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EMPIRICAL MODELLING FOR THE KINETIC OF THE NATURAL AND ARTIFICIAL DEHYDRATION PROCESS FOR APPLES AND GRAPES

BY

CLAUDIA COBZARU[1], ROXANA ŞTEFAN[1], GENOVEVA BORDEIANU[2], GABRIELA ANTOANETA APOSTOLESCU[1], RAMONA-ELENA TĂTARU-FĂRMUŞ[1], NICOLAE APOSTOLESCU[1] and CORINA CERNĂTESCU[1,*]

[1]"Gheorghe Asachi" Technical University of Iaşi, Romania,
"Cristofor Simionescu" Faculty of Chemical Engineering and Environmental Protection
[2]Tehnical College "Danubiana" Roman, Neamţ, Romania

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Abstract. In this paper the artificial and natural dehydration process kinetic for apples and grapes has been studied. Experimental data show that natural dehydration has the disadvantages of being a slow and dragging process, but also the benefits of preserving flavour, maintaining nutrients and long-lasting conservation due to the low moisture content of 5-10%. Instead, the artificial dehydration is faster but not economical, with the possibility of caramelizing some ingredients due to the contact with the intense heat source. Also, through modelling of kinetics the natural and artificial dehydration process with the Table Curve 2D program has been obtained an empirical model that successfully approximates the actual moisture variation for the products undergoing the dehydration process at different time values.

Keywords: artificial and natural dehydration; apples; grapes; mathematic model.

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*Corresponding author; *e-mail*: ccernat@tuiasi.ro

1. Introduction

Fruits are a class of foods with a high nutritional level that are used as raw materials for the food industry and as basic food for a balanced and healthy diet, being consumed both fresh and preserved. In addition to the intake of vitamins and minerals, fruits are also a source of essential fibers and nutrients with numerous beneficial health effects, the daily amount recommended being 400 g (Barrett and Lloyd, 2012). Although fresh fruit provides a much higher level of nutrients, keeping them fresh is only possible for a limited period of time, which has made preservation methods a topic of great interest (Cornell Cooperative Extension, 2011). Among the fruit-specific conservation methods, it has been showed that dehydration is the most advantageous, being also one of the oldest methods used for fruit preservation.

The dehydration process is performed both naturally (sun exposure) and artificially, each of them presenting advantages and disadvantages.

The artificial dehydration has the disadvantage of a high cost because it involves, in addition to basic pre-treatment operations (sorting, washing and splitting) other procedures such as blanching, enzyme inactivation and sulphur dioxide treatment. Instead, the drying time varies, depending on the process used, the dried products having a water content about 17-25% (Beceanu, 2009; Pop and Pop, 2006).

The natural dehydration has the disadvantage of requiring a long time, but the products are obtained at a low cost, the process missing the bleaching, enzyme inactivation and sulphur dioxide treatment operations. Furthermore, the products can be classified as bio-organic because they are not treated with different preservatives.

There is a wide variety of fruits with significant nutritional value to the human body. Among them, apples represent the category of products with a high nutritional value due to their very balanced composition, having over 170 substances found in their composition (Gradinariu and Istrate, 2003). In the literature there are studies of apple drying, and one of them claims that dehydration is a very important operation because a dried product remains unaltered for a long time, maintaining intact its organoleptic characteristics (Burtea and Fugel, 1985). Another study presents the benefits of apple drying, claiming that dried fruit can be consumed at any time of the year (Menges and Ertekin, 2006). Beside the apples, grapes are an important food source for humans because they are rich in sugars, organic acids, mineral salts, vitamins, amino acids, microelements, etc. They can also be consumed in a dehydrated form, a literature study asserting that obtaining raisins by dehydrating grapes has become one of the most important industries in many parts of the globe where huge vines are found (Fadhel *et al*., 2005).

