectively, According to the methodology proposed by Li et al. (2023) and Khuwijitjaru et al. (2022), as detailed in Table 1.

2.2 Statistical application

This experiment was performed using the model proposed by Taguchi, which is expressed as follows:
$Y = \alpha 0 + \alpha 1x1 + \alpha 2x2 + \alpha 3x3 + \ldots + \alpha ixi$
Where:
Y : Final moisture of the dehydrated product (% Moisture).
αi : Regression coefficients of the main effect of factor i.
xi : Independent variables or controllable factors of the process.
The methodology consisted of an orthogonal array to find the signal-to-noise ratio (S/N). The SN index is measured in decibels (db). According to the quality characteristic under study: dependent variable (% Final Moisture), the S/N ratio "lower is better" which is obtained from equation (1).
$S/N = -10*\log(\Sigma(Y^2)/n)$
(1)
Where:
Y = Final moisture of the dehydrated product (% Moisture).
n = number of responses.

2.3 Procedures

The experimental process was carried out in two stages: Stage 1 consists of the optimization of the parameters of the dehydration process, in which the raw material was characterized by its percentage of moisture, then the fruit was conditioned, obtaining the scalded seeds, then its moisture content was determined to continue with the rest of the process, the OD and HAD, manipulating the control variables for each of the 8 treatments. Once the 8 experimental samples were obtained, their final moisture content was determined and and was processed using the Taguchi design methodology as Srinivasa (2019). Stage 2 began with the determination and characterization of the product with the participation of a panel of 50 consumers, using a hedonic scale from 1 to 7 points; where 1 was equivalent to "I extremely dislike" and 7 to "I extremely like". The Friedman test was used. After inserting the factors and levels in the Minitab software version 2019, a Taguchi L8 (2^5) arrangement was designed, so we worked with 8 experimental runs.

2.4 Experimental Variables

The analysis of the variables was determined the final moisture content, physicochemical analysis of the tree bread seeds through the method AOAC (2005) for moisture, as for the Brix the digital refractometer by AOAC (2005), while for proximate analysis of the final product (dehydrated tree bread) Ash by AOAC (2005), protein by AOAC (2005), AOAC (2005) for fat, crude fiber, carbohydrate by Collazos (1993) and for total energy by Collazos (1993).

3. Results and Discussion

3.1 Optimización de los parámetros del proceso de deshidratación

Table 1 presents the results of the variable (% final moisture) of the dehydrated tree bread, showing that the lowest percentage of moisture was reported with T4 (40° Brix, 40°C, 8hrs in OD and at 65ºC, for 2 hrs in HAD drying) and T6 (60° Brix, 20°C, 8hrs in OD and at 65ºC, for 2 hrs in HAD drying) with averages of 16.75 and 16.23% moisture, respectively. The results are close to those reported by Lopez and Gómez (2017) who found that dehydration of tree bread at 60°C for 12 hr obtained 10.77% final moisture. Now, in this research, a moisture content of 12.8% was obtained after subjecting the tree bread for 8 hrs in OD (60°Brix) and for 2 hrs in HD drying. This difference is due to the fact that, in the first case, the tree bread was exposed for much longer to the drying process. Although the difference is minimal (2.03%), the extended drying time means a greater energy requirement and higher cost. In this research, the hot air drying (HD) was only 2 hours, which generates a great advantage from an energy and cost point of view. Similarly, Pavkov et al. (2021) found that apricot fruit during osmotic dehydration at 60°C, 65% and 3 hrs the product lost between 47 to 62% moisture and during 2 hrs in HAD lost another 17 to 18% moisture in the final apricot product. However, the data of the treatments (T4 and T6) were analyzed using Taguchi's method.

Table 1: Percentage of final moisture content of the treatments under study

Treatment	Osmodeshydrate (OD)			Hot air drying (HAD)		% Final moisture
	OD Concentration	OD Temperature	OD Time	HAD Temperature	HAD Time	
1	40	20	1	45	1	48.3 ± 0.29*
2	40	20	1	65	2	28.72 ± 0.24
3	40	40	8	45	1	34.1 ± 0.24
4	40	40	8	65	2	16.75 ± 0.08
5	60	20	8	45	2	27.61 ± 0.15
6	60	20	8	65	1	16.23 ± 0.1
7	60	40	1	45	2	37.56 ±0.18
8	60	40	1	65	1	29.4 ± 0.19

Note: *Means ± standard deviation; %=percentage

The results of the analysis of variance for the signal to noise ratio (SN) of the Taguchi design shown in Table 2 confirmed that OD concentration, OD time, temperature, HD, HD time were statistically significant ($p<0.05$) while OD temperature had no significant effect ($p>0.05$) on the moisture content of tree bread in the dehydration process. These results were similar to those found by Pavkov et al. (2021) who confirmed that temperature and osmotic agent concentration had the most significant effect on moisture reduction of the dehydrated product.

