APPLICATION OF PELEG MODEL TO STUDY EFFECT OF WATER TEMPERATURE AND STORAGE TIME ON REHYDRATION KINETICS OF AIR DRIED POTATO CUBES

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***Abstract*— Potato cubes (1×1×1 cm) were dried at 65ºC in hot air oven. Samples were rehydrated by immersion in water during different periods of time and temperatures (23±2ºC and 100±2ºC). Rehydration kinetic was monitored by measuring samples' weights at regular intervals. All measurements were repeated after two months to study effect of shelf life on rehydration. Peleg's model was successfully applied to experimental data and the corresponding parameters were obtained and correlated with temperature. The parameters of the model were found to be greatly affected by the water temperature during rehydration. Rehydration of samples was also dependent to water temperature. In particular, temperature increase led to higher final moisture contents in the samples after two months storage. On the other hand, higher temperatures decreased the moisture content of the samples at the end of first month which could be related to the structural changes in potato due to higher temperatures.**

***Keywords* - Rehydration kinetic, potato, water temperature, storage time.**

I. INTRODUCTION

The development of new, high quality and consumer attractive dried products is necessary to widen product availability and diversify markets, since fresh crops consumption is generally below the levels recommended in normal diet (Conteras *et al*., 2008).

Potato is one of the most important agricultural crops and there is remarkable loss of this produce because of unfavorable storage conditions. Therefore, it is vital to convert raw potatoes into some processed products such as dried ones.

Conventional air-drying is the most frequently used dehydration operation in food and chemical industry. In this case, drying kinetics is greatly affected by air temperature and material characteristic dimension, while all other process factors exert practically negligible influence (Kiranoudis and Tsami, 1997).

In air drying of foods, together with the partial evaporation of the product's water content, some physical and chemical changes in the tissue structure occur (Lewicki, 1998). Shrinkage, porosity decrease and changes in physical properties such as texture, are some of the alterations that may occur during drying (Maskan, 2001; Lewicki and Jakubczyk, 2004).

Dehydrated products are usually rehydrated prior to their use. Rehydration process depends on structural changes in vegetal tissues and cells of food material during drying, which produces shrinkage and collapse and reduces the water absorption capacity, thereby preventing the complete rehydration of the dried product (Krokida and Marinos-Kouris, 2003). In particular, Rehydration is a complex process aimed at restoration of the properties of the raw material. Typical rehydration curves show an increase in volume of absorbed water with time. The rapid initial water absorption period is followed by a slower rate in the latter stages (Kader, 1995; Maskan, 2001). The equilibrium moisture content at saturation does not reach the moisture content of the raw materials prior to dehydration, indicating that the dehydration procedure is irreversible (Krokida and Marinos- Kouris, 2003).

The effective design of rehydration and storage systems for dried potato cubes requires the knowledge of the absorption properties of them. Generally, the soaking process of cubes is inconveniently time consuming, taking up to 4 hour at room temperature. To minimize soaking time in water, high soak temperatures can be used (Abu-Ghannam and McKenna, 1998; Cunningham and McMinn, 2007).

Shelf life of products has a significant effect on rehydration ability of samples. This can be explained by structure degradation of potatoes because of changes which happen in starch during storage that lead to less capability for absorbing and holding water (Monteils *et al*., 2002).

The objectives of the present work were to determine the experimental conditions (shelf life, water temperature) which impress the quality of dehydrated potato cubes and their ability of water absorption to evaluate model of rehydration.

Nomenclature

X	moisture content (kg/kg db)
Xi	initial moisture content (kg/kg db)
Xf	moisture content of fresh sample (kg/kg db)
Xeq	equilibrium moisture content (kg/kg db)
M	weight of sample(kg)
Mi	initial weight of dried sample(kg)
Per	predicted moisture contents(kg/kg db)
Mf	weight of fresh sample(kg)
RR	rehydration ratio
K1	parameter of Peleg's model Eq. (kg d.b./kg water)
K2	parameter of Peleg's model Eq. (kg d.b./kg water)

t time of rehydration(min)
WAC water absorption capacity
Exp experimented moisture contents(kg/kg db)

