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Osmotic dehydration of cassava bagasse (*Manihot esculenta*) and its effect as pretreatment on the efficiency of convective drying

Deshidratación osmótica del bagazo de yuca (*Manihot esculenta*) y su efecto como pretratamiento sobre la eficiencia del secado convectivo

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Abstract

The cassava bagasse is an agroindustrial residue from the cassava starch industry which entails concerning environmental challenges. High moisture content and hydrophilic nature make it difficult to apply conventional drying efficiently. Osmotic dehydration (OD) is evaluated directly in this research, and taken as a pretreatment to convective drying (OD-Drying) of this residue with hypertonic NaCl solutions between 30% and 60% OD and between 5% and 20% in OD-Drying, using rates of 3 to 5 g solution/g sample, with an air velocity of 1.5 m/s and at 40° C. OD alone reduced cassava bagasse moisture in 67.25 %, while OD-Drying reduced moisture in 86.3 % and drying time to 41.1 % saving energy up to 51.913,8 kJ when applying OD-Drying. Found results show that OD improves convective drying of cassava bagasse, providing benefits in its post-industrial handling such as mitigation of the environmental problem associated with it, contributing this way to the sustainable development of the starch industry that can also be applied to other agroindustrial residues.

Keywords: Convective drying, cassava bagasse, sustainable development, agroindustry, starch.

Resumen

El bagazo de yuca, residuo agroindustrial de la industria de almidón de yuca, plantea preocupantes desafíos ambientales. El alto contenido de humedad y naturaleza hidrofílica dificultan su secado convencional de manera eficiente. En esta investigación se evalúa la deshidratación osmótica (DO) de manera directa y como pretratamiento al secado convectivo (DO-Secado) de este residuo con soluciones hipertónicas de NaCl comprendidas entre 30% y 60% en DO y entre 5% y 20% para DO-Secado, empleando proporciones de 3 a 5 g solución/g muestra, con velocidad de aire de 1.5 m/s y a 40°C. La DO por sí sola redujo la humedad del bagazo de yuca en 67.25 %, mientras que la DO-Secado redujo la humedad en 86.3 % y el tiempo de secado en 41.1 % con un ahorro energético de 51.913,8 kJ al aplicar DO-Secado. Los resultados encontrados demuestran que la DO mejora el secado convectivo del bagazo de yuca, favoreciendo su manejo postindustrial, y la mitigación del problema ambiental asociado a este residuo, lo que contribuye al desarrollo sostenible de la industria de almidón, lo cual puede escalarse a otros residuos agroindustriales.

Palabras clave: Secado convectivo, bagazo de yuca, desarrollo sustentable, agroindustria, almidón.

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1 Introduction

Humidity control in agrifood systems is paramount, both to preserve industrial products and to prevent proliferation of microorganisms in residues to improve post-industrial handling. Organic or biodegradable waste must be dehydrated to allow its long-term conservation and reduce its negative environmental impact. Moisture level varies according to the type of residue, and there are various drying alternatives available to reduce it (Vargas & Pérez, 2018). Particularly, the cassava starch extraction industry currently faces the challenge of managing cassava bagasse bran appropriately, representing 0.93 tons of solid residue for each ton of processed cassava approximately. This residue is discarded from the starch extraction process in between 82-87%, with a significant organic load, causing uncontrolled fermentation and unpleasant odors where it is deposited without previous treatment (Florencia *et al*., 2020; Escaramboni *et al*., 2018; CIAT, 2022). The bagasse contains around 16% dry matter, made up mainly of carbohydrates (up to 82.85%), including high starch content (greater than 50%), and fiber in a range of 15 to 50%.

Consequently, management of high humidity waste such as cassava bagasse entails challenges in its handling, storage, transportation, and conservation, especially when large daily volumes are obtained. To improve this waste post-industrial use, reducing its mass and volume is needed in order to facilitate handling. Nonetheless, due to the hydrophilic nature of cassava bagasse, conventional drying is highly expensive and inefficient, due to the long operation times, requiring to explore new technological options for a more efficient dehydration that allows its use in the different possibilities or alternative uses that this waste has in accordance with studies carried out in areas such as biotechnology, food, biomaterials, composting, and elimination of contaminants in water sources, aiming to take advantage of the bagasse (Keller *et al*., 2020; Liu *et al*., 2018; Vargas & Pérez, 2018; Paternina *et al*., 2016). As a whole, these applications require reducing its moisture to ease the handling and prevent decomposition and spread of microorganisms (García *et al*., 2020).

Advances in bio-based materials provide opportunities for the economic revaluation of agribusinesses, and there is a growing interest in finding new technological innovations in processing techniques to add value to such materials. These opportunities are due to advances in processing technologies and techniques (Florencia *et al*., 2020; Grasso, 2020). Thus, to take advantage of cassava bagasse in the starch industry, it is necessary to evaluate efficient drying technological options that allow a previous dehydration, regardless of use or application (Fiorda *et al*., 2015).

Now, convective drying is a dehydration process used to preserve food and treat waste. This process combines heat and mass transfer to remove water from solid products, easing their handling and preparation for sale and/or subsequent use. It is used in the food industry to extend shelf life of processed and unprocessed foods by inhibiting microorganism growth and enzyme activity. Furthermore, it has the advantage of being carried out in a simple way with low-cost technology, making it even more attractive (Assis *et al*., 2017; Bantle & Eikevik, 2014; Kaur *et al*., 2014).

In this sense, studies carried out by Salcedo-Mendoza *et al*. (2016) on cassava bagasse drying are highlighted. They subjected the bagasse to convective drying in trays, managing to reduce moisture content from 88 % to 10 % approximately on a wet basis for 11 h. Similarly, Contreras *et al*. (2016) applied combined methods of filtration and pressing with drying, arriving at the same results in 3.8 h. Nonetheless, traditional drying techniques suffer several drawbacks, among which, long processing time, high energy demand, low rehydration capacity, and change in food properties, significantly influencing the economic scope of its use and commercial value (Assis *et al*., 2017; Bantle & Eikevik, 2014; Kaur *et al*., 2014; Kowalski *et al*., 2014; Mujic *et al*., 2014; Andreou *et al*.,2021). These disadvantages have prompted research of combined methods that can improve energy efficiency and cost of this process (Chavan & Amarowickz, 2012; Massolo *et al*., 2020).

On the other hand, osmotic dehydration (OD) is an inexpensive and simple non-thermal treatment of food pre-drying that reduces energy consumption, improves product quality, and speeds up the drying process (Feng *et al*., 2019). It consists of submerging food in hypertonic solutions of sucrose, sodium chloride or a combination of both, among others (Massolo *et al*., 2020). This creates a concentration gradient that allows simultaneous water diffusion from the food into the solution and the incorporation of solutes from the solution into the product. Nonetheless, OD alone has disadvantages since osmotic pressure is the only driving force for mass transfer. The process itself is relatively inefficient to achieve low humidity and in some cases requires long treatment times (Bai *et al*., 2020; Ferreira *et al*., 2020; Gutiérrez-Salomón *et al*., 2021). Various OD studies have shown that the greatest mass transfer occurs in the process initial stage (30-100 min) (Andreou *et al*., 2021; Ghanem *et al*., 2016; Kaushal & Sharma, 2016; Dermesonlouoglou *et al*., 2018). Some authors have proposed OD as an early step of thermal drying, resulting in higher energy efficiency and cost reduction (Abbasi *et al*., 2012; Sharma & Dash, 2019); with decreases, also, of up to 42 % in drying time, and 31.1 % in the required energy (Andreou *et al*., 2021; Massolo *et al*., 2020; Da Costa *et al*., 2016; Masztalerz *et al*., 2021).

