

Modeling Desorption Isotherms of Four Onion Varieties Related to Temperatures

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How to cite this paper: Beye, N.F., Kane, C., Kane, A., Vodounnou, F.N.S., Ayessou, N.C., Sene, A. and Diop, C.M. (2025) Modeling Desorption Isotherms of Four Onion Varieties Related to Temperatures. *Food and Nutrition Sciences*, **16**, 1332-1346.

<https://doi.org/10.4236/fns.2025.169076>

Received: July 23, 2025

Accepted: September 23, 2025

Published: September 26, 2025

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Abstract

The sorption isotherm is useful for predicting changes in product stability and the choice of packaging. Therefore, this study aims to establish the desorption isotherm model of the Galmi Violet, Safari, Gandiol F1, and Orient F1 onion varieties related to temperature. The gravimetric method using saturated salt solutions was implemented to determine the desorption isotherms, whose modeling, based on empirical mathematical models, was carried out with MATLAB software 6.0.0 using the least squares method. The results show that the isotherms obtained are of type II. The equilibrium moisture content (X_{eq}) decreases with increasing temperature, but the effect is smaller at the end of desorption for water activity values < 0.2 and $X_{eq} < 1$ kg/kg db (Galmi Violet and Gandiol F1), < 0.7 kg/kg db (Safari and Orient F1), and < 0.4 kg/kg db (their mixture). It's also shown that the Henderson model provided the best overall fit for all varieties and their mixture (R^2 between 0.97 and 0.99, χ^2 between 0.0016 and 0.0079), though other models also performed better for specific varieties: the Oswin model was the best for Galmi Violet (R^2 : 0.9915 and χ^2 : 0.0020) and the Peleg model was more suitable for Orient F1 (R^2 : 0.9956 and χ^2 : 0.0023). Furthermore, the desorption isotherm of the onion mixture closely resembled that of Safari between 50°C and 60°C, and Gandiol F1 at 65°C. These findings suggest that drying and storage strategies for the mixture could be optimized based on these two varieties. Thus, model selection should consider both the specific variety and the intended use (individual or mixed).

Keywords

Modeling, Desorption Isotherm, *Allium cepa* L.

1. Introduction

Onion consumption, estimated at around 13 kg/person/year, puts Senegal in second place among onion-consuming countries in West Africa, behind Niger (16 kg/person/year) [1]. However, despite record production of 435,000 tons in 2021 [2], satisfying annual household demand still depends on imports. The reasons for this dependence are the significant post-harvest losses (5% to 10% in the field, 20%, and up to 40% respectively for three and six months of storage) linked to the onions' high moisture content, which varies between 80% and 95% depending on the variety. To overcome this dependence, some players are looking into the possibility of processing bulbs to increase shelf life [3]. This improvement in food preservation involves the partial or total inhibition, or even destruction, of degradation mechanisms dependent on water content, particularly its availability.

Various methods of stabilizing foodstuffs by reducing moisture content and lowering water activity are currently available. Among these recognized techniques, the oldest is dehydration, which consumes a great deal of energy and requires a certain amount of expertise [4] [5]. Consequently, the determination of the sorption isotherm, translating the correlation between moisture content and water activity, is of interest both thermodynamically (knowledge of sorption enthalpies and types of water binding) and technologically (better control of drying and prevention of certain deleterious effects during storage of products after drying, such as sticking and mass-setting), in order to predict the equilibrium moisture content of products at the end of drying and control their valorization by dehydration [6]-[8]. Among the many previous works on the modeling of sorption isotherms for various food products found in the literature, the following can be cited:

- ❖ [9] established, in Alberta, adsorption and desorption isotherms for yellow onion at 10°C, 30°C, and 45°C. The model validated is that of Brunauer-Emmett-Teller (BET).
- ❖ [10] determined the isotherms of potato, carrot, pepper, tomato, and onion (85% mf) in the water activity range of 10% to 90%, at temperatures of 30°C, 45°C, and 60°C, and equilibrium moisture content (X_{eq}) values between 10% and 30% db. The Guggenheim-Anderson-Boer (GAB) model was validated for all samples.
- ❖ [11] determined isotherms for tomato and white onion at 30°C, 40°C, and 50°C and RH 15% - 85%. The models validated for tomato and onion are Henderson-modified and Halsey-modified, respectively.
- ❖ [12] has shown that the Oswin model best describes the desorption isotherms for temperatures of 25°C and 30°C - 70°C in 10°C steps.
- ❖ [13] has shown that the GAB model better describes the desorption isotherm at 25°C.