The mathematical modelling of the drying process for various vegetable products has been extensively studied in literature, considering the large amount of studies (Abouo *et al*., 2016; Faal *et al*., 2015; Hii *et al*., 2008; Kaveh and Amirichayjan, 2014; Sankat and Balkissoon, 1994; Shahi *et al*., 2014; Wan Daud *et al*., 1996). There are also some studies focused on mathematical modelling of chemical processes (Cobzaru and Inglezakis, 2012; Cobzaru *et al*., 2015; Cobzaru *et al*., 2016; Marinoiu *et al*., 2017). However, there is no 2D mathematical model that details the kinetics of the dehydration process and find the equation that best describes the process for the vegetable material studied in this paper.

Taking into account the above mentioned reasons, in this study we wantto investigate the natural dehydration of grapes and apples and to establish a empirical mathematical model using Table Curve 2D program for the kinetics of dehydration.

2. Experimental

1. Vegetal material

For this study, apples of the Golden Delicious variety were harvested from orchards and grapes without seeds were purchased from the supermarket. In the case of apples, this variety was chosen because the pulp is more consistent, fine, sweet, with a pleasant flavour, retaining its consistency even after processing. Both apples and grapes have been dehydrated both naturally (sun exposure) and artificially in the laboratory oven.

2. Preparation and dehydration of apples

Before dehydration, the apples were washed, dried, and then cut into slices with 10 mm thickness. The slices were kept in a water and lemon juice mixture in order to avoid their oxidation, and then placed on drying grids with a height of about 15-20 cm to allow the air to circulate.

During the drying period, the materials were periodically mixed so that the drying operation to be as uniform as possible and to eliminate moulding, and at well-established time laps were weighed to calculate the amount of water lost (as percentage of humidity) over time. Throughout the dehydration under sun exposure, the fruits were covered overnight with foil to prevent moisture from dew. After about 6 days, equivalent to 144 h of sun exposure (until humidity of the dried product remained constant) the dehydrated apple slices were gathered and put into paper bags and kept in a cool place.

In order to highlight the importance of natural dehydration, in parallel, apples were dehydrated and prepared in the same way as before, but drying process was done in the laboratory oven at 60^{o}C. As with the natural drying, the materials were periodically mixed to achieve uniform drying. This operation was followed by weighing at well-established time intervals. After about 6 h (the amount humidity remained constant), apple slices were gathered and put in paper bags and kept in a cool place.

3. Preparation and dehydration of grapes

As described above for drying apples, the grape berries have undergone natural and artificial dehydration. After about 8 days, equivalent to 192 h of natural dehydration and 8 h of artificial dehydration respectively, the dehydrated products were placed in bags and stored in a cool place.

4. Modelling the kinetics of natural and artificial dehydration

The amount of water lost during natural and artificial dehydration, expressed as a percentage of moisture, for both apples and grapes, was calculated using the following formula (Banu, 2009):

$$U\% = (C\text{-}A)/(B\text{-}A)\ 100$$

where: U – sample humidity, [%]; A – the mass of the container on which the sample is placed, [g]; B – the mass of the container with the sample, [g]; C – the mass of the container with the dried sample, [g].

The analyses were conducted in triplicate for each sample and the arithmetic media has been noted in the paper.

Empirical modelling has been used as an alternative method for analysing the drying process of the studied fruits. Thus, we used the Table Curve 2D program that makes it possible to correlate between two working parameters in the form of a mathematical model. The experimental data is processed using the Table Curve 2D program with the following working procedure (Cobzaru *et al*., 2015; Cobzaru *et al*., 2016): introduction of experimental data; graphical representation of the data provided and choosing the best mathematical model based on the determination coefficient (R^2) and the simplicity of the characteristic mathematical equation.

