INVESTIGATING ON EFFECT OF HOT AIR AND WATER TEMPERATURE ON KINETIC OF REHYDRATION OF CELERY BY USING PELEG'S MODEL

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***Abstract*— The Peleg model was used to determine effect of drying and rehydration conditions on celery samples. Cubes were dried in a hot air oven (70ºC and 90 ºC) and rehydrated by immersing in water (25±2ºC and 100±2ºC). Results showed that the samples which were dried at 70℃ and rehydrated at 25ºC, reached to maximum moisture content after rehydration. Also, samples which were rehydrated at water temperature of 25°C, had higher levels of rehydration ratio (RR) as a function of physical properties. The Peleg's rate constant (K_1), decreased significantly while water temperature increased. Lower levels of K_1 indicate maximum rate of water absorption. In case of the Peleg capacity constant (K_2), it increased slightly while water temperature increased. Increasing of K_2 values is a sign of less water absorption capacity. Finally, it was observed that the predicted and experimental values had a good correlation which indicates that the Peleg model was adequate to describe rehydration kinetics of celery cubes.**

***Keywords*— Rehydration, Drying, Kinetic, Celery, Peleg model.**

I. INTRODUCTION

Dehydration is an old process, which is used for extending shelf life, facilitate shipping and storage and produce new products. By drying food, they can be preserved due to reducing moisture content and therefore avoiding or limiting the microorganism growths and chemical reactions (Mujumdar, 1995, Conteras *et al*., 2008)

Celery (*Apium graveolens L.*) belongs to *umbelliferae* plant. It is native to Mediterranean coastal marshes and nowadays is widely cultivated all around the world. It is rich in vitamins, inorganic salts, calcium, phosphorus, iron and essential oils (Engindeniz, 2008). It has been reported that celery can lower blood pressure as well as blood lipid and is also used as stimulants, antispasmodics, aphrodisiacs and so on (Kapoor and Bhatnagar, 2007).

Fresh celery contains high moisture content and it is difficult to control storage condition; so, to increase shelf life, some processes have to be used. Hot air drying is one of the most common processes which is used for different agricultural products (Yanishlieva-Maslarova, 2001). Shrinkage, disrupting the function of capillary tubes and some changes in physical properties of the samples may occur during drying (Maskan, 2001; Lewicki and Jakubczyk, 2004).

Dehydrated products are usually rehydrated prior to their use. Rehydration efficiency usually depends different parameters such as structural damages in vegetal tissues, soaking time and water temperature (Krokida and Marinos-Kouris, 2003, Ranjbari *et al*., 2011; Shafaei and Masoumi, 2013).

Generally, the soaking process is time consuming and takes up to 4 hours at room temperature. To minimize soaking time in water, higher water temperatures can be used (Cunningham *et al*., 2007; Kashaninejad *et al*., 2009; Shafaei and Masoumi, 2013; Khazaei and Mohammadi, 2009).

The relationship between moisture content during soaking and time is usually expressed by different models. Many theoretical and empirical approaches have been employed by now (Shafaei and Masoumi, 2014; Yildirim *et al*., 2013; Da Silva *et al*., 2013; Ghafoor *et al*., 2014).

One of the most popular models which has been used for modeling and analyzing water absorption kinetic of dried food, is the Peleg model. It is an empirical, non-exponential model which is illustrated as Eq. 1 (Peleg, 1988):

$$X=X_i+t\ /\ (K_1+ K_{2*}t) \quad (1)$$

where X is moisture content at time t, X_i is initial moisture content, t is time, K_1 and K_2 are kinetic parameters of Peleg model which are related to equilibrium moisture content, X_{eq}, when $t\rightarrow\infty$.

Equilibrium moisture content can be calculated by:

$$X_{eq}=X_i+1/K_2 \quad (2)$$

Equation 1 can be linearized as Eq. 3:

$$t\ /\ (X- X_i) = K_1+ K_{2*}t \quad (3)$$

This model is commonly used to describe water absorption characteristics of different dried food during soaking and rehydration (Vasudeva *et al*., 2010; Salimi Hizaji *et al*., 2011; Montanuci *et al*., 2013; Ranjbari *et al*., 2013; Botelho *et al.*, 2013; Oliveira *et al.*, 2013 and Shafaei *et al.*, 2016).