Now, even though these combined methods of OD with conventional drying have been used successfully in various food applications to achieve high-quality and efficient dehydration, the effects of these types of combined techniques on the efficiency of the residue drying process of high humidity and hydrophilic nature are unknown, such as on the cassava bagasse. Mass transfer processes for both, OD and drying operations, which characterize the mechanism of moisture/water loss (WL) in the products subject to them, are framed by Fick's second law for diffusion in a non-steady state (equation 1). In this equation, C is the moisture concentration, t is time, D is the diffusion coefficient, and z corresponds to the characteristic dimension.

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2}. \qquad (1)$$

In the drying process, the predominant mechanisms in the moisture transport from the interior to the material surface are liquid diffusion, vapor diffusion, liquid flow, and vapor flow. All of them are often included in an effective diffusivity parameter, evaluated in the modeling of the drying process of various materials (Borja-Málaga *et al*., 2022). This effective diffusivity depends both on the material characteristics and the used drying conditions and technique.

In addition, mathematical modeling is frequently used to study food drying kinetics, improve existing drying systems, and to develop and evaluate new manufacturing processes or new designs for efficient control of the drying process (Thuy *et al*., 2023), although several combined OD techniques have been successfully used as pretreatment to improve efficiency in time and energy consumption of the drying operation of various products, such as fruits, vegetables and fillets (Ferreira *et al*., 2020; Gutiérrez-Salomon *et al*., 2021; García *et al*., 2010; Álvarez & Barraza, 2013).

Nonetheless, there is no precedent for the effect that DO can have to improve the efficiency of the drying operation in products with a high-water load, particularly in cassava bagasse as an agroindustrial waste of the starch industry. Therefore, the objective of this research was to evaluate the OD effects in fresh cassava bagasse specifically on the WL and SG together with the effects of the combined OD-Drying technique on the efficiency of convective drying time of cassava bagasse. The obtained results contribute to the knowledge of combined technologies for the drying of an agroindustrial waste, generating a technological proposal to improve the specific drying process of cassava bagasse and providing reference parameters for the application of OD and OD drying technologies of cassava bagasse and other high-moisture agroindustrial waste, as a sustainable technical alternative for its management with a view to its valorization and use. Thus, mitigating the generated negative environmental impact and promoting the starch industry towards a sustainable agroindustry.

2 Materials and methods

2.1 *Research location*

This study was carried out in the pilot plant of unitary operations from University of Sucre in Colombia, located at Puerta Verde headquarters on the 7th kilometer of the Sincelejo-Sampués road. The used bagasse was collected at Almidones de Sucre S.A.S company, located on kilometer 4.5 from the Sincelejo-Corozal road.

2.2 *Sample preparation*

Evaluated samples were obtained from a general 3 kg sample collected with a scoop from the top of the pile, unloaded during the process of obtaining cassava starch. Approximately 3 kg were placed in percolators in similar proportions each, to drain off any surface free water. Subsequently, after 2.5 h, the cassava bagasse residue was combined and then, samples were taken in triplicate way for each test according to the research object.

2.3 *Proximal characterization of the cassava bagasse*

Estimation of moisture, ash, fat, fiber, and protein content was carried out based on the standards 977.11 AOAC oven method, 942.05 AOAC general method, 920.39 AOAC Soxhlet method, 962.09 AOAC gravimetric chemical method, and 955.04 AOAC Kjeldah method (AOAC, 1997), respectively. Carbohydrate content was obtained from the difference of equation (2) proposed by Eyerson & Ankrah (1975), where % TC refers to percentage of total carbohydrate; % H, sample moisture percentage; % G, fat percentage; % Ce, ash percentage; % F, crude fiber percentage; and % Pc, protein percentage.

$$\%TC = 100 - (\%H + \%G + \%Ce + \%F + \%Pc) \qquad (2)$$

2.4 *Evaluation of the direct effect of OD on cassava bagasse*

To evaluate the OD effect on cassava bagasse, the described methodology by Dermesonlouoglou *et al*. (2018) was followed, using osmotic solutions with concentrations of 30 %, 45 % and 60 % NaCl, and solution: sample ratios of 3:1, 4:1, and 5:1, respectively. Each assay was shaken at 320 rpm under ambient conditions of 1 atm and between 30-31°C for 10 min. Subsequently, the sample was drained through a 12-mesh sieve, and 20 min later, it was spread on absorbent paper, forming a sheet of 3 mm thick approximately until no water migration was observed. Sample humidity according to each treatment was estimated by the oven method according to AOAC (1997), determining moisture loss (WL) and solid gain (SG) in each case by corresponding material balance, according to equations 3 and 4, respectively. All assays were performed in triplicate way.

$$WL = \left(\frac{Wi * Xi - Wf * Xf}{Wi} \right) \times 100 \quad (3)$$

$$SG = \left(\frac{Wf * Xsf - Wi * Xsi}{Wi} \right) \times 100 \quad (4)$$

Where Wi is the sample initial mass. Xi is the initial moisture fraction. Wf is the final sample. Xf is the final moisture fraction. Xsf is the final fraction of solids and Xsi is the initial fraction of solids.

2.5 *Evaluation of OD as a pretreatment of convective drying of cassava bagasse (OD-Drying)*

Based on the results from Serpa *et al.* (2022), to evaluate the OD effects as a pretreatment to convective drying of cassava bagasse, the OD treatment was carried out using concentrations of 5%, 12.5%, and 20% NaCl of osmotic agent, with solution: sample ratios of 3:1, 4:1, and 5:1; at 320 rpm each, in ambient conditions during a 10 min immersion time. After the OD treatment, the samples were drained for 20 min using a 12-mesh sieve. Later, the samples arranged with a thickness of 5 mm were placed in the drying chamber of a TD-S/EV-tray dryer (Elettronica Veneta, Treviso, Italy) at a controlled temperature of 40 ± 1°C and an air velocity of 1.5 m/s. As a control, the experiment had fresh cassava bagasse without previous OD treatment. In each treatment, drying time was estimated until the samples reached 12 % humidity on a wet basis (Liu *et al.*, 2014).

2.6 *Drying kinetics*

To determine the drying kinetics of the cassava bagasse, the sample from each treatment was weighed at intervals of 5 min for the first 30 min. Subsequently, every 10 min until completing 90 min. Then, every 15 min until 210 min, and finally every 30 min until the sample reached the equilibrium moisture under drying conditions of 40 °C and 1.5 m/s air velocity.