In the literature, research results on sorption isotherm modeling of onion and other foods all lead to different models depending on product characteristics [14]. The lack of data on local varieties and the importance of desorption isotherms in

the control of the drying process and in the design of dryers justify the initiation of the present research work. The aim of this work is to establish desorption isotherms at different temperatures for each of the four onion varieties grown in Senegal, as well as for a mixture of the four, and to model these isotherms.

2. Material and Methods

2.1. Material

Plant Material

The onion varieties on which isotherms were determined were Violet of Galmi, Safari, Gandiol F1, and Orient F1. They came from the RAO cooperative in the Saint-Louis region of Senegal. The onions were collected directly from the field and transported to the laboratory to avoid any source of mixing with other varieties. The initial moisture content (% wet basis) and water activity of the four varieties were as follows:

- Violet of Galmi: $85.56 \pm 0.60/0.945 \pm 0.01$;
- Safari $88.11 \pm 0.61/0.950 \pm 0.001$;
- Gandiol F1: $86.99 \pm 0.10/0.940 \pm 0.001$;
- Orient F1: $89.13 \pm 0.69/0.947 \pm 0.009$.

Drying and Analysis Equipment

- The drying and analysis equipment used to determine isotherms is:
- An oven with an accuracy of 0.1°C ;
- An a_w meter (Rotronic HP 23);
- A thermo-hygrometer;
- A precision balance;
- Pyrex capsules, glass jars with hermetic lids, and laboratory glassware;
- Saturated salts.

Statistical Analysis and Modeling Tools

The various IT tools used for statistical analysis and modeling are:

- R software version 3.4.0 for measurement concordance tests and variance analyses;
- MATLAB software version 6.0.0 for mathematical modeling of desorption isotherms at different temperatures and resolution of the different models used to calculate R^2 and χ^2 . The least-squares method was programmed in MATLAB.

2.2. Methods

Study of Desorption Isotherms

The desorption isotherms of onion varieties (Violet of Galmi, Safari, Gandiol F1, and Orient F1, grown in Senegal), taken separately, and of the varieties' mixture, are determined gravimetrically in an oven with temperature and relative humidity control. Three randomly selected onion bulbs are peeled, washed with 100 ppm chlorinated water, rinsed three times with clear water, wrung out, and chopped with a mincer (thickness of around 1.7 mm). From the prepared bulbs, the test sample consists of ten grams (10 g of the same variety for separate monitoring and 2.5

g of each variety for the mixture). The onion samples taken are placed in dishes above seven saturated salt solutions with known water activities at different temperatures. For temperatures between 50 °C and 70 °C, the salt solutions used have water activity values between 0.05 and 0.96, enabling equilibrium relative moisture to be controlled (Table 1).

Table 1. Water activity at different temperatures of saturated salts used to establish the desorption isotherms of the onion varieties (Violet of Galmi, Safari, Gandiol F1, and Orient F1) separately and in their mixture.

Nature of salt	Water activity (a_w) of saturated salts used at different temperatures				
	50 °C	55 °C	60 °C	65 °C	70 °C
LiBr	0.055	0.054	0.053	0.053	0.052
KOH	0.057	0.056	0.055	0.054	0.053
MgCl ₂	0.305	0.299	0.293	0.285	0.278
K ₂ CO ₃	0.41		0.39		0.37
NaNO ₃	0.690		0.67		0.65
NaCl	0.744	0.744	0.745	0.747	0.751
KCl	0.812	0.807	0.803	0.799	0.795
BaCl ₂	0.88		0.87		0.86
K ₂ SO ₄	0.958	0.957	0.957	0.957	0.957

This less expensive static gravimetric method is the most widely used [9] [10] [15]-[17]. Experiments are carried out in triplicate without ventilation over a temperature range from 50 °C to 70 °C, with a step of +5 °C. The dishes are weighed three times a day at regular intervals until equilibrium is reached. The constant weight at this point corresponds to the wet mass (X_h) of the samples. After measuring water activity on the dried samples, their dry mass (X_s) is determined by drying at 105 °C for 2 hours. Moisture content and water activity are measured using the reference methods NF ISO 712:2009 and NF EN ISO 17025, respectively. The equilibrium moisture content (X_{eq} in kg·H₂O·kg⁻¹ db) is calculated according to the formula:

$$X_{eq} = \frac{X_h - X_s}{X_s} \quad (1)$$

Desorption isotherms (for onion varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1, taken separately, and their mixture) at temperatures of 50, 55, 60, and 65 °C are obtained by plotting equilibrium content curves (X_{eq} in kg·H₂O per kg d.b.) as a function of water activity.