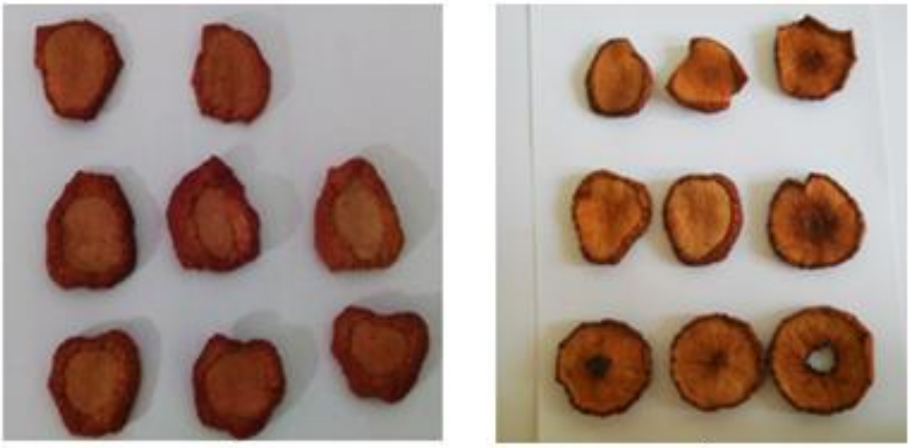
The symbols used in all the equations and graphical representations are: x – time, min or hours; y – humidity, %.

3. Results and Discussion

One of the conditions required to dry vegetal products, by the means of dehydration, is that the finished products must retain as many of their original characteristics as possible (taste, colour, nutritional value, vitamins, etc.).

Figs. 1 and 2 show the vegetal material analysed after being naturally and artificially dehydrated.

Although they are dehydrated, the products do not have the same characteristics. During the dehydration process, the products undergo a series of physical, chemical and biochemical changes, the chemical composition and the internal structure changes as well (Tsotsas and Mujumdar, 2012).



a. b.

Fig. 1 – Dehydrated apple slices; *a* – Natural, *b* – Artificial.

a. b.

Fig. 2 – Dried grape berries; *a* – Natural, *b* – Artificial.

One of the physical changes is the decrease in volume, which is significant in the case of the analysed products, and which occurs at the same time as the product weight decreases, due to the combined effect of contractility and contracting (Tsotsas and Mujumdar, 2012). This feature is very important from an economic point of view because their storage does not raise very large problems, their volume being considerably reduced after the dehydration process. Dehydrated products can also be stored for a long time. Another change, this time of a biochemical nature, which is manifested in the analysed products, is the colour change, and can be observed in the two materials subjected to drying. After analysing the colour of the two dehydrated products, it is observed that natural dehydrated products have a much more pleasant colour commercially speaking than those obtained by artificial dehydration. This can be explained by the fact that the naturally dehydrated products are not exposed to a strong heat source comparing with those artificially dehydrated.

Regarding the kinetics of the dehydration process (Fig. 3) it was represented the variation of the percentage moisture versus time for the analysed vegetal materials.

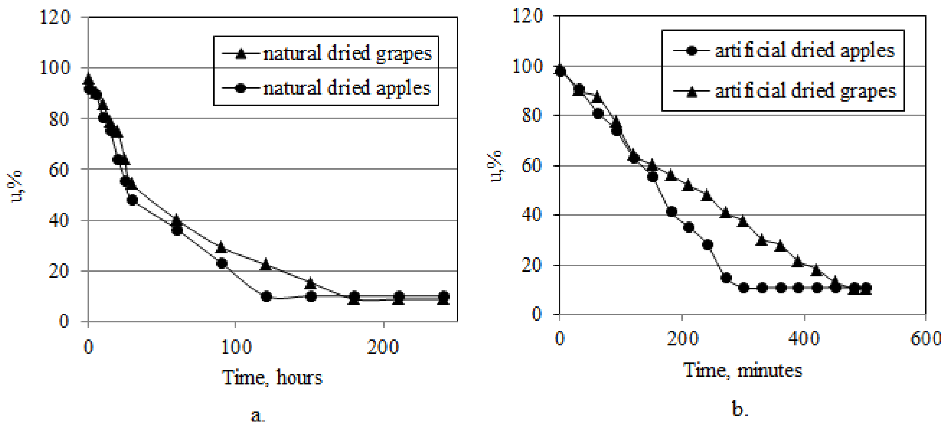


Fig. 3 – Vegetal materials dehydrated; *a* – Natural; *b* – Artificial.