The mathematical model that best describes the kinetic behavior of cassava bagasse drying with and without prior OD treatment to convective drying was determined according to Salcedo-Mendoza *et al.*, 2016. Nine drying kinetics models for cassava bagasse were evaluated to select the model that best fit the experimental data of the drying treatment with or without DO prior to convective drying of cassava bagasse. The diffusion coefficient (Df) was determined from the experimental data adjustment to a straight line obtained by plotting the Ln of the moisture loss ratio (MR) as a function of the drying time in hours and its relationship with the value theory of the graph ln (MR) with respect to the Df expressed in equation 5 (Geankoplis, 1998) for a flat sheet. Df is the diffusivity, t is drying time, and z is the sample thickness, whereas MR is the rate of moisture loss, expressed in equation 6, where Xt is moisture in time, Xequil is moisture in equilibrium, Xt1 is the initial moisture, X is the free moisture in time t, X_1 is the free initial moisture in $t = 0$, $a1 = (\pi/2)^2$, and Fo is Dft/z^2 .

$$Df = \left[\frac{Dft}{z^2} \right]_{\text{theor (for a flat sheet)}} \times \left[\frac{z^2}{t} \right] \quad (5)$$

$$MR = \frac{Xt - Xequil}{Xt1 - Xequil} = \frac{X}{X1} = \frac{8}{\pi^2} \left[e^{-a1Fo} + \frac{1}{9} e^{-9a1Fo} + \frac{1}{25} e^{-25a1Fo} + \ldots \right] \quad (6)$$

Equation 6 assumes that Df is constant, but it is rarely constant, and varies with water content, temperature, and humidity. For long drying times ($F_o > 1$), the only term in the series that is relevant is the first.

2.7 *Experimental design*

To evaluate the effects of the individual OD application and combined DO-Drying on cassava bagasse, a completely randomized experimental block design was proposed in a factorial experiment with two quantitative factors, each with three levels. Factor 1 represented the concentration of osmotic agent using 30%, 45% and 60% NaCl levels for the individual OD, and 5%, 12.5% and 20% levels for the combined DO-Drying methods. Factor 2 corresponded to the solution: sample ratio, with levels of 3, 4 and 5g of solution per 1g of sample in both cases. All tests were performed in triplicate way. Statistical analysis was performed using the R-Studio v.2.9.1 program (The R Foundation for Statistical Computing, 2009). The response surface figures were generated using the free computational tool WolframAlpha (2009).

An ANOVA with a 95% confidence level was used to evaluate the impact of the factors and their interaction on moisture loss (WL), solids gain (SG) and drying time in the OD treatment integrated to the convective drying. Once the linear and quadratic effects of the evaluated factors and their interactions

Table 1. Proximal Characterization of the cassava bagasse.

Component	Content (%)
Humidity (wet basis)	87.877 ± 0.314
Dry matter (wet basis)	12.123 ± 0.315
Ash (dry basis)	1.6310 ± 0.017
Protein (dry basis)	1.8840 ± 0.250
Fat (dry basis)	0.5120 ± 0.075
Fiber (dry basis)	24.692 ± 0.277
Carbohydrates (dry basis)	71.281 ± 0.468

were estimated by applying the Akaike Information Criterion (AIC) for the data simplification and adjustment, the mathematical model that best explains the behavior of the variable of response -water loss, solids gain and drying time- was estimated.

3 Results and discussion

3.1 Proximal characterization

The proximal characterization of the cassava bagasse (Table 1) showed a carbohydrate content greater than 70 %, with a fat content below 0.6 %, like the one reported by Romero de Armas *et al*. (2017). Fiber content is not consistent with the results presented by Paternina *et al*. (2016) and presents a difference greater than 20 % with the fiber content present in the bagasse characterized by Polachini *et al*. (2018). These differences may be due to factors such as technology involved in the extraction process, efficiency of the starch extraction process and the peeling of raw material (Bussolo *et al*., 2018).

Dry matter composition of cassava bagasse makes it a useful input in different industrial processes such as in biotechnology, food, biomaterials, composting, and elimination of pollutants in water sources (Keller *et al*., 2020, Liu *et al*., 2018; Vargas & Pérez, 2018; García *et al*., 2016). Therefore, an efficient and economic drying method to favor its post-industrial handling would cause a strong recovery of this current residue.

3.2 Direct evaluation of OD in cassava bagasse

Moisture loss (WL) and solid gain (SG) are the main mass transfer parameters used to determine the efficiency of the OD process (Bchir *et al*., 2021). Table 2 records the results of WL and solid gain (SG) after the OD process

In a solution: sample ratio of 3:1, for each increased unit of NaCl, water content in the bagasse will be reduced by 1.25 %, and a solid gain of 0.813 % will be obtained. Nonetheless, even when the elimination of water in the cassava bagasse and solid gain increase, as the 5:1 ratio increases, the linear adjustment is less than in the 3:1 ratio, but statistically acceptable in each R^2.

Now, the water content found in the fresh bagasse was on average 87.877 ± 0.3 %. When working with the highest osmotic concentration and the solution: sample ratio corresponding to 5:1, it was possible to remove 66.377 ± 1.3% of the initial humidity, while the SG was 79.9778 ± 0.18% (Table 2). These results were obtained after 10 min of treatment, while other studies perform this process for times between 2 and 8 h, only reaching moisture losses around 40 % when using up to 65 °Brix of sucrose as osmotic medium (Grzelak *et al*, 2021; Thuy *et al*., 2021; Julca-Huarnizo *et al*., 2019). In this regard, Assis *et al*. (2017) highlights that one of the most important factors in the OD study is the material type to be treated, as well as its structure and geometry. Thus, the moisture loss reached in this research in the OD stage is compared with the WL of up to 70 % in the first 10 min of OD, reported by Ghanem *et al*. (2016) when subjecting lemons to a 70 °Brix solution of sucrose.

This agrees with other authors who state that the highest rate of mass transfer and water loss from food during OD occurs during the treatment initial stage (Andreou *et al*., 2021; Ghanem *et al*., 2016; Kaushal & Shama, 2016; Dermesonlouoglou *et al*., 2018). The ANOVA shows that both, the main studied factors -concentration of the osmotic agent and solution: sample ratio- and their interaction significantly affect WL and SG respectively (p-value < 0.05).

Table 2. WL and SG of cassava bagasse after OD treatment.