The rehydration ability of the dehydrated products is usually expressed by the rehydration ratio (RR), defined as Eq. 4:

$$RR=(X+1)/(X_i+1) \quad (3)$$

The purpose of this research was to determine the effect of experimental conditions (hot air temperature during drying and water temperature during rehydration) on kinetic of water absorption of dried celery by using Peleg model.

Nomenclature:

X: moisture content (kg water/kg wet basis)
X_i: initial moisture content (kg water/kg wet basis)
X_f: moisture content of fresh sample (kg water/kg wet basis)
X: equilibrium moisture content (kg water/kg wet basis)
M: weight of sample (kg)
M_i: initial weight of dried sample (kg)
M_f: weight of fresh sample (kg)
RR: rehydration ratio
K_1: parameter of Peleg's model Eq. (kg wet basis/kg water)
K_2: parameter of Peleg's model Eq. (kg wet basis /kg water
t: time of rehydration (min)
WAC: water absorption capacity
Pre: predicted moisture contents (kg water/kg wet basis)
Exp: experimented moisture contents (kg water/kg wet basis)

II. METHODS

A. Martials

Fresh celery was supplied from the agricultural center of Semnan (Iran). Initial moisture content was 94.09% (wet basis). Celeries were cut to 2×1×0.5 cm cubes. To inhibit browning, samples were blanched in water bath (Pars Azma-R.J.42) at 97±2ºC for three minutes.

B. Drying treatments

To dry samples, a hot air oven (Memmert, D-91126) was used. Air temperature was set on 70 and 90ºC to reach to 16% moisture content (wet basis).

C. Rehydration

The dried celery samples were rehydrated by immersing in distilled water at controlled temperatures. The time intervals for monitoring weight changes of the samples were one minutes and ten seconds for water temperature of 25±2ºC and 100±2°C respectively (Cunningham *et al*., 2007; Maskan, 2001). Each experiment was performed in triplicate and graphs were carried out by Microsoft excel 2013.

D. Rehydration kinetics

As it is illustrated in Fig. 1, after rehydration, the highest final moisture content, belonged to the samples which were dried at 70℃ and rehydrated at 25ºC water temperature. Totally, Samples which were rehydrated at hot water (100ºC), had the lowest moisture content and the ones which were rehydrated in lower water temperature (25ºC), had higher moisture contents.

Dried materials, especially the ones which are processed in hot air ovens, have low porosity and high apparent density (Krokida and Maroulis, 1997). In addition, destruction of texture and structure during drying processes, can affect water absorption negatively (Krokida *et al.*, 1999; Lewicki and Jakubczyk, 2004). The main reason for this phenomenon is the shrinkage of the tissue due to loss of a large amount of free water as well as the inefficiency of capillary tubes due to shrinkage and precipitation of solid materials. So, in order to rehydrate dried food, usually samples should be immersed in water for longer times or higher water temperatures to be completely hydrated.

Observed results, showed that the samples which were dried at 70℃ and rehydrated at 25ºC, could absorb and keep more water in their tissues which resulted to higher moisture contents.

It is accepted that rehydration phenomenon is strongly related to the cellular and structural condition of the samples. Overall, during rehydration, three phenomena can happen which are penetration and Imbibition of water, swelling and leaching of soluble solids. It has been reported that at higher drying temperatures, shrinkage and severe structural damages might result to lower capability of cells to absorb and keep water molecules which lead to lower rehydration efficiency (Krokida and Philippopoulos, 2005). Also, although higher water temperatures can accelerate the rate of rehydration, but some structural damages might reduce the water holding capacity of the samples (Moreira *et al*., 2008).

Similar results were reported by Abu-Ghannam and McKenna (1997), Maharaj and Sankat (2000), García Pascual *et al*. (2005), Miranda *et al*. (2010), Vega-Gálvez *et al*. (2011) and Vega-Gálvez *et al.* (2015).