II. REHYDRATION KINETICS MODELING

Among the various models so far proposed, empirical models are the most widely employed because of their mathematical simplicity and utility. Peleg (1988) proposed an empirical model to describe the water absorption kinetics during rehydration, which is given by:

$$X=Xi+t/(K1+K2*t), \quad (1)$$

where K1 is a kinetic parameter and K2 is another parameter related to equilibrium moisture content, Xeq. When $t\rightarrow\infty$, equilibrium moisture content can be calculated by:

$$Xeq=Xi+1/K2. \quad (2)$$

Equation 1 can be linearized:

$$t/(X-Xi)=K1+K2*t. \quad (3)$$

This model has been successfully applied to different products such as chestnut (Moreira *et al*., 2008), apple (Bilbao- Sáinz *et al.*, 2005) and potato (Cunningham and McMinn, 2007).

The rehydration ability of the dehydrated products is usually expressed by the rehydration ratio (RR), defined as follows:

$$RR=(X+1)/(Xi+1). \quad (4)$$

III. MATERIALS AND METHODS.

A. Materials

Three potato cultivars (Agria, Satina and Kenebek) were supplied by the agricultural center of Gorgan (Iran). Initial moisture contents were 82.05, 82.28 and 81.405 percent, respectively. Potatoes were peeled and cut to 1×1×1 cm cubes. To inhibit browning, samples were blanched in hot water (97±2ºC) for three minutes.

B. Drying treatments.

To dry samples, a hot air oven (Memmert, WB14) was used and samples were dried in 65ºC in an air velocity of 2m/s to reach to 6% moisture content (wet basis). Some of the dried samples were packed in polyethylene bags and stored in room temperature (25±2ºC). vacuum of packages was 30%, their thickness was 1mm and there was not any permeability of water and moisture.

C. Rehydration

The dried potato samples were then rehydrated by immersing in distilled water at a thermostatically controlled temperature (Cunningham and McMinn, 2007). At specified time intervals, the samples were removed, blotted with tissue paper to remove superficial water, and weighed. Soaking times to reach constant weight of samples were recorded in time intervals ranging from 10 min at the beginning of the rehydration process to 30 min towards the end of water absorption at water temperature of 23±2ºC and 10sec at 100±2Cº (Cunningham and McMinn, 2007). No correction was made for lost solids, as the quantity of absorbed water was much greater than the quantity of solids leached (Maskan, 2001). Each experiment was performed in triplicate.

III. RESULTS AND DISCUSSIONS

A. Rehydration kinetics

Figures 1 and 2 show that for fresh samples (immediately rehydrated potato cubes), the highest final moisture content was observed at 23ºC rehydration temperature, but at the end of two months storage, it was changed to 100ºC. In hot air oven, dried products were characterized by low porosity and high apparent density (Krokida and Maroulis, 1997). In addition, there is a partial destruction of texture and structure, which leads to less water permeability (Krokida *et al.*, 1999; Lewicki and Jakubczyk, 2004) so samples should be immersed in water for longer times to reach the proper moisture content. Therefore, at 23ºC, structural damages can be considered very low but remarkable at 100ºC because of higher temperatures (Moreira *et al*., 2008). In other words, samples rehydrated in higher temperatures had lower final moisture content because of textural damages and could not hold water as high as samples rehydrated at 23ºC. Similar results were reported by Abu-Ghannam and McKenna (1997), Maharaj and Sankat (2000) and Garcia Pascual *et al.* (2005).

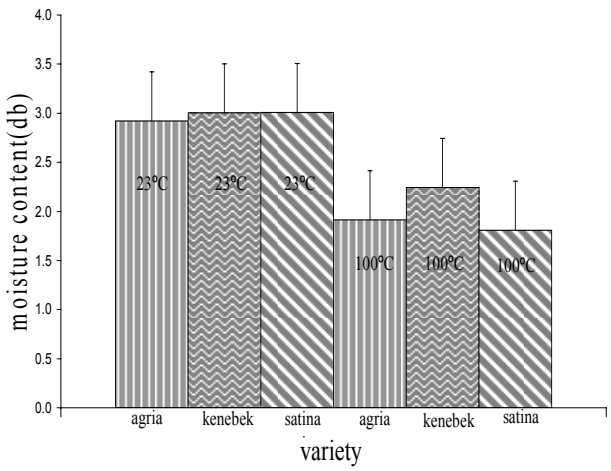

Fig.1. Effect of variety and water temperature in final moisture content of cubes in first month