The evaluation of the reproducibility and the repeatability of the measurements is made by the numerical method, which is the LIN coefficient. Lin's concordance coefficient varies between -1 and 1, where the values -1, 0, and +1, respectively, mean perfect discordance, zero concordance, and perfect match.

The Student's t-test is used for comparisons between varieties and within the same

variety at different temperatures.

Isotherm Modeling of the Onion Varieties (Violet of Galmi, Safari, Gandiol F1, and Orient F1) and Their Mixture at Different Temperatures

Eleven empirical mathematical models are tested to model desorption of isotherms at different temperatures for the four onion varieties, taken separately, and their mixture. The models used are Langmuir [18], Brunauer-Emmett-Teller (BET) [13], Henderson [12] [19], Halsey [12], Iglesias-Chirife [20], Oswin [12] [19], Caurie [12], Smith [21], Peleg [22], and Chung-Pfost [19]. Equations are presented in **Table 2**.

Table 2. Mathematical models tested and their equations.

Model name	Model equation	Area of a_w Validity
Langmuir	$X_{eq} = 1/(A + Ba_w^{C-1})$	Complete curve
Brunauer-Emmett-Teller (BET)	$X_m Ca_w / [(1 - a_w) * (1 - a_w + Ca_w)]$	0 - 0.45
Guggenheim-Anderson-Boer (GAB)	$X_m CKa_w / [(1 - Ka_w) * (1 - Ka_w + Ca_w)]$	0 - 0.93
Halsey	$X_{eq} = (B/\ln a_w)^{1/A}$	0.10 - 0.80
Henderson	$X_{eq} = [-\ln(1 - a_w)/B]^{1/A}$	Complete curve
Iglesias & Chirife	$X_{eq} = A + B[a_w/(1 - a_w)]$	0.10 - 0.80
Oswin	$X_{eq} = A[a_w/(1 - a_w)]^B$	Complete curve
Caurie	$X_{eq} = A \exp(-Ba_w)$	0 - 0.85
Smith	$X_{eq} = C_1 - C_2 \ln(1 - a_w)$	Complete curve
Peleg	$X_{eq} = K_1 a_w^{n_1} + K_2 a_w^{n_2}$	Complete curve
Chung-Pfost	$X_{eq} = 1/A_1 * (-\ln a_w / A_2)$	

The least squares method is used to determine the best model. The statistical parameters are R^2 , which must be close to 1, and χ^2 , which must be close to 0, for the best model with:

$$X^2 = \frac{\sum_{i=1}^n (X_{eq \text{ pred},i} - \bar{X}_{eq \text{ pred}})^2}{\sum_{i=1}^n (X_{eq \text{ exp},i} - \bar{X}_{eq \text{ exp}})^2} \quad (2)$$

$$\chi^2 = \frac{\sum_{i=1}^n (X_{eq \text{ exp},i} - X_{eq \text{ pred},i})^2}{n - N} \quad (3)$$

where N is the number of parameters for each model, and n is the number of experimental points.

3. Results and Discussion

Lin's coefficients between 0.997355 and 0.999817 for the concordance test of equilibrium moisture content and water activity measurements reveal a perfect agreement between the measurements carried out.

3.1. Determination of Desorption Isotherms for the Onion Varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1

The evolution of equilibrium moisture content (calculated from Equation (1)) as a function of water activity reflects the fact that the desorption isotherms of the four onion varieties are virtually identical. The equilibrium moisture content and water activity values shown are mean values of the three measurements carried out, with standard deviations ranging from 0.0028 to 0.0047 and from 0.002 to 0.005, respectively.