Results which are illustrated in Figs. 2 and 3, represent kinetic of moisture content changes during rehydration process. According to the obtained data, these diagrams have two main parts: an initial sharp slope at the beginning of process, followed by a slow and gradual increase of rehydration rate. At the beginning of rehydration process, samples have the lowest level of moisture content and the water flux in to the dried material is in the maximum rate but gradually, as the process progresses and the system becomes closer to equilibrium moisture content, the driving force which induce water transfer in to the dried tissue, decreases and finally result to lower rate of water absorption (Salimi Hizaji *et al*., 2010; Salimi Hizaji *et al*., 2011)

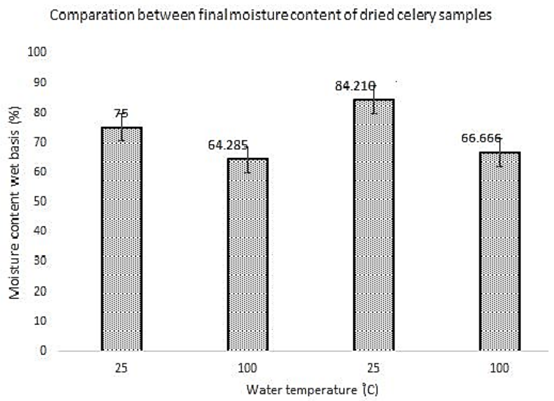

Fig. 1. Effect of drying and rehydration temperature on moisture content of samples.

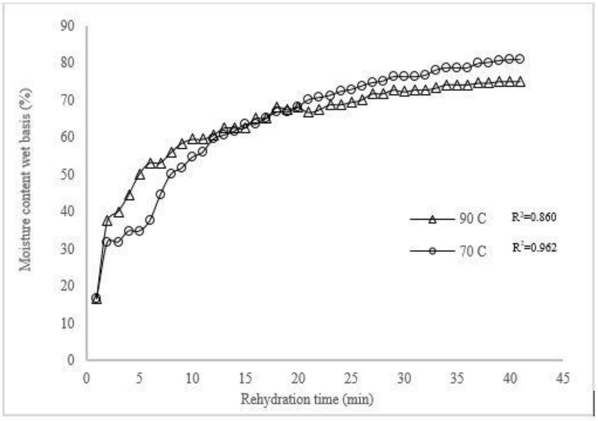

Fig. 2: Kinetic of moisture content changes during rehydration at 25 °C water temperature.

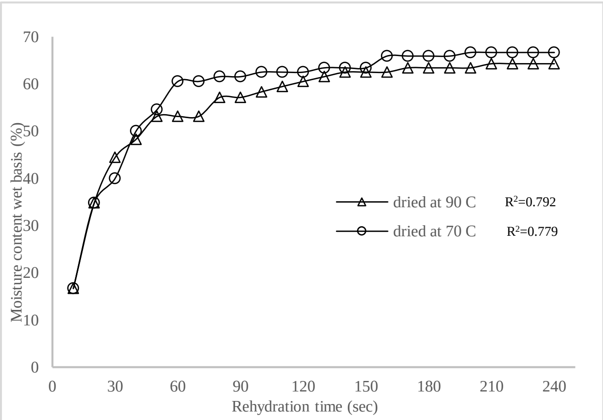

Fig. 3: Kinetic of moisture content changes during rehydration at 100 °C water temperature.

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

Drying hot air temperature [°C]	90	90	70	70
Rehydration water temperature [°C]	100	25	100	25
K_1	0.527	5.109	0.481	8.800
K_2	0.0185	0.015	0.017	0.012
X_{eq}	70.720	82.456	72.846	99.311

E. Peleg's modeling

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

As it is illustrated in Table 1, the Peleg's rate constant (K_1), decreased significantly while water temperature increased. It shows that water transfer (which is reversely related to K_1) was promoted by increasing water temperature. Also, the minimum calculated K_1, belonged to the sample which was dried at 70°C and rehydrated at 100°C. Since lower levels of K_1 indicate the maximum rate of water absorption, it can be concluded that the samples which were dried at 70°C, were in better structural conditions and had more efficient capillary tubes. Also these results confirm the positive effect of higher water temperatures on accelerating the rate of rehydration of dried celery samples.

Similar behavior of K_1 was found by other authors with regard to the rehydration of other products (Maskan, 2001; Turhan *et al*., 2002; García-Pascual *et al*., 2005; Djomdi and Ndjouenkeu, 2007; Moreira *et al*., 2008; Shafaei *et al*., 2016).

Results showed that K_2, (Peleg capacity constant), increased slightly while water temperature increased. That is a sign of lower water holding capacity of the rehydrated samples. K_2 changes depend on many different parameters such as type, structure and chemical composition of dried materials. Although higher water temperatures can increase rate of water absorption and result to faster hydration process, but it also can damage and demolish the structure which might affect water holding capacity and final moisture content, negatively.