X_1: NaCl Concentration (%)	X_2: s:s rate (g/g)	WL (%)	SG (%)	Adjustment Equation WL (%)	Adjustment Equation SG (%)
30	3:1	19.160 ± 0.78	43.670 ± 0.96	WL = 1.2577 X_1 - 15.505	SG = 0.8131 X_1 - 6.5003
45	3:1	47.220 ± 0.07	66.760 ± 0.68	(R^2 = 0.9266)	(R^2 = 0.9735)
60	3:1	56.898 ± 0.27	79.593 ± 0.21		
30	4:1	23.852 ± 0.07	33.810 ± 0.27	WL = 1.3707 X_1 - 13.857	SG = 0.5855 X_1 + 9.2905
45	4:1	54.465 ± 0.99	65.135 ± 0.94	(R^2 = 0.9236)	(R^2 = 0.9800)
60	4:1	64.973 ± 0.77	84.021 ± 0.05		
30	5:1	20.521 ± 0.03	29.160 ± 0.82	WL = 1.5283 X_1 - 20.225	SG = 0.5581 X_1 + 12.576
45	5:1	58.766 ± 0.34	65.157 ± 0.59	(R^2 = 0.8705)	(R^2 = 0.9453)
60	5:1	66.377 ± 1.30	79.978 ± 0.18		

Table 3. Linear and quadratic effects of the studied factors and their interactions on WL of cassava bagasse subjected to OD.

Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Rep	2	0.1	0.04613	0.0949	0.90995
Trat	8	9005.2	1125.6	2316.0542	$< 2.2\times10^{-16}$ ***
LC	1	7777.0	7777.0	16001.4795	$< 2.2\times10^{-16}$ ***
Cc	1	827.1	827.1	1701.8593	$< 2.2\times10^{-16}$ ***
LSS	1	250.5	250.5	515.4709	1.343×10^{-13} ***
SMc	1	60.0	60.0	123.4343	6.230×10^{-9} ***
LC x LSS	1	49.4	49.4	101.6796	2.446×10^{-8} ***
LC x SSc	1	0.5	0.5	0.9375	0.34734
Cc x LSS	1	37.5	37.5	77.1223	1.621×10^{-7} ***
Cc x SSc	1	3.1	3.1	6.4500	0.02185 *
Residuals	16	7.8	0.5	——	——

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; LC: linear osmotic agent concentration; Cc: quadratic osmotic agent concentration; LSS: linear solution-sample relationship; SSc: quadratic solution-sample relationship.

Table 3 records the results of the orthogonal contrast test for the evaluation of the linear and quadratic effects of the studied factors and their significant interactions on the WL of cassava bagasse (p-value < 0.05) when subjected to an OD process.

The linear and quadratic effects of the osmotic agent concentration factor used in this research, as well as the solution: sample ratio factor, were significant with 95 % confidence for WL in the cassava bagasse during the OD treatment, indicating that the WL response of cassava bagasse increases with a certain degree of curvature when increasing both levels of NaCl concentration and solution: sample ratio, with a greater effect given by the concentration of the used osmotic agent. The interaction of the linear effects of the osmotic agent concentration with the solution: sample ratio was equally significant for the WL response variable, indicating that the NaCl concentration over WL at the ratio level of 3 g of solution/g of sample is statistically different at the level of 5 g of solution/g of sample, with an increase in WL when going from 30% to 60% of NaCl, respectively. The significance of the concentration interaction of the quadratic osmotic agent by the solution relationship both, linear and quadratic sample, indicates that there is a difference in the uniformity of the WL response when increasing the NaCl concentration from 30% to 45% with respect to 45 % to 60% and the ratio solution: sample from 3 to 5g of solution/g of sample, respectively.

With the obtained results on the effects of the studied parameters in OD, the mathematical model that explains the behavior of the response variable of water loss (WL) was estimated, and based on the information criterion of Akaike AIC (Akaike Information Criterion) for simplification and adjustment purposes, the equation 7, corresponding to a second-order model adjusted for WL was obtained. In this equation: X_1 corresponds to the NaCl concentration (%) in the hypertonic solution, and X_2 is the solution: sample ratio (g solution / g sample) used in the assay.

$$WL(\%) = -58.57810 + 0.85315X_1 + 1.30500X_1X_2 - 3.33342X_2^2 - 0.01302X_1^2X_2 \quad (7)$$

The R^2 statistic indicates that the model explains the 99.85% of the variability of the WL percentage of cassava bagasse when it is subjected to OD treatment. Similarly, a hypertonic solution of 56.9% NaCl and a solution: sample ratio of 4.8:1 g of solution / g of sample are used to maximize WL, conditions under which the highest possible WL is achieved, equivalent to 67.25%. Figure 1 shows the response surface of the model determined for the WL percentage of cassava bagasse during the OD treatment. It can be observed that the studied factors present a directly proportional relationship with WL in the cassava bagasse. Similar results were obtained in pumpkin slices, carrot strips, cylindrical apple pieces, and pear samples (Da Costa *et al.*, 2016; Çağlayan & Barutcu, 2018; Deshmukh *et al.*, 2021; Muñiz-Becerá *et al.*, 2022).

In addition, this occurs as a consequence of the concentration of the hypertonic solution that increases the osmotic pressure gradient at the product/solution interface, generating a driving force for a two-way mass transfer, and allowing a simultaneous mass exchange of water from the product to the solution and solids from the solution to the product, respectively (Bera & Roy, 2015; Sutar & Prassad, 2011). The obtained results agree with Fick's second law, in the sense that a mass transfer occurs by virtue of a concentration differential and a change in the speed of said transfer over time. This has been observed by different authors when they exposed carrot, apple and white root samples to different osmotic solutions prepared with sucrose, sucrose and stevia, and sucrose and salt, respectively, under maximum concentrations

Table 4. Linear and quadratic effects of the studied factors and their interactions on the SG of cassava bagasse during DO.

Variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Rep	2	0.2000	0.1000	0.2222	0.80315
Trat	8	10069.1	1258.6	3003.9751	$< 2.2\times10^{-16}$ ***
LC	1	9377.8	9377.8	22382.0640	$< 2.2\times10^{-16}$ ***
Cc	1	320.9	320.9	765.7969	6.100×10^{-15} ***
LSS	1	123.5	123.5	294.6735	9.950×10^{-12} ***
SSc	1	0.4	0.4	1.0345	0.324236
LC x LSS	1	166.3	166.3	396.7989	1.018×10^{-12} ***
LC x SSc	1	46.8	46.8	111.6740	1.267×10^{-8}***
Cc x LSS	1	29.8	29.8	71.2034	2.758×10^{-7} ***
Cc x SSc	1	3.6	3.6	8.5555	0.009913**
Residuals	16	6.7	0.4	——	——

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1; LC: linear osmotic agent concentration; Cc: quadratic osmotic agent concentration; LSS: linear solution-sample relationship; SSc: quadratic sample solution ratio.

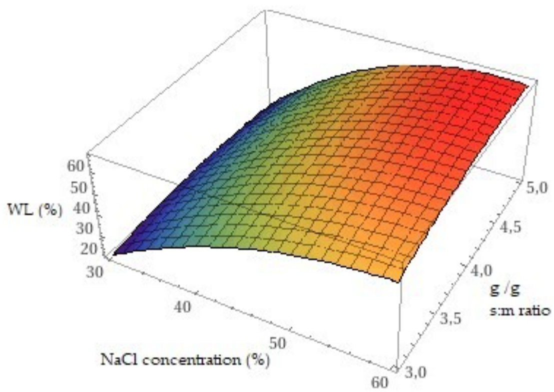

Figure 1. Response surface for WL in the OD treatment of cassava bagasse.

of 60 % (Thuy *et al*., 2021; Deshmukh *et al*., 2021; Muñiz-Becerra *et al*., 2022).