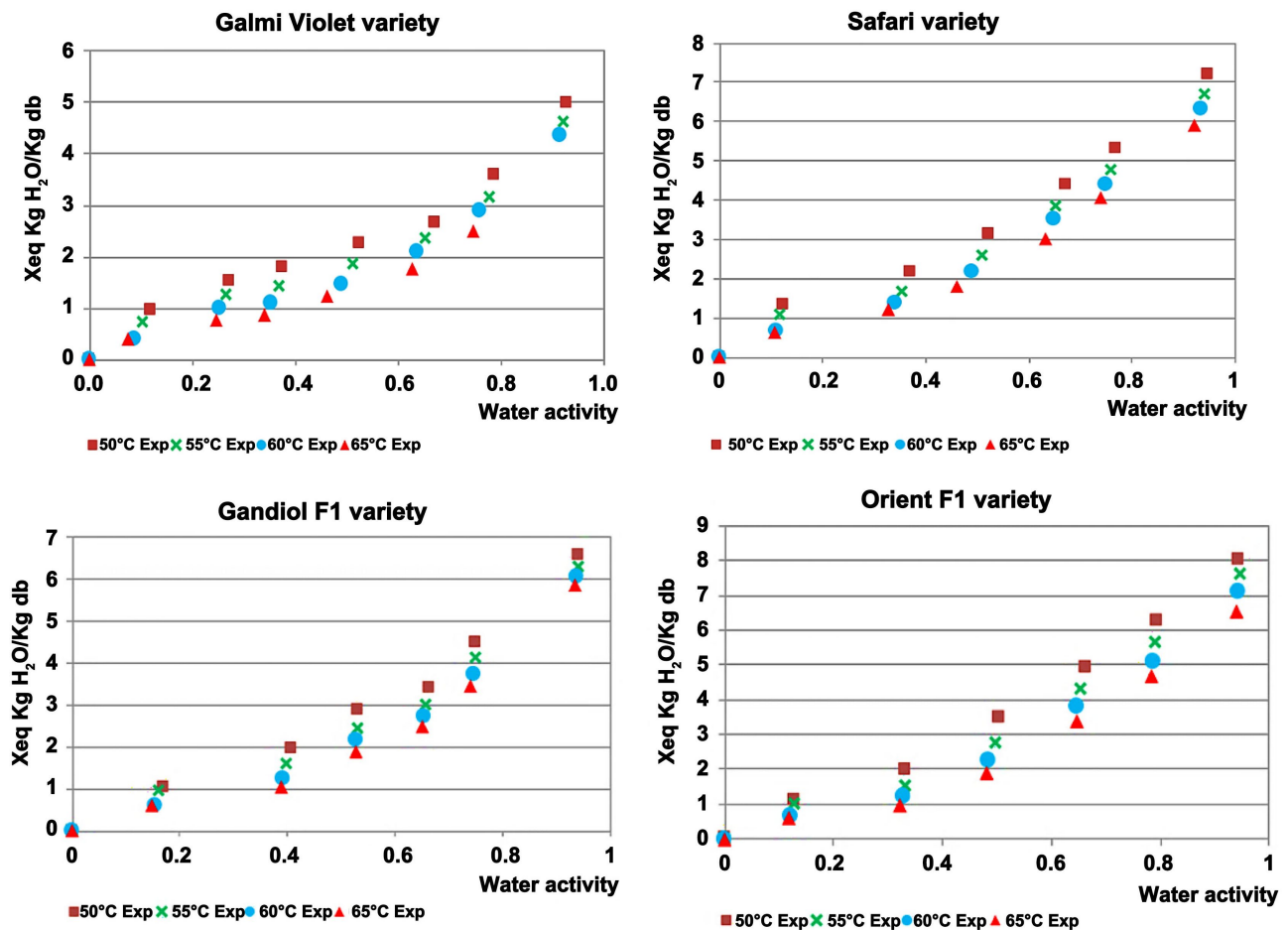


Figure 1. Desorption isotherms of the onion varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1 at temperatures of 50°C, 55°C, 60°C, and 65°C.

Both within and between varieties, tests comparing the average equilibrium moisture content at different temperatures show no significant differences (p-values > 5%).

Desorption isotherms for the onion varieties: Violet of Galmi, Safari, Gandiol F1 and Orient F1, established at 50°C, 55°C, 60°C and 65°C (Figure 1), show that, at constant temperature, the lower the equilibrium water content, the lower the water activity. This is due to the fact that the more desorption proceeds at constant temperature, the more water is bound to onion constituents. Increasing tempera-

ture leads to a decrease in equilibrium moisture content for fixed water activity values. This effect of temperature is explained by the increased agitation of water molecules, facilitating desorption. This has also been demonstrated by previous work on numerous food products, such as lemon citron [23], spearmint [16], pumpkin [24], garlic [25] and different varieties of onion [10] [11] [13] [26].

Furthermore, at identical temperatures, the decrease in equilibrium moisture content is more pronounced for Orient F1, followed by Gandiol F1, Safari, and Violet of Galmi. The impact of variety on isotherms is linked to differences in dry matter content (14.44%, 11.89%, 13.01%, and 10.87%, respectively, for Violet of Galmi, Safari, Gandiol F1, and Orient F1). Indeed, the higher the dry matter content, the more hydrogen bonds there are, slowing down desorption. However, an exception was noted between Gandiol F1 and Safari, due to the presence of soluble compounds such as sugars, which are probably more important in Safari, slowing down desorption compared with Gandiol F1 [14]. As shown by [27], the influence of the variety on desorption isotherms is more marked for a_w above 0.6.