As it is shown in Table 1, the minimum value of K_2 belonged to the sample which was dried at 70°C and rehydrated at 25°C. Since K_2 is related to water holding capacity, it can be concluded that the samples which were dried at 70°C and soaked in 25°C water, were more capable to keep and hold absorbed water due to less thermal damages during drying and having more efficient tubular tubes. Reversely, K_2 values increased for the samples which were dried and rehydrated at high temperatures which show the negative effect of sever heating on the structural capability of the samples for absorbing and holding water inside their textures. Same results were reported about chickpea (Turhan *et al.*, 2002), carrot (Planinic *et al*., 2005) and strawberry **(**Ciurzynska and Lenart, 2009).

Figures 4 and 5 show that the predicted and experimented values had good correlation and high levels of R^2 were observed for the samples. It indicates that the Peleg model is adequate to describe rehydration kinetics of celery cubes. Some other researchers have reported that this model can be used for chestnut (Moreira *et al*., 2008), tiger nut (Djomdi and Ndjouenkeu, 2007), potato (Salimi

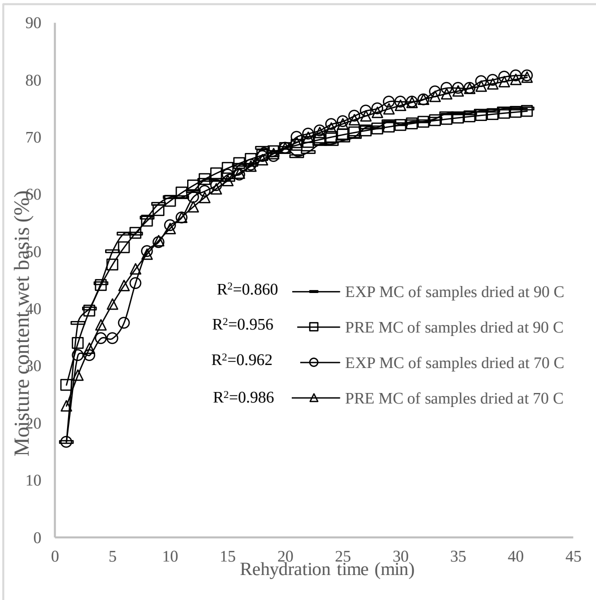

Fig. 4. Comparison between experimental and predicted moisture contents at 25ºC.

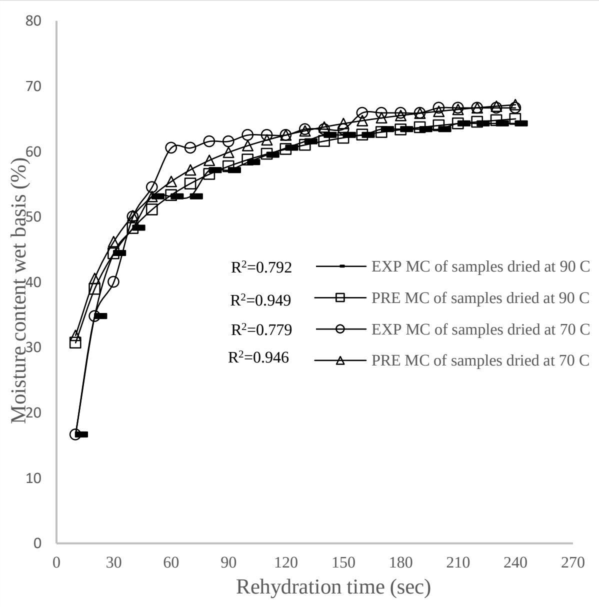

Fig. 5. Comparison between experimental and predicted moisture contents at 100ºC.

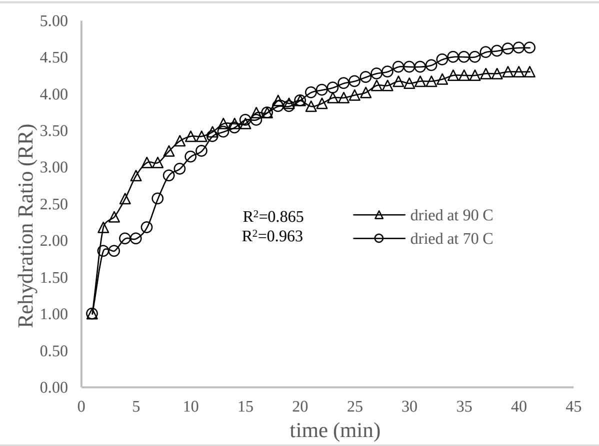

Fig. 6. Kinetic of RR changes of the samples rehydrated at 25℃.