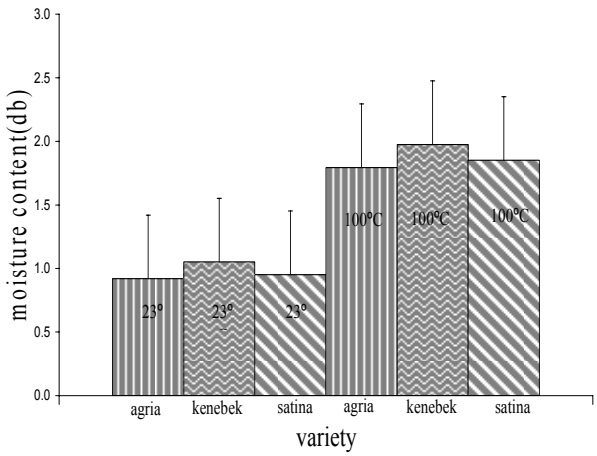

Fig.2. Effect of variety and water temperature in final moisture content of cubes in second month

The trend was opposite after two months storage of potato cubes. Samples which were rehydrated at 100ºC, had higher moisture content than their counterparts at 23ºC. In fact, conditions were reversed during storage. This could be due to the effect of high temperature on reviving structure of starch in potato which leads to more capability for water absorption. This important role of hot water can overcome the textural. Also, gelatinizing of starch which happens at temperatures above 70ºC, can cause more water absorption and higher final moisture contents. This phenomenon can lose its positive role in absorbing water if process takes long time because at that situation, deterioration of starch and texture lead to lower moisture contents. Same results were reported by Monteils *et al.* (2002).

Figures 3 and 4 show that rehydration rate had an initial sharp at the beginning followed by a slow graduation increase of rehydration rate. This asymptotic behavior is related to the decrease of driving force for water transfer as rehydration progresses and the system becomes closer to equilibrium conditions. In hot water (100±2ºC), among three studied cultivars, Kenebek had the highest moisture content but in lower water temperature (23±2ºC), Satina had the highest moisture content. Fig. 3 and 4 clearly show that rehydration behavior of potato cubes is not significantly different at higher temperatures (100ºC) in terms of storage time but there is a gap at lower rehydration temperatures (23ºC)..

From these results, it can be concluded that Satina variety had the highest susceptibility to higher temperatures as its rehydration and moisture content was decreased at 100 ºC. Another important result is that after two months storage, water absorption and moisture content of all samples was significantly ($p<0.05$) decreased. This can be explained by structural degradation of potatoes. This phenomenon happens because of the changes in starch during storage that leads to less capability for absorbing and holding water. Similar results have been reported by Monteils *et al.* (2002) also Krokida and Marinos (2003) and Krokida and Philippopoulos (2005) showed the positive effect of higher water temperatures in water holding capacity and rate of water absorptionn.

B. Peleg's modeling:

Parameters of Peleg's model were calculated according to Eq. (1). In order to do this, Eq. (1) was linearized as it has been shown in Eq. (3). Results have been shown in Table1.

The Peleg's rate constant (K1), decreased with temperature, which shows that water transfer (related to the inverse of K1) is promoted by increase of temperature but in this case, the Peleg capacity constant (K2) had more complicated manner than K1. Similar behavior of K1 was found by other authors with regard to the rehydration of other products (Djomdi and Ndjouenkeu., 2007; García-Pascual *et al.*, 2005; Maskan, 2001; Moreira *et al.*, 2008; Turhan *et al.*, 2002). As it is shown in table1, K2 increased with temperature in samples (first month of storage) but decreased with temperature after two months storage. When K2 values decreased with temperature, it means that water absorption capacity increases with temperature. This capacity depends on the type of material, structure of tissue, and chemical composition.