Water is known to be in large amounts in fresh fruits. According to literature (Beceanu and Chira, 2003), fruits contain between 78-93% water, and in order to ensure good capacity of conservation, they have to be dehydrated to a water content of 17-25% (Beceanu, 2009). As is showed in Fig. 3, the analysed materials were dehydrated to a water content of 5-10%. Also, between the two vegetal materials subjected to natural dehydration in the sun (Fig. 3*a*), apple slices dried faster than grape berries. Moreover, the amount of water retained in apple slices is higher than for grapes. From the experimental data presented in Fig. 3*b*, can be noticed that artificial dehydration has the advantage that the finished products can be obtained in a much shorter time than for natural dehydration (Fig. 3*a*), the amount of retained water also being in the recommended values (Beceanu, 2009). However, this is done with high energy consumption, which is not economically advantageous. Furthermore, the products removed from the oven have required a special attention to handling so that there is no possibility of grinding and, implicitly, lowering the quality of the finished product.

Table 1 presents the results of regression analyses performed on the experimental data.

Table 1
Regression Analysis of Experimental Data

Sample	Model equation		(R^2)
Grapes	Natural dehydration	$y = (a+cx^2+ex^4+gx^6)/(1+bx^2+dx^4+fx^6+hx^8)$	0.9975
	Artificial dehydration	$y = a+bx+cx^2+dx^3+ex^4+fx^5+gx^6+hx^7+ix^8+$ $+jx^9+kx^{10}$	0.9992
Apples	Natural dehydration	$y = (a+cx^{0.5}+ex+gx^{1.5}+ix^2)/(1+bx^{0.5}+dx+$ $+fx^{1.5}+hx^2+jx^{2.5})$	0.9934
	Artificial dehydration	$y^2 = (a+cx^2+ex^4+gx^6+ix^8+kx^{10})/(1+bx^2+dx^4+$ $+fx^6+hx^8+jx^{10})$	0.9991

In all of above, the x variable refers to the time and y variable represents the humidity. The best model that describes the dehydration operation is the one that has the highest R^2 values, and the characteristic equation is simple. As seen in Table 1, in all cases, the R^2 values vary between 0.99753 and 0.99926, and the equations characteristic of the patterns are very simple. The significance of each coefficient was determined by t-test and p-values. The larger the magnitude of the t-value and the smaller the p-value, the more significant is the R^2 values.

Figs. 4 and 5 show the characteristic 2D models best describing the kinetics of the natural and artificial dehydration process of the analysed samples.

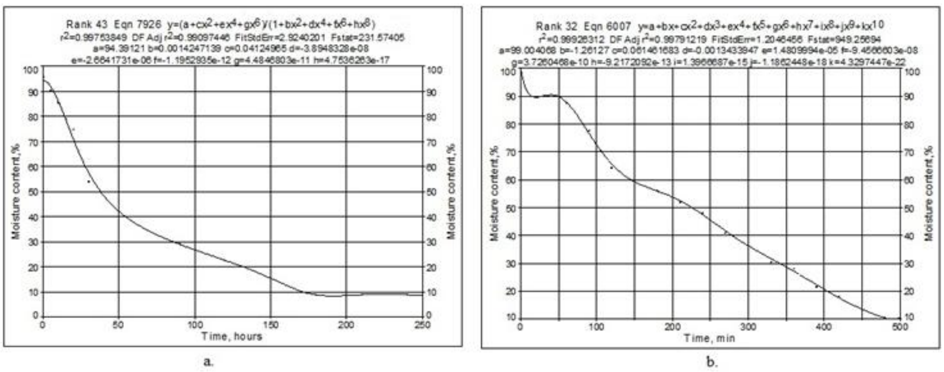


Fig. 4 – The empirical mathematical model of the grape dehydration process; *a* – Natural dehydration, *b* – Artificial dehydration.