Hizaji *et al.*, 2010 and 2011), amaranth leaves (Mujaffar and Lee Loy, 2016), Dumpling Wrapper (Chen *et al*., 2016), carrot (Kaleta *et al*., 2017) and edible films (Puscaselu, 2018) properly.

E. Rehydration Ratio (RR):

The rehydration ratio ranges between 1 and 5 for all the examined samples. Generally, dried celeries which were rehydrated at water temperature of 25℃, had higher levels of *RR*.

RR is a function of physical properties of samples and by reducing hydrophilic properties and water absorption efficiency, *RR* decreases (Krokida and Marinos-Kouris, 2003). So according to calculated rehydration ratios, the samples which were dried at 70℃ and rehydrated at 25℃ had the highest level of *RR* (4.82±0.926) but samples which were dried at 90℃ and rehydrated at 100℃ showed the lowest level of *RR* (3.69±0.635). These results (see Figs. 6 and 7) confirmed that the samples which were dried under gentler situation at lower temperatures

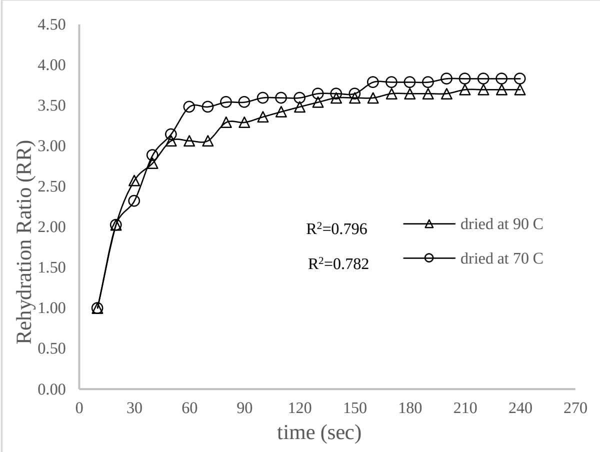

Fig. 7. Kinetic of RR changes of the samples rehydrated at 100℃.

and rehydrated at temperate water, could absorb more water and reach to higher levels of moisture content and RR. These results were confirmed by other researchers (Jokic *et al.*, 2009; Salimi Hizaji *et al.*, 2010 and 2011; Doymaz, 2014).

Ш. CONCLUSION

The highest final moisture content belonged to the samples which were dried at 70℃ and rehydrated at 25ºC water temperature. Usually dried products have low porosity and high density; In addition, destruction of texture and structure, can affect water absorption negatively. Obtained results showed that at water temperature of 25ºC, structural damages could be considered very low but it was remarkable at 100°C. On the other hand, dried celeries which were rehydrated at water temperature of 25℃, had higher levels of rehydration ratio (*RR*). As *RR* is a function of physical properties of samples, the ones which were dried at 70℃ and rehydrated at 25℃ had the highest level of *RR* (4.82±0.926) but the samples which were dried at 90℃ and rehydrated at 100℃ showed the lowest level of *RR* (3.69±0.635).

The Peleg's rate constant (K_1), decreased significantly while water temperature increased. It showed that water transfer was promoted by increasing water temperature. Also, the minimum amount of K_1 belonged to the sample which was dried at 70°C and rehydrated at 100°C. Since higher levels K_1 indicates the maximum rate of water absorption, it can be concluded that the samples which were dried at 70°C, had better structural quality. The Peleg capacity constant (K_2), increased slightly while water temperature increased. Increasing of K_2 values is a sign of lower water absorption capacity. This characteristic depends on many different parameters such as type, structure and chemical composition of samples. Since K_2 is related to water holding capacity, it can be concluded that the samples which were dried at 70°C had higher levels of water holding capacity due to less thermal damages on their structures during drying. Finally, it was concluded that Peleg model could be adequately fitted by experimental data and was adequate to describe kinetic of moisture content changes of celery cubes.

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