3.2. Modeling Desorption Isotherms for the Onion Varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1

Of the eleven mathematical models tested, only four (Table 3) are presented for the selection of the best model, as the other seven (BET, GAB, Halsey, Iglesias-Chirfie, Caurie, Smith, and Chung-Pfost) have mean R^2 values below 0.6 for all temperatures combined.

Table 3. Statistical parameters determined with the different models tested for modeling the desorption isotherms of the onion varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1.

Model	Varieties							
	Violet of Galmi		Safari		Gandiol F1		Orient F1	
	Average statistical parameters							
	R^2	χ^2	R^2	χ^2	R^2	χ^2	R^2	χ^2
Henderson	0.9903	0.0016	0.9922	0.0079	0.9940	0.0017	0.9799	0.0292
Oswin	0.9915	0.0020	0.9644	0.0319	0.9848	0.0121	0.9381	0.0786
Peleg	0.9509	0.0283	0.9876	0.0079	0.9585	0.0151	0.9956	0.0023
Langmuir	0.9737	0.0104	0.9444	0.0086	0.7841	0.5399	0.9276	0.0218

The mean R^2 and mean χ^2 values (Table 3) obtained with the different models show that, whatever the temperature, the best models are Henderson for the Safari and Gandiol F1 varieties, Oswin for the Violet of Galmi, and Peleg for the Orient F1 variety. The comparison between the R^2 of the Henderson and Oswin models tested on the Violet of Galmi variety shows a non-significant difference, with a p-value (0.67) > 5%, while that between the R^2 of the Henderson and Peleg models on the Orient F1 variety reveals a significant difference, with a p-value (4.94×10^{-5}) < 5%. Despite this significant difference, the Henderson model (R^2 of 0.9799,

close to 1) can also be retained as the best model for the Orient F1 variety. Thus, only the Henderson, Oswin, and Peleg models achieve less dispersion and a better fit, with R^2 values between 0.97 and 0.99 and χ^2 values between 0.0016 and 0.029, respectively (Table 3). The Henderson model describes the isotherms of all four varieties well, while the other two do not fit all of them (Oswin model for the Violet of Galmi and Gandiol F1 varieties, and the Peleg model for the Safari and Orient F1 varieties).

This model differs from those found in the literature on modeling onion isotherms [9]-[13] [26]. This difference corroborates the importance of cultivation practices, variety, shape, and size on isotherms [14] [15] [27]. However, the sigmoidal shape of the four onion varieties' isotherms (Figure 2) studied in our experiments is identical to that of the isotherms of several food products. The different zones observed are [17]:

