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ORIGINAL RESEARCH ARTICLE

The effect of water activity and temperature on the water content during the preservation of dates "MAJHOUL variety"

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ABSTRACT

Several parameters, including temperature, water activity and water content, play a crucial role in maintaining food quality over time. Temperature control during the preservation process is essential to inhibit the growth of unwanted microorganisms while avoiding the degradation of nutrient and aromatic compounds. Proper storage conditions help to prolong the life of food. The main objective of this study is to optimize the preservation process of dates to maintain their quality, including organoleptic quality and nutritional characteristics, by examining the influence of temperature, water activity on water content. The research aims to determine how these parameters influence the quality of dates. In this perspective, an uncoded unit regression equation of water content, temperature and water activity was developed. The model is more meaningful and has a better predictive capacity for new observations. Water activity is the main characteristic influenced, followed by temperature. Specifically, increasing water activity increases water content, while increasing temperature reduces water content.

Keywords: Date; water activity; water content; temperature

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1. Introduction

Despite significant advancements in modern biotechnology facilitating substantial growth in date production, the processing industries for dates in Arab countries, particularly in the Arabian Gulf nations, have not progressed at the same rate. This presents a notable disparity between the production capabilities and processing infrastructure of the date palm industry. There is significant untapped potential in both fresh dates and their derivatives, which could offer improved quality characteristics[1]. The harvest of dates in Morocco, reaching about one hundred thousand tons per year in good times, plays a significant role in income generation, contributing 40 to 60% for nearly 2 million people living in oases. Nonetheless, challenges persist in date production regarding optimal harvesting practices, post-harvest treatments, conservation efforts, and storage methods. The condition of the water is a critical factor in the process of preserving food[2]. The outcome of preserved food items is influenced by various elements like the amount of moisture, the movement of moisture, and the absorption of water by the food substance during storage. Determining the water absorption or release by a food item relies on both the water vapor pressure within the food sample and its surrounding environment. The point at which the moisture level in the food aligns with the water vapor pressure in the environment is termed the equilibrium moisture content. The correlation between Equilibrium Moisture Content and relative humidity at a consistent temperature is depicted by the humidity sorption isotherm. Water activity (a_w) and the glass transition temperature serve as crucial indicators for estimating the water content in food and determining the solid state of food products. Water activity is defined as the ratio of water vapour pressure in a food to pure water vapour pressure at the same temperature. The concept of water activity has been integrated by food regulators to establish safety regulations regarding the growth of undesirable microorganisms, food risk definitions, critical control points, standards for various preserved foods and packaging requirements[1].

Many isotherm models with varying parameters have been developed and applied across a wide range of industrial separation processes via adsorption, including oil and gas refineries, food processing, and wastewater treatment industries[3].Understanding water activity is of significant importance in the field of food technology. Indeed, the thermodynamic activity of water influences the speed and intensity of chemical reactions (such as oxidation and Maillard reaction), enzymatic reactions, micro-physiology and development organisms, while modifying most rheological, mechanical and organoleptic properties of food products. In the context of a storage or preservation operation, the isotherm plays a crucial role in indicating the hygroscopic nature of a product. This allows to anticipate the impact of changes in relative humidity in the storage environment on the hygroscopic stability of the product, while allowing to estimate the amount of water that could be adsorbed as a function of the storage time. Therefore, it becomes possible to predict the shelf life of the product under specific conditions[4].

Water sorption in food is a complex process, influenced by various mechanisms dictated by the material's structure and composition. Consequently, numerous models have been proposed to characterize water sorption behavior in food matrices. These models typically fall into three categories: empirical, semi-empirical, and theoretical. Empirical models, such as the equations of Oswin, Smith, and Henderson, are characterized by two parameters. An example of a semi-empirical model is the Peleg model (1993), which incorporates four parameters. Finally, derived from the Langmuir isotherm, two theoretical expressions are prominent: the BET (Brunauer, Emmett, Teller) and GAB (Guggenheim, Anderson, de Boer) equations. These theoretical models are widely utilized for describing water sorption in food materials[5]. This study focused on investigating the influence of water activity and temperature on water content, aiming to develop a mathematical equation for predicting changes in food water content based on temperature and water activity. Additionally, the research sought to comprehend, predict, and optimize date conservation conditions by considering interactions with water activity.