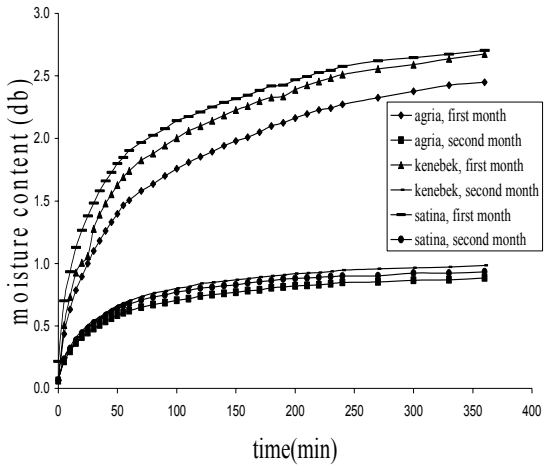

Fig.3. Effect of variety and shelf life on moisture content of cubes in 23ºC

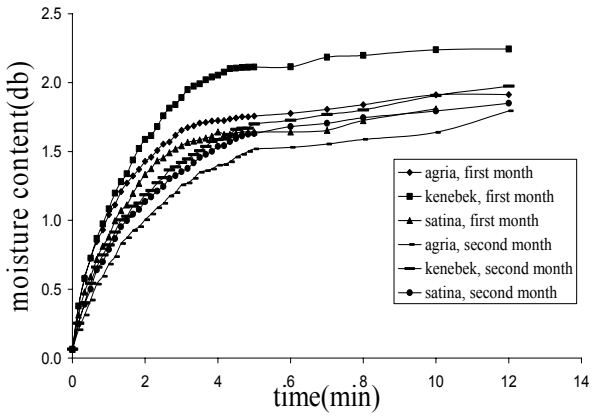

Fig.4. Effect of variety and storage time on moisture content of cubes at 100ºC

Table1. Parameters and coefficients of determination of Eq. (1) for rehydration at two temperatures

Variety Temp time	Agria 23ºC First month	Agria 23ºC second month	Kenebek 23ºC first month	Kenebek 23ºC second month	Satina 23ºC first month	Satina 23ºC Second month	Agria 100ºC First month	Agria 100ºC second month	Kenebek 100ºC first month	Kenebek 100ºC second month	Satina 100ºC first month	Satina 100ºC Second month
K1	23.326	37.343	17.200	34.470	15.903	28.916	0.466	1.082	0.480	0.834	0.579	0.859
K2	0.340	1.141	0.331	0.991	0.350	1.100	0.496	0498	0.403	0.457	0.515	0.482
Xeq	3.002	0.940	3.080	1.072	3.064	0.972	2.076	2.069	2.541	2.249	2.004	2.136

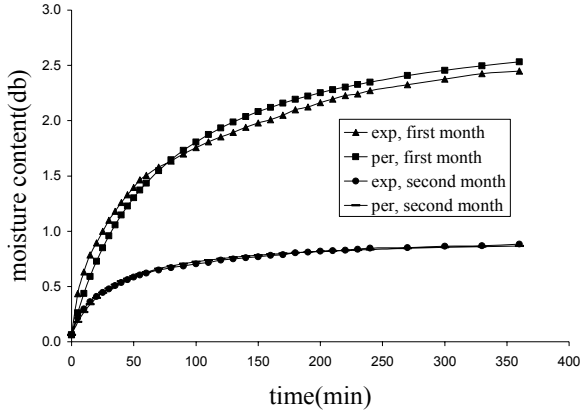

Fig. 5. Comparison between experimental and predicted moisture contents in Agria, 23ºC

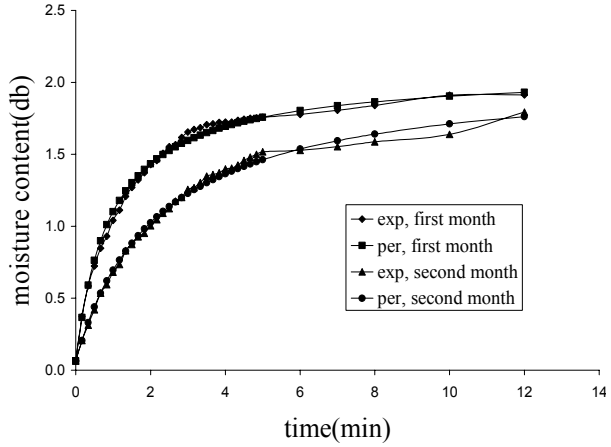

Fig.6. Comparison between experimental and predicted moisture contents in Agria, 100ºC