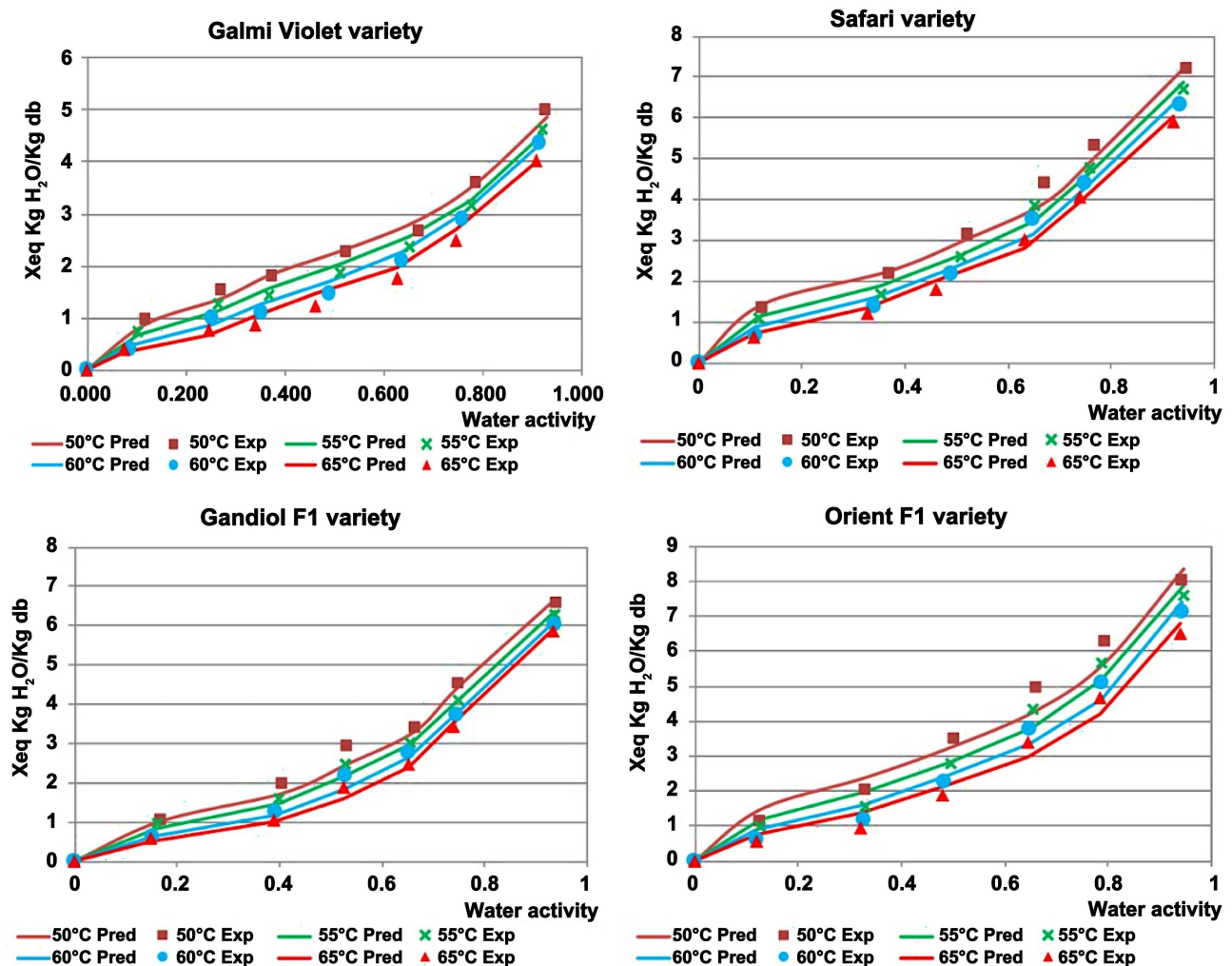


Figure 2. Experimental and predicted desorption isotherms with the best Henderson model for the onion varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1.

- Zone 1: $a_w < 0.2$, monolayer with hydrogen bonding between water molecules

and polar groups of onion constituents;

- Zone 2: $0.2 < a_w < 0.65$, poly-molecular layer linked to the monolayer by hydrogen bonds;
- Zone 3: $a_w > 0.65$: water molecules are easily held in the spaces between the various constituents by Van der Waals bonds, weaker than hydrogen bonds [26] [28].

The equation of the Henderson model, which provides less dispersion and a better fit with experimental data, is:

$$X_{eq} = \left[-\ln(1 - a_w) / B \right]^{1/A} \quad (4)$$

The modeling of desorption isotherms at temperatures of 50°C, 55°C, 60°C, and 65°C with the best Henderson model is shown in **Figure 2**.

Whatever the desorption temperature, the curves in **Figure 2** show an almost perfect match between experimental equilibrium moisture contents and those predicted by the Henderson model.

For all combined temperatures and varieties, the average equilibrium time is between 9 and 13 days.

The desorption isotherms predicted with the Henderson model reflect that, for fixed equilibrium moisture contents, each 5°C increase in temperature leads to an increase in water activity. However, an exception is observed with equilibrium moisture contents < 1 kg water/kg db (for the varieties: Violet of Galmi and Gandiol F1) and < 0.7 kg water/kg db (for the varieties Safari and Orient F1). For these low equilibrium moisture contents, water activity is identical regardless of the desorption temperature. The Henderson model parameters (**Table 4**) show that *B* parameter values increase with temperature, whereas *A* parameter values decrease for all four varieties.

Table 4. Henderson model parameters for the onion varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1.

Temperature (°C)	Varieties							
	Violet of Galmi		Safari		Gandiol F1		Orient F1	
	Henderson model Parameters							
	<i>B</i>	<i>A</i>	<i>B</i>	<i>A</i>	<i>B</i>	<i>A</i>	<i>B</i>	<i>A</i>
50	0.178	1.705	0.093	1.736	0.166	1.491	0.091	1.635
55	0.256	1.523	0.142	1.547	0.219	1.372	0.136	1.482
60	0.367	1.302	0.196	1.401	0.301	1.218	0.198	1.337
65	0.468	1.175	0.249	1.292	0.365	1.124	0.245	1.275

The parameters of the Henderson model evolve linearly with temperature. With each 5°C step increase in temperature, the *B* parameter of the Violet of Galmi variety, which is the highest, rises faster (on average +0.097), followed by that of the Gandiol F1 variety (on average +0.067), while those of the lower Safari and Orient F1 varieties are virtually identical (on average +0.052). As for parameter *A*, those

of the Violet of Galmi, Safari, and Orient F1 varieties, which are almost identical, are higher than those of the Gandiol F1 variety, with decreases of -0.177 , -0.148 , -0.120 , and -0.122 , respectively. However, from one variety to another, there was no significant difference between the evolution of the B and A parameters as a function of temperature (p -values $> 5\%$).