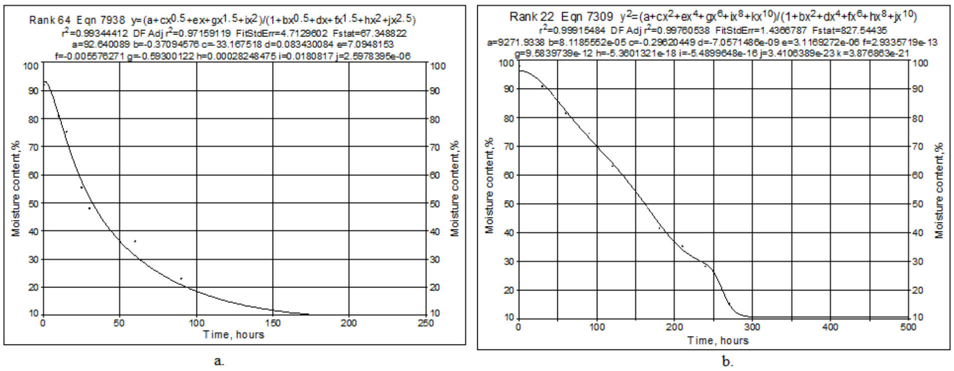


Fig. 5 – The empirical mathematical model of the apples dehydration process; *a* – Natural dehydration, *b* – Artificial dehydration.

From the comparison of the graphical representations it can be stated that the chosen mathematical model successfully approximates the actual variation of moisture in the dehydrated products at different time values, which confirms that it can be applied also in the case of dehydration of other fruit species and at different temperatures and time amounts.

3. Conclusions

In this study a kinetic for natural and artificial dehydration process was made and an empirical model with Table Curve 2D program describing the process was established. Even though the artificial dehydration method is faster, it is not economically advantageous. Artificially dehydrated products in contact with the intense heat source have a less pleasant commercially aspect than naturally dehydrated products. Natural dehydration by sun exposure is a slow process and allows the products to retain their flavour, avoiding the loss of nutrients due to temperature and caramelization. Moreover, naturally dehydrated products can be preserved over a longer period of time because they have a water content of 5-10%, which is lower than that in literature.

By comparing the graphical representations of the empirical mathematical models established for the natural and artificial dehydration process it was established that the best empiric mathematical model obtained with Table Curve 2D program describes the process kinetics and successfully approximates the actual moisture variation of the dehydrated products at different time values. The model can also be applied to the dehydration of other fruit species at different temperature and time values.

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MODELAREA EMPIRICĂ A CINETICII DESHIDRATĂRII NATURALE ȘI ARTIFICIALE A MERELOR ȘI STRUGURILOR

(Rezumat)

În această lucrare s-a studiat cinetica deshidratării naturale și artificiale a merelor și a strugurilor și s-a stabilit un model matematic empiric. Datele experimentale arată că deshidratarea naturală prezintă dezavantajele unui proces lent și de lungă durată, dar și avantajele păstrării aromei, a menținerii unor substanțe nutritive și a conservării îndelungate datorită conținutului mic de umiditate cuprins între 5-10%. În schimb, deshidratarea artificială este mai rapidă însă nu și economică, existând posibilitatea caramelizării produselor datorită contactului cu sursa de căldură intensă. Modelarea cineticii deshidratării naturale și artificiale a fost realizată cu ajutorul programului 2D, iar selecția celui mai bun model a fost obținută prin compararea coeficientului de determinare (R^2) și a simplității ecuației caracteristice. Modelul empiric 2D obținut descrie cel mai bine cinetica procesului de deshidratare naturală și artificială și aproximează cu succes variația reală a umidității din produsele supuse procesului de deshidratare la valori de timp diferite.