Table 4 shows the results of the orthogonal contrast test for the evaluation of the linear and quadratic effects of the studied factors and their significant interactions (p-value < 0.05) on SG of cassava bagasse during OD.

The linear and quadratic effects of the concentration factor of the used osmotic agent, as well as the linear effect of the solution: sample ratio factor was significant for the SG of cassava bagasse during the OD process. Similarly, all interactions of the linear and quadratic effects of the factors concentration of the osmotic agent and solution: sample ratio were significant for the SG, indicating that the SG response of cassava bagasse increases with a certain degree of curvature when increasing the levels of both NaCl concentration and solution: sample ratio, also with a greater effect given by the concentration of the used osmotic agent, with a difference in the uniformity of the SG response when increasing NaCl concentration from 30 to 60% and from 3 to 5 g of solution/g of sample respectively.

Based on the Akaike AIC (Akaike Information Criterion) information criterion, equation 8 corresponding to a second-order model adjusted for SG was generated, in which X_1 corresponds to the NaCl concentration (%) in the hypertonic solution, and X_2 is the used solution: sample ratio (g solution / g sample) in the assay.

$$SG(\%) = 7.449850 + 6.291370X_1 - 2.417613X_1X_2 - 0.102731X_1^2 - 4.563338X_2^2 + 0.469553X_1X_2^2 + 0.049814X_2 - 0.007742X_1^2X_2^2 \quad (8)$$

The R^2 statistic indicates that the model explains the 99.91 % of the SG percentage of cassava bagasse when it is subject to an OD process. The optimization route for the studied response variable showed that the working conditions to maximize SG are achieved using a hypertonic solution of 60% NaCl and a solution: sample ratio of 4:1 g of solution: g of sample, conditions under which the highest possible SG, equivalent to approximately 84 %, is achieved. While the conditions that minimize SG correspond to a 30 % NaCl concentration and a solution: sample ratio of 5:1 g of solution: g of sample; conditions under which an SG of 29.13 % is obtained. Figure 2 shows the response surface of the model determined for the SG percentage of cassava bagasse during the OD operation.

Consistent with Fick's law, a directly proportional relationship is observed in Figure 2 between the concentration of the osmotic agent and the mass transfer related to SG, in which, as the concentration of the osmotic agent in the solution increases, diffusion velocity increases and the gain of solids is greater by the sample of cassava bagasse. The relatively high SG values of cassava bagasse when subject to a DO process with NaCl can be attributed to the increase in

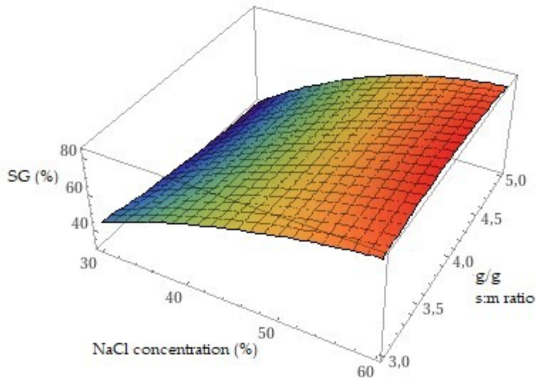

Figure 2. Response surface for SG in the OD process of cassava bagasse.

the bagasse surface area, according to the particular behavior of cassava bagasse in solution, which is completely released, forming a suspension with a larger transfer surface arrangement. These results are consistent with those reported by Ghanem *et al*. (2016) and Masztalerz *et al*. (2021), which state that transfer of solute from the osmotic solution to the product does not depend only on the used osmotic agent concentration but also on the characteristics of the material and the possible physical changes of the material during the process.

The SG turned out to be minimal for the conditions of 30% NaCl concentration and a solution: sample ratio of 5:1 g of solution: g of sample. Also, it is observed that under this 30% NaCL concentration, as the solution: sample ratio increases, the SG of the cassava bagasse decreases. The reasons for this behavior are not clear, nonetheless there are reports of certain osmotic dehydration studies in which it has been the case that, the greater the amount of osmotic agent generated by the greater solution: sample ratio, although it may be favorable for greater water loss to occur, it may reduce the SG, probably due to an impregnation phenomenon in the initial process stage, in which a layer of osmotic agent may form at the product periphery acting as a barrier. According to Muñiz-Becerra *et al*. (2022) during the DO process, the solute that migrates towards the food begins to occupy the empty spaces left by water in the cellular structure. Water flow from the food is transferred simultaneously and in the opposite direction to the movement of the solids. This slows down the advance of the solutes, remaining retained mostly on the surface of the product matrix. In such a way that the progressive uptake of solids at the interface gives rise to the formation of a layer of solutes on the surface of the plant tissue, which may be associated with the presence in some cases of solute impregnation phenomena, causing the greater amount of solids to be retained on the surface of the osmo-dehydrated samples, acting as a barrier, and reducing the SG.

With the osmotic dehydration of cassava bagasse carried out from concentrations of osmotic agent between 30% and 60% salt, a product of intermediate humidity is obtained that can be used in animal feed, especially cattle, which does not have salt restrictions in their diet, and can be used, for example, as an ingredient in silo-type feed with carbohydrate and fiber content, since there are reports of good results about use of cassava bagasse in livestock diets. For this reason, the results of this study provide reference parameters for the osmotic dehydration of other organic waste using salt as an osmotic agent and its subsequent drying.

3.3 Effect of OD as pretreatment of convective drying of cassava bagasse

In order to evaluate the OD effect as a pretreatment of the convective drying of cassava bagasse, the drying time in which the sample reaches a 12% humidity on a wet basis was established as a response variable, since it is an indicator of the energy expenditure and efficiency in this last operation (Andreou *et al*., 2021). Table 5 shows drying times and total process times, which includes 35 min corresponding to the pretreatment time with the OD operation, as well as the drying time of the control sample (fresh bagasse). The OD operation as a pretreatment to the convective drying of cassava bagasse, using salt as an osmotic agent, presents restrictions regarding the used NaCl concentration and the drying temperature, limited to a maximum of 20 % NaCl and 40 °C respectively, since at higher concentrations and temperatures, a crust is formed on the sample surface affecting the efficiency of the mass transfer and heat transfer processes, and the decrease in the sample moisture (Serpa *et al*., 2022).

According to the results of the applied ANOVA, it is observed that both, main studied factors (osmotic agent concentration and solution: sample ratio) and their interaction, affect the drying time of cassava bagasse significantly (p-value < 0.05).

Table 5. Drying time and total process time for cassava bagasse pretreated with OD

X_1: NaCl Concentration (%)	X_2: S:S Rate (g/g)	Drying Time (min)
5.0	3:1	413.7 ± 14.57
5.0	4:1	413.3 ± 17.39
5.0	5:1	417.0 ± 18.08
12.5	3:1	462.7 ± 11.24
12.5	4:1	456.7 ± 14.57
12.5	5:1	540.3 ± 26.31
20.0	3:1	462.0 ± 29.82
20.0	4:1	476.7 ± 32.15
20.0	5:1	456.7 ± 28.43
Control	-	701.4 ± 20.28

Table 6. Linear effect and its interaction of the drying time of cassava bagasse pretreated with OD.

Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Rep	2	3439	1719	4.7698	0.023727 *
Trat	8	38254	4782	13.2647	9.889×10^{-6} ***
LC	1	11451	11451	31.7651	3.718×10^{-5} ***
Cc	1	13067	13067	36.2474	1.782×10^{-5} ***
LSS	1	2863	2863	7.9413	0.012372 *
SSc	1	580	580	1.6094	0.222723
CL x LSS	1	56	56	0.1563	0.697834
CL x SSc	1	374	374	1.0369	0.323701
Cc x LSS	1	6188	6188	17.1669	0.000764 ***
Cc x SSc	1	3675	3675	10.1946	0.005662 **
Residuals	16	5768	360		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1; LC: linear osmotic agent concentration; Cc: quadratic osmotic agent concentration; LSS: linear solution-sample relationship; SSc: quadratic solution-sample ratio.

Table 6 shows the results of the orthogonal contrast test for the evaluation of the linear and quadratic effects of the studied factors and their significant interactions (p-value < 0.05) on the drying time of cassava bagasse when it was subject to a previous OD process.

With a 95% confidence level, the linear and quadratic effects of the used osmotic agent concentration were significant for the drying time. Similarly, the linear effect of the solution: sample relationship was significant. The interactions of the quadratic effects of the osmotic agent concentration due to the linear effect of the solution: sample ratio and the interaction of the quadratic effects of both studied factors were also significant.

From the significant effects, the mathematical model that explains the behavior of the response variable - drying time - was determined, based on the study factors. Applying the Akaike Information Criterion (Akaike Information Criterion) for simplification purposes and adjustment, the following equation 9 was obtained, corresponding to a second order model adjusted for the drying time, in which X_1 corresponds to the concentration of NaCl agent in the hypertonic solution, and X_2 is the solution: sample ratio (g solution: g sample) used in the assay.

$$\begin{aligned} Tdrying(min) = & -719.4815 + 293.3481X_1 \\ & + 612.2963X_2 - 159.1630X_1X_2 \\ & - 12.3437X_1^2 - 84.8889X_2^2 \\ & + 22.0444X_1X_2^2 + 6.7674X_1^2X_2 \\ & - 0.9333X_1^2X_2^2 \end{aligned} \quad (9)$$

Figure 3 illustrates the response surface corresponding to the model estimated for the drying time of cassava bagasse previously treated with an OD process.

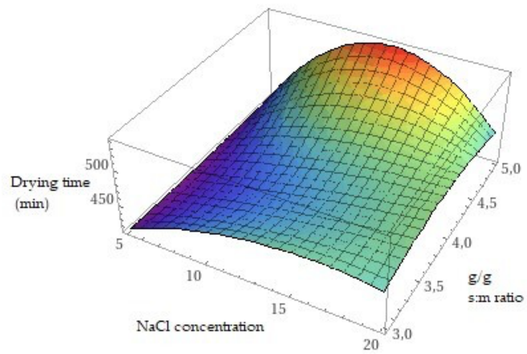

Figure 3. Response surface for cassava bagasse drying time with an OD pretreatment.

The obtained statistic R^2 estimation coefficient indicates that the model explains 80.6% of the drying time variable. This suggests that there are factors not considered by the model that may be affecting the response variable. Additionally, it can be influenced by the bagasse behavior before the process and drying conditions, presenting hardening or partial crust formation in some sample areas caused by the concentration of the used osmotic agent and drying temperature. All of the above, added to the effects of environmental conditions, and even the experimental error can affect these results to a certain extent (Martínez, 2005; Novales, 2010). Similar results were observed when treating *kosia* pear slices, even with a greater effect of the concentration of osmotic agent, to such an extent that when they worked with an osmotic concentration of 75 % sucrose, the drying time of the samples was even longer than the time that the control sample required (Taşova *et al.*, 2022; Domínguez-Niño *et al.*, 2021). This is due to the fact that the particles of the osmotic agent adhere to the sample surface, forming a layer that delays the mass transfer during the convective drying operation, resulting in a decrease in the effectiveness of the latter. It is also caused by the hardening or contraction of some areas, which prevent the water removal located in the central area of the samples and reduce the drying velocity (García-Noguera *et al*., 2010; Mendes *et al*., 2013; García *et al*., 2007).

The operating conditions that minimize the drying time of the cassava bagasse previously exposed to OD treatment, are achieved using a hypertonic solution with 5% NaCl and a solution: sample ratio of 3.582 g of solution/g of sample, conditions under which the lowest drying time corresponding to approximately 412.99 min is achieved. The optimal OD conditions as a pretreatment to cassava bagasse drying compared to the standard treatment, allowed an approximate reduction of 41.1 % for the drying time (412.99 min vs 701.4 min respectively) and 36.8% for the total drying time process when the pretreatment time with OD is included (447.99 min vs 701.4 min respectively).

The 41.1% reduction achieved in drying time is largely due to the previous treatment of OD in which a certain amount of the initial moisture content of the sample migrates towards the hypertonic solution, causing a consequent decrease in drying time. García *et al*. (2010), Moreira *et al*. (2011) and Massolo *et al*. (2020) achieved reductions of up to 25 % in drying time, after subjecting shoe snacks for 2h in 2 % w/v NaCl osmotic solutions. However, due to the duration of the pretreatment they did not observe a difference between the control and the total time of the combined methods. Similarly, it has been possible to reduce drying time by 42% and 10% in figs and *kosia* pear respectively (Andreou *et al*., 2021; Taşova *et al*., 2022).

Other authors optimized the convective drying process of cassava bagasse, obtaining optimal conditions of 50 °C and 3.4 m/s, taking 11 h to decrease its humidity from 88 % to 10 % (Salcedo-Mendoza *et al*., 2016), result comparable with the 701.4 min obtained in this study for the control treatment. Nonetheless, in this research, the obtained results after the OD application as a pretreatment to the drying of cassava bagasse, under the drying conditions of 40 °C and 1.5 m/s, show a reduction of the humidity of the cassava bagasse from 88 % down to 12 % in 412.99 min, which translates into a decrease in energy expenditure, an increase in process efficiency and a minimization of operating costs (Andreou *et al*., 2021). Application of DO-Drying has evidenced the obtaining of a potential source of dried cassava bagasse to be used in the different applications that have been given to it in different fields such as, the biotechnological, food, biomaterials, composting, and removal of pollutants in water sources (Keller *et al*., 2020, Liu *et al*., 2018; Vargas & Pérez, 2018; García *et al*., 2016).