3.3. Determination and Modeling of Desorption Isotherms for a Mixture of the Four Onion Varieties: Violet of Galmi, Safari, Gandiol F1, and Orient F1

According to the work on drying kinetics modeling [29], the variety Violet of Galmi, with the slowest reduced drying speed across all temperatures, is the limiting variety for drying the four varieties' mixture. To this end, the two best models (Henderson, followed by the Oswin model) of the Violet of Galmi variety were tested on desorption isotherm data from the four varieties' mixture. The statistical parameters are shown in Table 5.

Table 5. Statistical parameters determined with the Henderson and Oswin models tested for the modeling of the four onion varieties mixture desorption isotherms.

Model	Mixture of Violet of Galmi, Safari Gandiol F1, and Orient F1 varieties	
	Average statistical parameters	
	R^2	χ^2
Henderson	0.9930	0.0363
Oswin	0.9676	0.1284

Table 5 shows that the Henderson model, with mean R^2 and mean χ^2 values of 0.9930 and 0.0363, respectively, is the best model for the mixture of the four varieties.

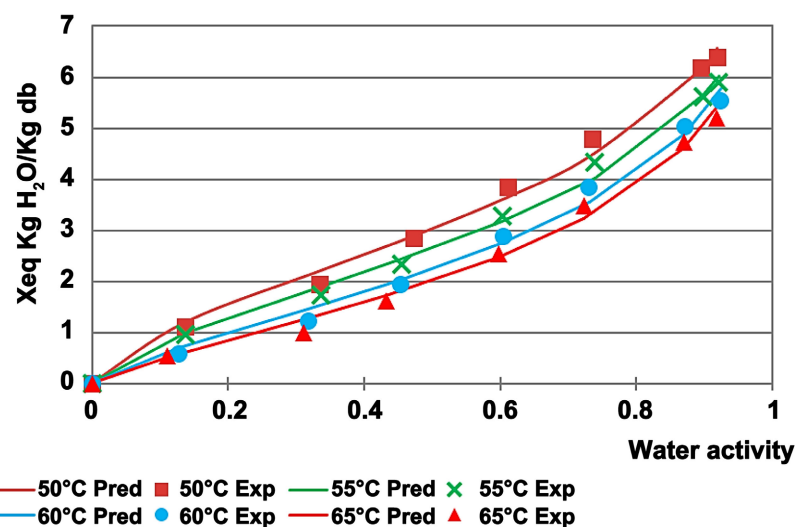


Figure 3. Experimental desorption isotherms and those predicted with the best Henderson model for the four onion varieties mixture.

Experimental desorption isotherms for the four-variety mixture at temperatures of 50 °C, 55 °C, 60 °C and 65 °C and those predicted by modeling with the best Henderson model are shown in **Figure 3**. These desorption isotherms for the mixture of the four varieties, compared with those for the varieties taken separately (**Figure 2**), reflect a fairly similar trend. Furthermore, tests comparing mean equilibrium moisture contents at different temperatures between the mixture and the separate varieties reveal no significant difference (p -value > 5%).

As observed for individual varieties (**Figure 1**), as temperature increases, equilibrium moisture content and water activity decrease for the four-variety mixture (**Figure 3**).

It can be seen from the predicted isotherms that, for fixed equilibrium moisture contents, each 5 °C step increase in temperature leads to an increase in water activity in the mixture of the four onion varieties, except for equilibrium moisture contents < 0.4 kg water/kg db. The Henderson model parameters for the mixture of the four onion varieties are shown in **Table 6**.

Table 6. Henderson model parameters for the mixture of the four onion varieties (Violet of Galmi, Safari, Gandiol F1, and Orient F1) at different temperatures.

Temperature (°C)	Mixture of Violet of Galmi, Safari Gandiol F1, and Orient F1 varieties	
	Henderson model parameters	
	<i>B</i>	<i>A</i>
50	0.1095	1.6639
55	0.1482	1.5819
60	0.2258	1.3882
65	0.2794	1.3011

The evolution of the *A* and *B* parameters of the mixture of four onion varieties as a function of temperature is similar to that of the individual varieties. In fact, the *B* parameter increases with temperature, while the opposite is observed for *A*. With each 5 °C step increase in temperature, the *B* parameter increases on average by +0.057, and the *A* parameter decreases by -0.121.