2. Materials and methods

2.1. Sample

The dates used in this study come from the province of ERRACHIDIA in MOROCCO, in particular the variety MAJHOUL, from a storage unit. The samples were collected during the accompanying year 2024 and stored in cold rooms in cartons. The MAJHOUL variety is renowned in Morocco for its distinctive appearance and flavor, highly appreciated by Moroccan consumers. This variety of dates is characterized by a high average weight of 22.43 g, with a pulp weighing 20.87 g and seeds of 1.56 g. It measures about 4.64 cm in length, 2.47 cm in width and 0.70 cm in thickness[6,7] .

2.2. Method

The relationship between the water content of a product, its temperature, and water activity depends mainly on two factors: water content (X) and temperature (T). When plotting a curve representing the water content of a product as a function of water activity (a_w) or equilibrium relative humidity (RH) for a given temperature (T):

- It is termed an adsorption isotherm if this curve is established experimentally from a dry product.
- It is termed desorption isotherms if this curve is experimentally constructed from a water-saturated product[8].

The static gravimetric method involved correlating the equilibrium water content with the relative humidity of the surrounding atmosphere. The dates are cut in thin slices, 2 cm long and 1 to 2 mm thick. The samples of about 30g are placed in a stainless-steel capsule weighed beforehand, the latter is placed in a glass jar containing sulphuric acid with different concentrations ranging from 10% to 85% to maintain the desired water activity in the medium. The glass pot is closed and placed in the oven (**Figure 1**).

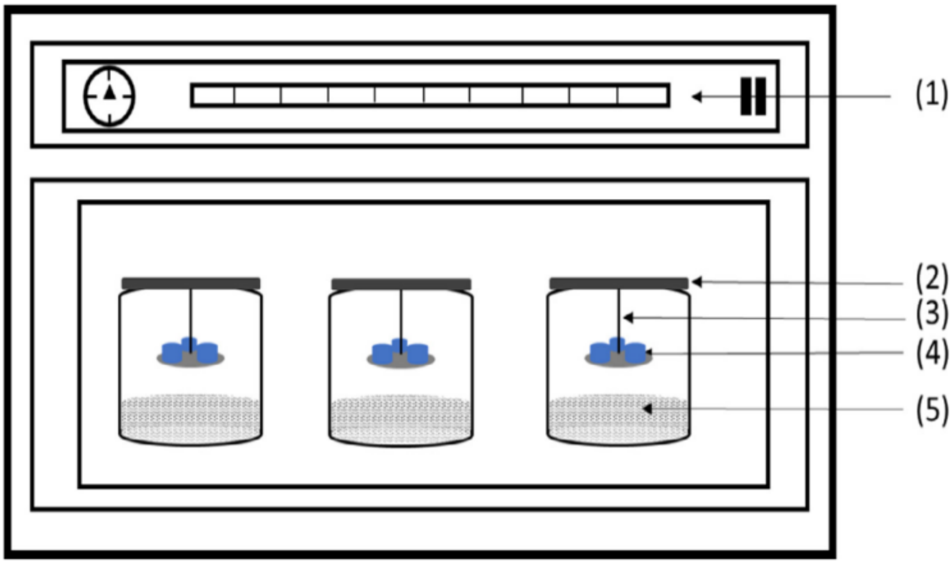

Figure 1. Experimental apparatus for sorption isotherm: (1) thermostated bath; (2) sample jars (3) sample holders; (4) date sample; (5) sulphuric acid solutions.

Samples are weighed every 24 hours until equilibrium is reached. Equilibrium is reached in 15 days. To avoid the influence of the medium conditions on the sample, the weighing time is about 30 s. and for the determination of the water content the samples is placed in the oven under a temperature of 105 for 24 hours.

The equilibrium water content (X) is derived from the following formula [9].

$$X = \frac{\textbf{humid mass-dry mass}}{\textbf{dry mass}}$$

2.3. The parameters processed

2.3.1. Factor plan

To assess the impact of water activity on water content throughout storage, the Minitab 18 software employs a factorial design. This experimental design consists of three replications and enables the investigation of specific parameters, namely temperature and water activity, concerning 30 grams of dates.

2.3.2. Water activity

The activity of water in a product is the ratio between the water vapor pressure on the surface of the product and the pure water vapor pressure at the temperature T of the product. The value of the activity studied in this work is between 0.16% and 96% [8].