Table 2: Analysis of variance of the Taguchi design

Source	**GL**	**SC Sec.**	**SC Adjusted**	**MC Adjusted**	**Value F**	**Value P**
OD Concentration	1	36.4322	36.4322	36.4322	18.9857	0.0488
OD Temperature	1	1.1641	1.1641	1.1641	0.6066	**0.5176**
OD Time	1	303.6904	303.6904	303.6904	158.2602	0.0063
HAD Temperature	1	398.6156	398.6156	398.6156	207.7279	0.0048
HAD Time	1	37.8006	37.8006	37.8006	19.6988	0.0472
Residual error	2	3.8379	3.8379	1.9189		
Total	7	781.5408				

Table 3 shows the variability on the response by the effect of each factor level and classifies it according to the delta value, where value 1 has the greatest effect and value 5 has the least effect, which contrasts with Taguchi's analysis showing that the factors HD Temperature and OD Time were more significant in the final moisture content of the tree bread during dehydration. Therefore, Taguchi recommends working with OD Concentration at its high level (60ºBrix), OD Time at its high level (8hrs.), HAD Temperature at its high level (65ºC) and HAD Time at its high level (2hrs.) to obtain a lower final product moisture. This was corroborated by Mehta et al. (2023) who confirmed that osmotic solution concentration, processing time and temperature are significant factors favoring moisture removal. Table 4 shows the prediction through regression analysis, obtaining the following equation: % Moisture = 93.77 - 0.2134 OD Concentration - 1.760 OD Time - 0.7059 HAD Temperature - 4.347 HAD Time.

Table 3: Response table for signal to noise ratios

Level	**OD Concentration**	**OD Temperature**	**OD Time**	**HAD Temperature**	**HAD Time**
1	-29.4946	-28.9676	-30.9260	-31.1625	-29.4768
2	-28.4722	-28.9992	-27.0408	-26.8044	-28.4900
Delta	1.0224	0.0316	3.8852	4.3581	0.9868
Classify	3	5	2	1	4

Table 4: Model coefficients for the polynomial model

Term	Coef	EE coef.	T-value	p-value	IVF	Regression	Value
Constante	93.7702	3.7341	25.1118	0.0001		S	1.292
OD Concentration	-0.2134	0.0457	-4.6745	0.0185	1	R-cuad.	99.36
OD Time	-1.7604	0.1304	-13.496	0.0009	1	R-cuad. (ajust.)	98.51
HAD Temperature	-0.7059	0.0457	-15.4621	0.0006	1	R-cuad. (pred.)	95.45
HAD Time	-4.3474	0.913	-4.7615	0.0176	1		

3.2 Analysis of dehydration kinetics

Figure 1 (a) and (b) shows the dehydration kinetics curves for treatments T4 (40° Brix, 40°C) and T6 (60° Brix, 20°C). Figure 1 (a) shows the free moisture curve in the osmhydrate, where it can be observed that the water loss of the breadfruit at T4 has a higher rate compared to T6 during the first 4 hours, this may be due to the temperature difference that favors T4. However, after the fifth hour the water loss rates of T4 and T6 come to equilibrium and remain constant as an equilibrium is established between the solute concentrations in the breadfruit and in the osmotic solution, i.e., the osmotic pressure on both sides of the semipermeable membrane is balanced. At this point, the osmotic pressure within the product and in solution equalizes, resulting in a decrease in of water loss. The osmotic pressure balances the flow of water across the product membrane and the rate of water loss stabilizes.

Now, both T4 and T6 reach this equilibrium in a time of 5 hours to maintain the rate of water loss constant, which leads to infer that the temperature of 40 °C of the medium in T4 only has a significant effect during the first hours of osmotic dehydration, which compensates the difference in Concentration in favor of T6; However, T6 reaches the same period at room temperature, hence the importance and significant effect of the concentration of the osmotic solution (40 - 60°Brix) and the non-significant effect of the temperature of the medium (20-40°C) during the osmodeshydration, both parameters of study. The moisture content (%) curve of tree bread is shown in Figure 1 (b), from the initial state (t0) to a time (t) during OD. The curves best fit a second degree polynomial trend and the best fitting equation is from treatment T6 within the range of 0 to 8 hr. The drying temperature has a significant influence on the drying time, since the higher the temperature, the greater the heat output and the easier the air movement, resulting in a shorter drying time (Somjai et al., 2023). In the OD of aguaymanto, Marceliano et al. (2023) reported that the drying kinetics for the loss of moisture of the fruit at 60ºBrix of panela, 60ºC is fast in the first three hours and then presents a logarithmic tendency showing constant for seven hours, which is correct that the fruit when submerged in the OD solution generates mechanisms such as cellular dehydration, diffusion of soluble solids of the osmotic agent to the interior of fruit and the diffusion of water from the fruit to the osmotic solution.