According to **Figure 3** and **Table 6**, it appears that the desorption isotherms of the four onion varieties mixture between 50 °C and 60 °C are closer to those of the Safari variety ($p < 5\%$). This can be attributed to the compositional dominance of the Safari variety within this temperature range. The Safari variety exhibits a water retention capacity and desorption dynamics that are shared, or largely dominated, by the mixture at these temperatures. Specifically, Safari has unique cell wall structures and hygroscopic properties that facilitate relatively higher water retention at moderate temperatures. This explains why, as the temperature increases within this range, the mixture tends to follow a similar moisture content and water activity pattern as Safari. Additionally, a water balance between the Violet of Galmi and Orient F1 varieties could also explain why the moisture content and dry matter values

of the four onion varieties mixture tend towards those of the Safari variety between 50°C and 60°C.

At 65°C, the elimination of water leads to an increase in dry matter for the four onion varieties mixture, which becomes similar to that of Gandiol F1. In fact, a significant difference ($p > 5\%$) was observed between the predicted moisture contents of the four onion varieties mixture and those of Orient F1 and Violet of Galmi at different temperatures. This situation can be attributed to a more pronounced water elimination at higher temperatures. The Gandiol F1 variety, known for its resistance to dehydration and its ability to maintain dry matter at elevated temperatures, likely influences the behavior of the mixture at 65°C. At this higher temperature, the water retention properties of the other varieties become less significant, and the mixture's behavior aligns more closely with that of Gandiol F1, which shows greater stability in dry matter and moisture content at 65°C. The observed increase in dry matter and decrease in moisture content at this temperature are therefore a direct result of this transition.

4. Conclusions

This study investigated the desorption isotherms of four onion varieties, which are Violet of Galmi, Safari, Gandiol F1, Orient F1 and their mixture. All the varieties followed sigmoidal type II behavior, with both temperature and variety influencing the equilibrium moisture content (X_{eq}) and water activity (a_w). As temperature increased, X_{eq} decreased at a fixed a_w , while a_w increased for the same moisture content, which can lead to quality degradation. The most significant decrease in X_{eq} was observed for Orient F1 ($X_{eq} < 0.7$ kg/kg db at 65°C), followed by Gandiol F1 and Safari ($X_{eq} < 0.7$ kg/kg db), and Violet of Galmi ($X_{eq} < 1$ kg/kg db). For the mixture of the four varieties, the desorption isotherms closely resembled those of the individual varieties, with temperature having a similar impact. However, the effect of temperature on a_w and X_{eq} was less pronounced at the end of desorption ($a_w < 0.2$; $X_{eq} < 1$ kg/kg db for Violet of Galmi and Gandiol F1, 0.7 kg/kg db for Safari and Orient F1, and < 0.4 kg of water/kg db for the mixture). These results show that Safari and Gandiol F1 primarily control the desorption behavior of the mixture at 50°C, 60°C and 65°C, respectively.

The use of the Henderson model to describe the desorption isotherms allows to predict the behavior of all varieties and their mixture during industrial-level's drying. By accurately predicting the desorption behavior across different temperatures, onion producers in Senegal could adjust drying protocols to maximize efficiency while minimizing energy consumption. Furthermore, understanding the specific temperature ranges where different varieties dominate the desorption behavior, such as Safari at 50°C - 60°C and Gandiol F1 at 65°C, could help adapt drying strategies to maintain quality and prevent excessive loss of moisture or degradation of water activity.

The practical implications of these findings extend beyond drying optimization. By applying the Henderson model to predict moisture content and water activity

dynamics, storage stability for onions can also be improved. In these conditions, producers can extend the shelf life of onions, reducing post-harvest losses, improving marketability, and enhancing both the economic stability of farmers and the availability of quality produce in local markets.

Acknowledgements

The authors thank the Center for Studies on Food Safety and Functional Molecules (CESAM-RESCIF) and the Laboratory of Water, Energy, Environment, and Industrial Processes (L3EPI) of the Polytechnic School (ESP) in Dakar for technical support during this research.

Authors' Contributions

Ngoné Fall Beye: Conceptualization, methodology, investigation, supervision, writing—original draft, writing—review and editing, validation, and data curation. Cheikhou Kane: Writing—original draft, statistical analyses and editing, and data curation. Alé Kane: Writing—original draft and editing. Francisca Nadège Sètonджи Vodounnou: Investigation, writing—original draft, and writing—review. Nicolas Cyrille Ayessou: Resources and supervision. Abdou Sene: Statistical analyses. Codou Mar Diop: Resources and supervision.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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