2.3.3. Water content

The water content of a material is the ratio of the weight of water contained in that material to the weight of the same dry material. The equilibrium water content (X) is deduced from the following formula [10]:

$$X = \frac{wet\ mass - dry\ mass}{dry\ mass}$$

2.3.4. Temperature

The temperature studied in this work was chosen according to the prevailing climate in Morocco, we worked on a temperature between 25°C and 40°C.

2.4. Data analysis

Minitab 18, a popular software developed by Minitab Inc., facilitates the generation of factorial designs, conducts corresponding analyses, creates normal plots illustrating standardized effects, generates Pareto charts, and provides descriptive statistics for the water content of dates.

3. Results

The mean and standard deviations of date samples are provided along with the parameters. A total of 18 tests are conducted sequentially, with results for temperature, water activity, and water content documented in the **Table 1**:

Table 1. Mean and standard values deviations of date samples.

Ordre	T (°C)	Water activity	Water content (X) (%)
1	40.0	0.0016	2.25
2	40.0	0.9562	51.20
3	32.5	0.4789	23.00
4	32.5	0.4789	22.80
5	40.0	0.0016	3.10
6	25.0	0.0016	3.16
7	40.0	0.9562	51.33
8	25.0	0.9562	32.00
9	25.0	0.0016	3.10
10	32.5	0.4789	22.91
11	25.0	0.9562	32.11
12	40.0	0.9562	51.11
13	32.5	0.4789	21.80
14	25.0	0.9562	32.12
15	32.5	0.4789	22.84
16	40.0	0.0016	2.31
17	25.0	0.0016	3.15
18	32.5	0.4789	22.81

3.1. Uncoded water content unit regression equation

We derived an uncoded unit water content regression equation from the provided table data, incorporating water activity and temperature as the determining factors. The model fit's quality was assessed using the coefficient of determination, squared R[11].

With an R-squared value of 99.96%, the model elucidates 99.96% of the total variation, leaving only 0.04% unaccounted for, underscoring its exceptional fit to the data. The adjusted R-squared value (R-sq (adj) = 99.95%) further strengthens the model's significance due to its high value. Additionally, the predicted R-squared value of 99.94% suggests robust predictive capability for new observations.

Table 2. Descriptive statistics of the factor.

Regression equation in uncoded units	R-sq	R-sq (adj)	R-sq (pred)
X=4.265- 0,0411 T 4.11 a_w+ 1.3772 T*a_w	99.96%	99.95%	99.94%

X: water content; T: temperature (°C); a_w: water activity; R-sq: R squared; R-sq (adj): R squared; R-sq (pred): predicted R squared

However, there are several models in the literature that can predict water content as a function of water and temperature activity[12], the adapted model can be chosen based on the correlation coefficient calculated from the adjustment of the experimental data of the food adsorption isotherms[1]. The equilibrium isotherms of sorption of water vapor are correctly represented by the model G.A.B with a correlation coefficient of 99.93%[13], OSWIN, GAB and BET models were used to explain sorption data for green, brown and red peppers over a range of water and temperature activities. Among these models, the GAB and BET models described the sorption of green chilli with a correlation coefficient of 99.93%[14]. The GAB and Peleg models were considered the best to describe the relationship between equilibrium moisture content for olive leaves of the variety Chemlali, water activity with a correlation coefficient 99%[15]. Another study of sorption isotherms was conducted on eleven varieties of dates. The study concluded that the BET model was preferred over the GAB model to describe the isotherms. Therefore, the BET model can accurately describe the interaction of water with the studied material over a wide range of water activity (a_w)[9], another study on date paw adsorption isotherms was well described by the GAB model[1].