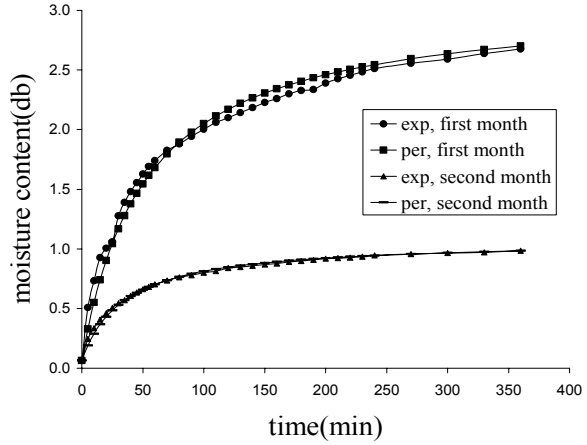

Fig.7. Comparison between experimental and predicted moisture contents in Kenebek, 23ºC

In the first month, as it was described in previous parts, shrinkage and hardness of samples delayed water penetration and samples needed to be immersed for longer time in 100ºC water. This caused some damages in structure and texture of cubes and their water capacity decreased, so K2 which is capacity constant of Peleg's model, increased with temperature. After two months, higher temperature prevailed against structural degradation due to changes in starch and this was more effective than undesirable changes, so water capacity of samples, increased and K2, decreased. Some authors indicate that K2 value can change if structure or other properties are modified by temperature during rehydration (García-Pascual *et al.*, 2005; Lopez *et al.*, 1995). In this manner, K2 parameter increases with temperature during rehydration of chickpea (Turhan *et al.*, 2002), and carrot (Planinic *et al.*, 2005) and decreases for some other foods such as hazelnut (Lopez *et al.*, 1995), blueberries (Lim *et al.*, 1995), pasta (Cunningham *et al.*, 2007), amaranth (Resio *et al.*, 2006), or wheat products (Maskan, 2001).

Figures 5 to 10 show that predicted moisture contents which were calculated according to Peleg's model (Eq. 1), were near to what was recorded during experiments. It indicates that the model is adequate to describe rehydration kinetics of potato cubes over the range of experimental conditions tested. Some other authors have reported that this model can be used for chestnut (Moreira *et al.*, 2008), tiger nut (Djomdi and Ndjouenkeu, 2007) and carrot (Planinic *et al.*, 2005) adequately.

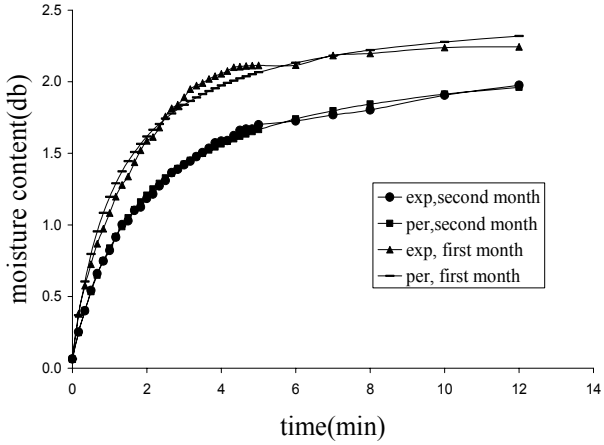

Fig.8. Comparison between experimental and predicted moisture contents in Kenebek, 100ºC

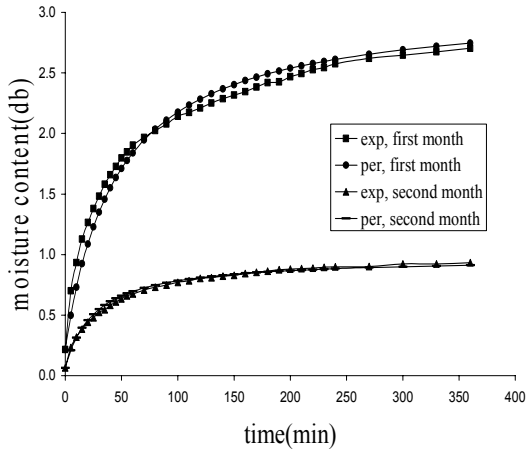

Fig.9. Comparison between experimental and predicted moisture contents in Satina, 23ºC