Table 7 illustrates the kinetic models evaluated for the standard treatment (drying without OD pretreatment) and for the best treatment when OD is used as pretreatment to cassava bagasse drying, the constants estimated for each evaluated model, and the statistical adjustment parameters. All the evaluated models presented a good degree of adjustment, with a coefficient of determination R^2Adj greater than 0.98 and root mean square error (RMSE) values less than 0.07. However, the Wang and Singh model presents the best degree of adjustment, both for the standard treatment, and for the best treatment when OD is used as a pretreatment to cassava bagasse drying, with an R^2Adj of 0.9986 and 0.9982, respectively; and RMSE values of 0.01331 and 0.0141 respectively. These results are consistent with those reported by Salcedo-Mendoza *et al*., (2016) to explain moisture ratio behavior in the drying of cassava bagasse, coinciding also with the five kinetic models that best represent the cassava bagasse drying phenomenon without OD pretreatment, which in their order are, the Wang and Singh, Henderson and Modified Pabis, Approximate Diffusion, Page, and Logarithmic models, with values of R^2Adj >0.99 and RMSE < 0.023.

Unlike the above, the kinetic models that represent the cassava bagasse drying phenomenon when OD is used as pretreatment are in their order, the Wang and Singh, Approximate Diffusion, Logarithmic, and Page models, with values of R^2Adj > 0.99 and RMSE < 0.0235. In this case, the Henderson and modified Pabis kinetic model presented the worst degree of adjustment with R^2Adj of 0.9573 and RMSE of 0.06871. Despite the fact that the Wang and Singh model presents the best degree of adjustment, both for the standard treatment and for the best treatment when OD is used as a pretreatment to cassava bagasse drying, there are significant differences between parameters *a* and *b* which describe the model constants (p<0.05) of both treatments, which explains the difference found in drying time between those treatments.

Table 7. Drying kinetics models evaluated for cassava bagasse

Model	Parameters	Standard[1]	OD-Drying Tment[2]
Newton	k	0.2119	0.3422
MR= exp (-k t)	R^2adj	0.9821	0.9813
	RMSE	0.04786	0.04548
Two-term exponential	a	0.9507	0.9515
MR= exp(-kt) + 1(1-a) exp(-kat)	k	0.2249	0.3616

	R^2adj	0.9853	0.9842
	RMSE	0.04335	0.04178
Wang & Singh	a	-0.1570	-0.2561
MR= 1 + at + bt^2	b	0.006199	0.0167
	R^2adj	0.9986	0.9982
	RMSE	0.01331	0.0141
Approximate Diffusion	a	-13.6400	6.2900
MR = a exp(-kt) + 1(1-a)exp(-kbt)	b	0.9512	0.8571
	k	0.3949	0.1622
	R^2adj	0.9967	0.9969
	RMSE	0.02067	0.01843
Page	k	0.1364	0.2554
MR = exp(-kt^n)	n	1.2780	1.2570
	R^2adj	0.9965	0.9952
	RMSE	0.0211	0.02309
Modified Page	k	1.1030	0.3178
MR = exp(-kt)^n	n	0.1920	1.0770
	R^2adj	0.9816	0.9806
	RMSE	0.0485	0.04625
Henderson and Pabis	a	1.0490	1.0490
MR = a exp(-kt)	k	0.2244	0.3608
	R^2adj	0.9853	0.9842
	RMSE	0.04334	0.04177
Henderson and Modified Pabis	a	0.4799	20.4200
MR = a exp(-kt) + b exp(-gt) + c exp(-ht)	b	11.4000	-19.88
	c	-10.9000	0.5532
	g	0.3723	0.3615
	h	0.3953	0.8084
	k	0.3412	0.3560
	R^2adj	0.9968	0.9573
	RMSE	0.02025	0.06871
Logarithmic	a	1.1730	1.1980
MR = a exp(-kt) + c	c	-0.1557	-0.1870
	k	0.1622	0.2494
	R^2adj	0.9960	0.9966
	RMSE	0.02251	0.01945

[1]Just Drying without OD as pretreatment.

[2]OD-Drying treatment developed from operating conditions that minimize drying time (hypertonic solution with 5% NaCl and a solution: sample ratio of 3.582 g of solution/g of sample).

Equations 10 and 11 illustrate the model with the highest degree of adjustment for the standard treatment and the optimal treatment when OD is used as a pretreatment to cassava bagasse drying, respectively.

Wang and Singh Model, Tment (Standard) :

$$MR = 1 - 0.1507t + 0.006199t^2 \tag{10}$$

Wang and Singh Model, Tment (OD-Drying):

$$MR = 1 - 0.2561t + 0.0167t^2 \tag{11}$$

Figure 4 illustrates the experimental data and the adjustment curve according to the Wang and Singh model for the MR moisture loss ratio as a function of bagasse drying time with and without the application of OD as pretreatment. Differences can be observed in each case, both for drop in humidity ratio and for the drying times. The application of OD treatment as a pretreatment to the conventional drying of cassava bagasse generates a significant effect on the MR moisture loss ratio, affecting the efficiency of its drying process.

Figure 5-a shows the theoretical MR moisture ratio as a function of $[Dft/z^2]_{theor}$ for a flat sheet and Figure 5-b shows the experimental data of MR as a function of time cassava bagasse with and without OD as pretreatment.

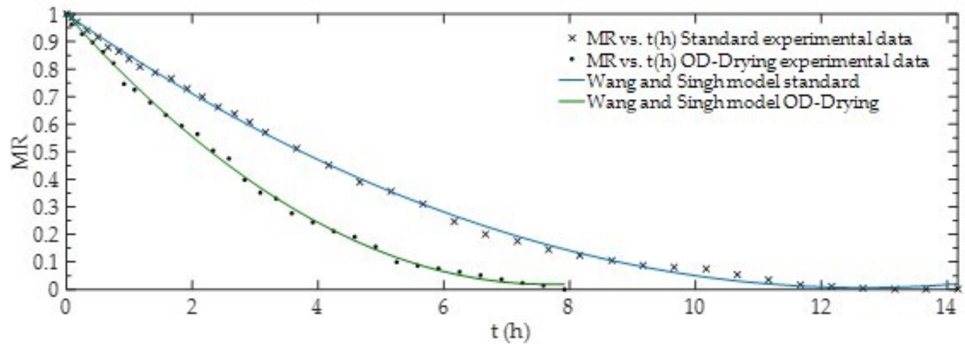

Figure 4. Moisture ratio (MR) vs. Time for cassava bagasse drying with and without OD as pretreatment, adjusted to the Wang and Singh model.