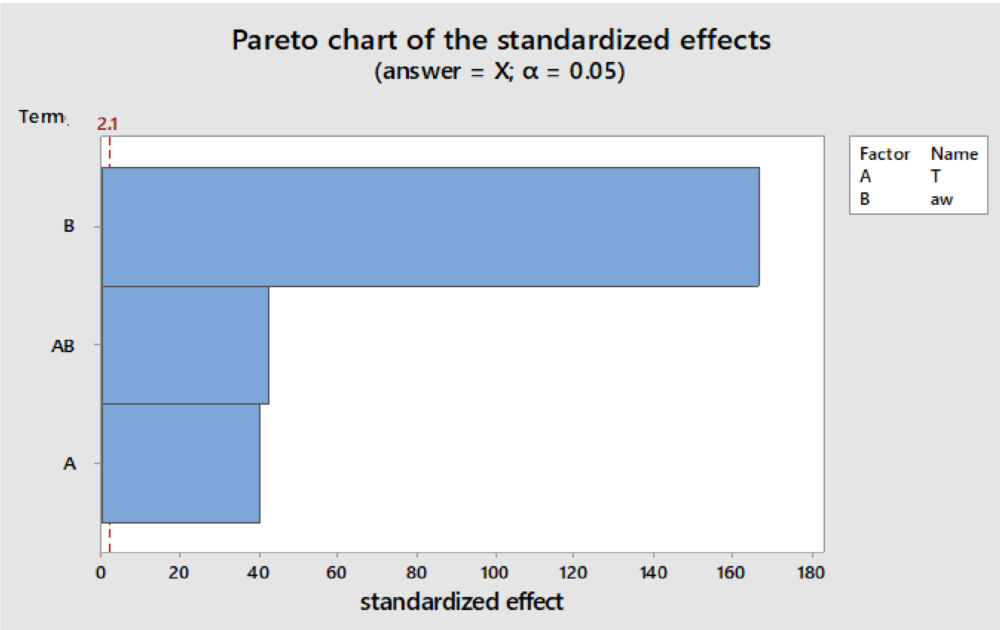

Figure 2. Illustrates a Pareto chart presenting the absolute values of the normalized effects.

Figure 1 illustrates the Pareto diagram, designed to evaluate the significance and magnitude of effect terms. It displays the absolute values of normalized effects, arranged in descending order of magnitude. Notable terms on the graph denote statistical significance, surpassing the baseline with a 95% confidence level. Notably, water activity emerged as the predominant factor influencing water content in this experiment.

However, the storage temperature significantly affected the isothermal curves of the sample at a constant water activity, this was noticed for millet milk [16].

Table 3. The coded coefficients are utilized in the analysis of the variability of the regression equation for cutting time.

Term	Effet	Coefficient	SE Coef	T-value	P-value	VIF
Constant		22.3944	0.0950	235.69	0.00	
T (°C)	9.277	4.638	0.116	39.86	0.00	1
a_w	38.800	19.4	0.116	166.71	0.00	1
a_w*T	9.860	4.93	0.116	42.37	0.00	1

SE Coef: coefficient standard error ; VIF: the variance inflation factor ; T-value: Indicates the statistical significance of regression coefficients ;P-value : Indicates the significance of observed results.

Table 3 exhibits the coded coefficients employed in the variability analysis of the regression equation. The factor's impact signifies the expected alteration in the average response as the factor shifts from the lower level to the higher level. Water activity exhibits the predominant positive effect, indicating that this parameter drives the increase in the response (water content).

However, the other terms have minor positive effects, including temperature and temperature * water activity, meaning that an increase in these terms results in a decrease in water content. These results are similar to the results found by Zhang Z et al [12].The results indicated that the equilibrium moisture content of the tiger Nuts tend to increase with the increase in water activity and the decrease in temperature [12].

The standard error coefficient of 0.1116 underscores the accuracy of the estimate, with the coefficient's magnitude indicating half the effect size. Importantly, the p-value, below the significance level α = 0.05 (widely accepted in humanities and social sciences), signifies a statistically significant correlation between the response variable (water content) and the terms [17] , Moreover, a variance inflation factor (VIF) of 1 indicates no multicollinearity among predictors, streamlining the assessment of statistical significance.