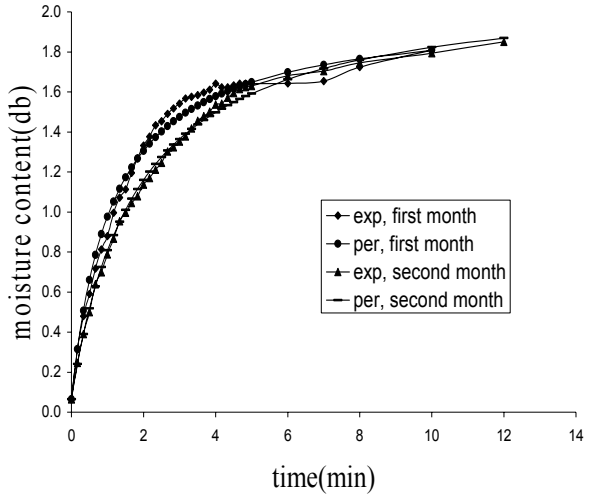

Fig.10. Comparison between experimental and predicted moisture contents in Satina, 100ºC

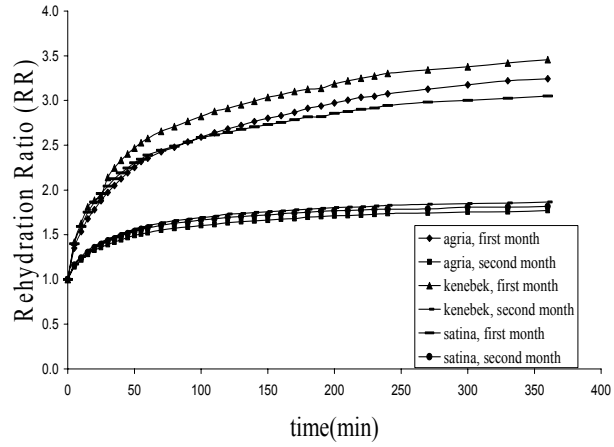

Fig.11. Effect of storage time and variety on rehydration ratio (RR) in 23ºC

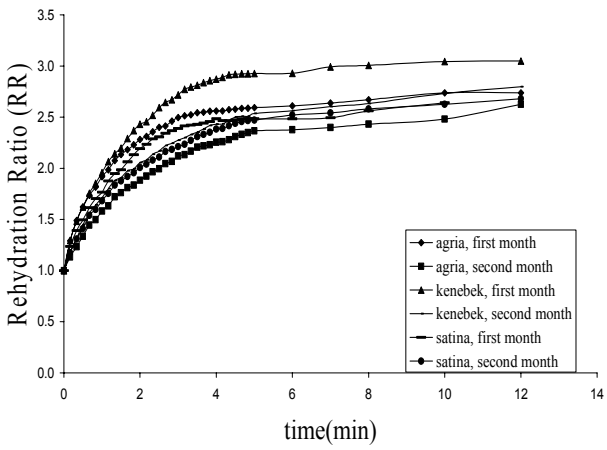

Fig.12. Effect of storage time and variety on rehydration ratio (RR) in 100ºC

C. Rehydration Ratio (RR):

The rehydration ratio ranges between 1 and 4 for all the examined samples, having the highest values for Kenebek and lowest values for Agria in both water temparatures.

Lower RR values are caused by reduced hydrophilic properties and inability to imbibe sufficient water, leaving pores unfilled and structural damages taking place during dehydration (Krokida and Marinos-Kouris, 2003). So according to calculated rehydration ratios, Agria variety had more deterioration in structure during dehydration, storage and rehydration conditions in compare to Satina and Kenebek.

IV. CONCLUSION

This study has established the suitability of Peleg model to describe rehydration behavior of air dried potato cubes. High soaking temperatures had a complex effect on rehydration ability of samples. Although hot water accelerates the water absorption phenomenon, but lead to significant damages in structure and tissue of cubes, so final moisture content decreased in samples which were rehydrater in hot water in first month of storage. But, there was another phenomenon which could lead to lower water absorption during storage, and it was degradation of starch and spoilage of samples which normally lead to lower ability of water absorption. But in this case, higher temperatures of water could over come and decrease the effect of degradation of starch and samples were able to absorb more water in compare with low temperature water. So after two months storage, the cubes which were rehydrated in hot water, had higher final moisture content than samples which were immersed in 23ºC water.

The rehydration ratio ranges between 1 and 4 for all the examined materials. The rehydration ability appeared to show a hysteresis during rehydration due to cellular and structural disruption that take place during dehydration.

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