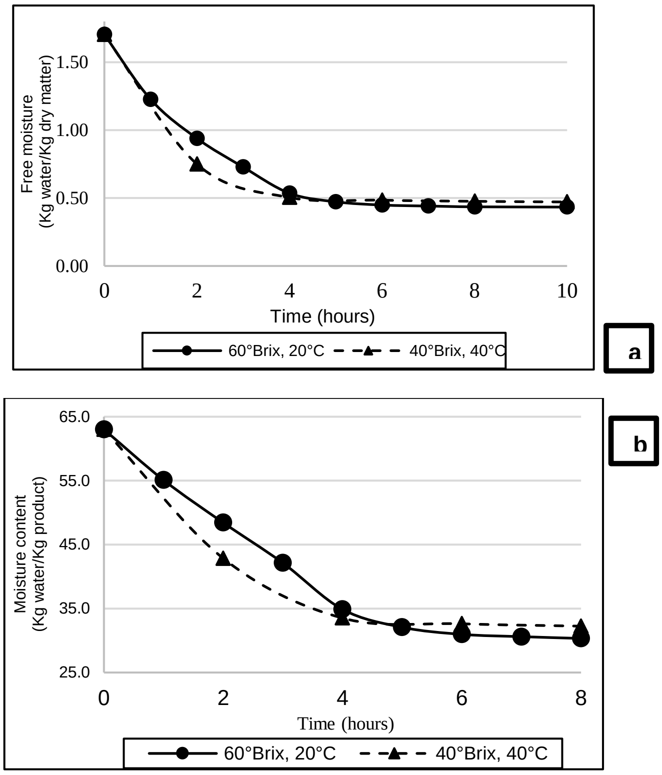

Figure 1: (a) Free moisture curve in osmodeshydrate and (b) percentage moisture curve in osmodeshydrate.

3.3 Sensory analysis

Tables 5 show the results of the sensory analysis according to the friedman's nonparametric test, where it can be seen that for color, flavor, texture and acceptability were highly significant ($p<0.05$), while for odor there was no statistical significance. However, it should be noted that the higher the temperature, the greater the loss of physicochemical and organoleptic properties. Similar results were obtained by Somjai et al. (2023) who indicate that the product with osmosis at 60° Brix at 20ºC obtained the highest score in the organoleptic evaluation and the general acceptance of the sensory evaluations was classified as "moderately", with respect to texture, it is a characteristic that determines the chewiness of the product, showing that fresh lime slices are harder than osmotized lime slices because the latter, when subjected to the osmotic solution, disintegrates the structure of the tissue, which results in a softer texture and therefore the force exerted by chewing when eating is less. However, Araújo and da Silva (2023) indicate that fruits are difficult to dehydrate during the hot air process due to their high moisture content, which can prolong the drying time, causing changes in characteristic of the final product.

Table 5: Friedman's test for sensory characteristics of tree bread

Treatment (T)	Represent ation (T)	Medium									
		Odor		Color		Flavor		Texture		Acceptability	
T4	X	5		5		5		5		5	
T6	Y	5		5		5		5		5	
T-op	Z	5		6		6		6		6	
General		5		5.33		5.33		5.33		5.33	
Method	GL	X^2	Vp	X^2	Vp	X^2.	Vp	X^2	Vp	X^2.	Vp
NAE	2	4.96	0.084	13.33	0.001	12.25	0.002	1.99	0.037	28.47	0.000
AE	2	8.00	0.072	18.77	0.000	14.58	0.001	2.76	0.025	35.81	0.000

X^2 = Chi-square, pv = p. value, Unadjusted for ties = NAE, Adjusted for ties =AE

The physicochemical tests of the final product showed 76.5% carbohydrates, 8 % protein, 1.7% fat, 1% ash, 0.9% crude fiber and total energy of 353.3 Kcal, making it suitable for consumption. These results were similar to Castillo (2007) showing that dehydrated tree bread obtained 11.48% moisture, 78.17 % carbohydrates, 6.20% protein, 3.01% ash, 0.30% crude fiber, 1.07 % fat and 1.07% energy. Tree bread, despite being subjected to dehydration through the use of combined OD and HD methods, its nutritional value remains high and prolongs the shelf life of the product. This is corroborated by Li et al. (2023) when combining OD and HAD generates that the fruit loses water and gains soluble solids, through two types of flow, the first through the diffusion of water from the fruit to the osmotic solution and the second flow is the diffusion of solutes from the osmotic solution to the interior of the fruit, which leads to a partial elimination of water, maintains the nutritional value, reduces heat stress, stabilizes the sensory parameters and prolongs the shelf life of the fruit.

4. Conclusions

It was found that the best drying conditions by using combined methods of OD and HAD in tree bread was using a concentration of 60 ºBrix, time 8 hrs and temperature at 65 ºC in OD and a time of 2 hrs in HAD, obtaining a product with 12.8% moisture, with better sensory results such as general acceptability, flavor, color and texture. In terms of physicochemical properties, 76.5% carbohydrates, 8% protein, 1.7% fat, 1.0% ash, 0.9% crude fiber and total energy of 353.3 Kcal were obtained. Therefore, the study demonstrated that the combined OD and HAD methods reduce heat stress, stabilize sensory parameters and maintain the nutritional value of osmodeshydrated tree bread, being these data practical for industrial purposes, prolonging the shelf life of the fruit making it more available for a longer time and easier to transport.

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