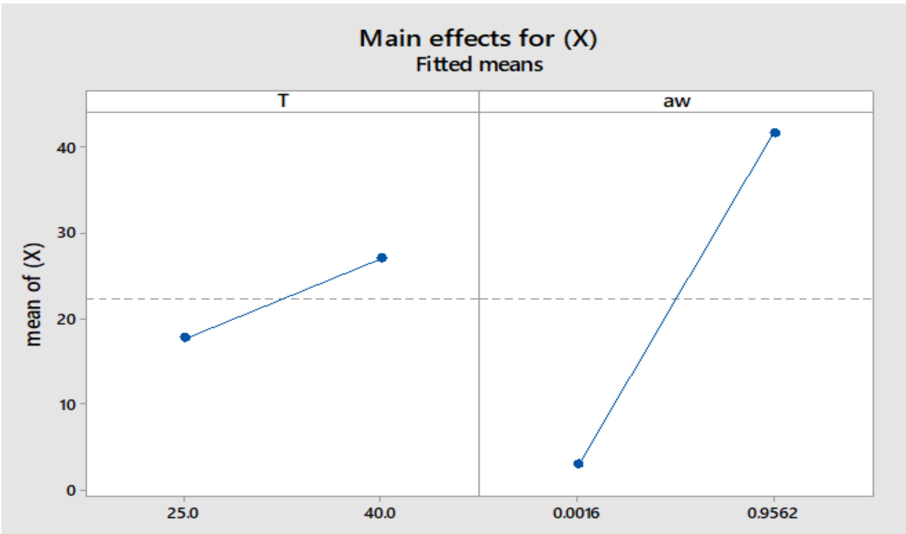

Figure 3. The main effects graph for clotting time.

Explore the impact of terms on the response variable (water content) through the graph of the main effects of water content (**Figure 2**). As water activity increases from 0.0016 to 0.9562, there is a noticeable increase in water content, followed by a marginal reduction as temperature decreases. These results validate the observed trends. It can be concluded that water activity has a significant influence with respect to temperature on water content, however that temperature influences water content. A study carried out on figs showed that the water content increases with the drop in temperature [18].

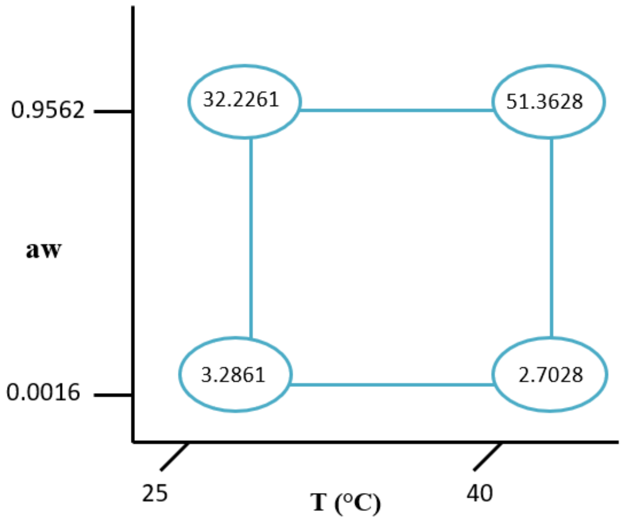

Figure 4. The cube plot (adjusted mean) for water content.

To depict the correlation between factors (temperature and water activity) and the response (water content), a cube plot (adjusted mean) was employed **Figure 4** showcases the water content values derived from the multiple linear regression equation outlined in **Table 2**, encompassing all conceivable combinations of water and temperature activity. For water activity equal to 0.0016 at a temperature of 25°C the water content equal to 3.2861%, this value is deprived when the temperature increases with the activity of the constant water or when the activity of the water increases with a fixing of temperature these results are similar to the results found by Ferradji A et al [13] . Comparing figures 3 and 4, we can observe that the effect of temperature on water content varies. At the same water activity, the water content increases with temperature (**Figure 3**), while it decreases with temperature (**Figure 4**). This observation could be explained by the presence of a crossing point where the effect of temperature is reversed. Similar conclusions were observed by L.Hssaini et al [18].

4. Conclusion

Uncoded regression equations of water content as a function of parameters (temperature, water activity) were studied. These models demonstrate improved predictive capabilities for new observations with a correlation effect of 99.96%. Water activity is the parameter that has the most influence on the water content, that is, the increase of this parameter changes the water content. However, the increase in temperature increases the water content, but not with the same effect as water activity. The uncoded regression model developed in this study has a significant utility to optimize date preservation by predicting water content as a function of temperature and water activity during storage.

Author contributions

Oubouali Morad: writing,review and editing

Zine-eddine Yassine and Ajbli nouhaila: editing and review

Ellaite Mohammed, Kzaiber Fouzia and Oussama Abdelkhalek: review and editing

Boutoial Khalid: review,editing and supervision

All authors have read and agreed to the published this version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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