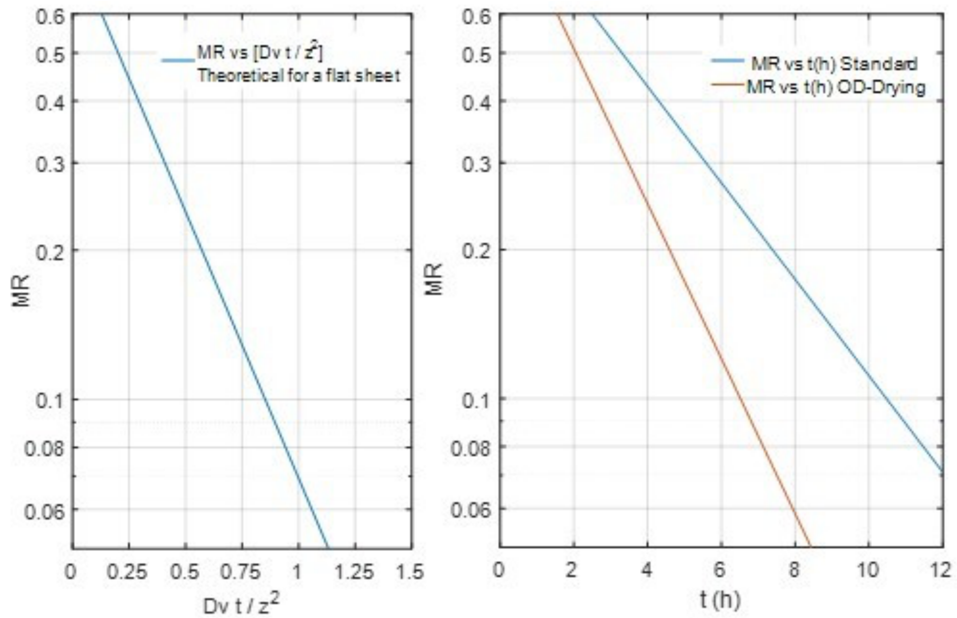

Figure 5. Moisture loss ratio MR (a) theoretical for a flat sheet; (b) according to experimental data of drying time in this research.

It was established that the average diffusivity of the standard treatment (dried without OD pretreatment) was 5.1068×10^{-10}m^2/s, a result higher than the diffusivity ranges from 2.5438×10^{-11} to 1.5027×10^{-10} m^2/s for cassava bagasse reported by Salcedo-Mendoza *et al*. (2016). When OD combined methods were applied as pretreatment to the convective drying of cassava bagasse, the diffusivity turned out to be 8.1731E-10 m/s, greater than the diffusivity when OD is not applied as pretreatment and greater than the diffusivity of cassava bagasse from 1.1381×10^{-10} - 2.6467×10^{-10} m^2/s reported by Contreras *et al*. (2016) when applying combined methods of mechanical pressing and drying, respectively. Figure 5-b shows the difference in the respective slopes for the MR moisture loss ratio as a time function, which is greater for the drying of cassava bagasse with an OD pretreatment, which leads to a greater diffusivity and explains the shorter drying time obtained for the cassava bagasse (412.99 min) when combined OD is applied as a pretreatment to convective drying, in relation to the drying time of the standard treatment (701.4 min) when OD is not applied as a pretreatment.

Table 8 describes the obtained results for drying cassava bagasse with and without OD as a pretreatment to convective drying. The values of the analyzed variables are contrasted with the results of cassava bagasse drying reported by Salcedo-Mendoza *et al*. (2016) and Contreras *et al*. (2016) by direct and combined drying respectively.

Finally, according to the obtained drying times for the OD-Drying treatment and the standard treatment (701.4 min-vs-412.99 min) and the characteristics of the drying equipment (ELECTTRONICA VENETA) used in this research, which consists of a fan of 300 W and 9 resistors of 300 W each, the energy saving was determined at 51.913,8 kJ when OD is applied

Table 8. Results of cassava bagasse drying by direct method and combined methods.

	Drying of cassava bagasse through direct method		Drying of cassava bagasse through combined methods	
Parameters	Drying with no OD (Standard)	Drying, according to Salcedo-Mendoza *et al*. (2016)	OD - Drying	Filtration - Pressing -Drying, according to Contreras *et al.* (2016)[1]
Initial humidity of the Cassava bagasse (%)	87.87	83.4	87.87	66.49
Temperature (°C)	40	50	40	60
Air velocity (m/s)	1.5	3.4	1.5	2.0
Drying time (h)	11.69	11	6.9	3.8
Final humidity (%)	12	10	12	10
% reduced humidity	86.3	88	86.3	84.96

[1] Results of themal drying after mechanical dehydration of filtration-pressing by applying a pressure of 17.24Mpa.

as a pretreatment to the convective drying of cassava bagasse compared to when cassava bagasse is dried without pretreatment with OD (74.338,2 kJ vs 126.252 kJ, respectively).

Conclusions

The kinetics of the drying process of cassava bagasse was significantly influenced by the factors 'concentration of osmotic agent and solution: sample ratio', and in their interaction for the moisture loss (WL), the solids gain (SG), and the cassava bagasse drying time.

The Wang and Singh Model satisfactorily described the experimental data of the drying process, with a greater degree of adjustment for the rate of moisture loss obtained when OD-Drying is used compared to only drying. This explains that when OD treatment is used as a pretreatment to cassava bagasse drying, the diffusivity turns out to be higher than the diffusivity when DO is not applied as a pretreatment. Indeed, OD application is a technically feasible alternative, either individually or as a pretreatment of the convective drying operation to reduce WL in cassava bagasse to at least 67.25% and 86.3 % of its initial humidity, respectively. It was observed that the higher the concentration of NaCl, a greater loss of water was achieved in the bagasse sample. In the OD of cassava bagasse, the optimal conditions to maximize water loss were obtained with a concentration of 56.9 % NaCl and a solution/sample ratio of 4.8:1 g of solution/g sample. Similarly, the use of OD as pretreatment of the traditional method of thermal drying, decreased process time and drying time of cassava bagasse by 36.8 and 41.1%, respectively, which means a decrease in energy and economic expenditure of the process. Whereas, when OD is used prior to thermal drying, the optimal conditions to minimize drying time were achieved with a 5% NaCl concentration and a solution: sample ratio of 3.582 g of solution/g sample.

With the osmotic dehydration of cassava bagasse carried out from concentrations of osmotic agent between 30% and 60% salt, a product of intermediate humidity is obtained that can be used in animal feed, especially cattle, which does not have salt restrictions in their diet. The results of this study provide reference elements for the osmotic dehydration of other organic waste that use salt as an osmotic agent and its subsequent drying.

This research provides operating parameters for an integrated process from OD to convective drying for the recovery and use of agroindustrial residues, and the development of sustainable alternatives for the management of agroindustrial residues with high moisture content. It also opens a research agenda in the application field of alternative dehydration techniques to improve the efficiency of the waste drying process, with the purpose of increasing the post-industrial value in similar agroindustrial residues and encouraging the drive of the starch industry towards a sustainable agroindustry.

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Nomenclature

OD	osmotic dehydration
OD-Drying	osmotic dehydration as a pretreatment to convective drying
C	moisture concentration
t	time
D, Df, Dv	diffusion coefficient
z	characteristic dimension

TC	percentage of total carbohydrate
H	moisture
G	fat
Ce	ash
F	crude fiber
Pc	protein
WL	moisture loss
SG	solid gain
MR	moisture loss ratio
AIC	Akaike Information Criterion
X_1	NaCl concentration percentage, %
X_2	solution: sample ratio, (g solution / g sample)
a, b,c,g,h,k,n	constants estimated

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