Effect of Time and Temperature on Moisture Content, Shrinkage, and Rehydration of Dried Onion

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Abstract

In this paper, the experimental data of the onion drying process by a batch cabinet dryer is investigated. Obtained experimental data including moisture content, shrinkage, and rehydration via random factorial scheme are analyzed. Comparison of data average is carried out with the help of the multi amplitude test of Duncan. Statistical analysis of experimental data shows that time, temperature, and their combined effect have a reasonable impact on the moisture content and rehydration value of dried samples. However, a combined effect of time and temperature on the shrinkage value is not meaningful (P>0.05). The results also show that increasing time and temperature leads to a decrease in the moisture content of the samples, but it increases the value of rehydration and the shrinkage of samples.

Keywords: *Drying, Onion, Moisture content, Rehydration, Shrinkage*

1- Introduction

Nowadays, the amount of agricultural waste is estimated to be about 30-35%, part of which is due to lack of relevant industries. One of the most important methods for food maintenance is drying or the dehydration process. In addition to the conservational effect on the product, drying reduces its weight and volume significantly and therefore decreases its transportation and storage costs.

Producing dried products such as pistachio, grapes, barberries, and saffron and many others are still common with traditional methods. Problems concerned with these methods are the long drying time, chance of microbial contamination of foods due to moisture, the undesirable quality of final products, an so on. By applying industrial drying methods, not only is food quality preserved, but also production time decreases considerably.

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With an annual production of 47 million tons, onion has the third place among vegetables globally. In the past, onion was used as a spice for nutritional and medical purposes. Recently, it has been used as a raw vegetable in foods, a spice in chips and also an ingredient in canned food.

Dried onion is available across the globe as an important and desired product in different forms including powder, flake, and slice. This product can be used as an aromatic ingredient in various foods such as soups, sauces, salads and desserts [1-4].

Hot air dryers such as the batch cabinet dryer are extensively used for drying biological products at commercial level. The drying time and operational temperature of these dryers have a major effect on the quality of dried product [5-11].

A detailed understanding of the rehydration process is essential for dried products optimization with respect to increasing their amount and expected quality by consumers [12-14]. During rehydration, two opposite mass transfer flows are contributed including the water transfer into nutrition and extraction of water-soluble substances in opposite directions. Pretreatment, drying and rehydration conditions result in structural changes in food tissues, affecting quality. Different factors such as temperature [15], the nature of the rehydration process, and type of nutrition [13] impact the rehydration amount. In the research done by Farid et al. [16] a mathematical model was developed based on water flow within capillary tubes. This model evaluates the rehydration amount of dried products including kiwi, apple, banana and potato by freezing method. In the Weiball empirical model that was used for modeling a carrot rehydration process, a shape parameter was also considered [12].

An important physical change that occurs during food drying is the decrease in the outer surface of the product. Losing water and heat both result in generating tension in the cell structure of the product, which causes deformation and dimension reduction [17-19]. Nutrition shrinkage has a negative effect on the quality of dried products. Deformation, volumetric decrease and hardness increase affect product overall acceptance by consumers.

Researches showed that shrinkage amount is greatly related to nutrition type and shape and in some cases to operational conditions with respect to different rates of drying. It is rarely possible to ignore the shrinkage amount in food material, and this physical change must be taken into account in evaluating profiles of moisture variations. In order to do this, different models have been suggested to investigate shrinkage in food materials during the drying process [20-22]. Shrinkage modeling is typically based on the definitions presented by Rahman [23] and Zogzos [24] and is a function of size, surface, volume or dimension reduction. These models are either empirical or fundamental. Empirical models are based on shrinkage amount and its relation to the operational parameters of drying. Fundamental models consider mass transfer, porosity, and density and take the volumes of different phases during the drying process into account.

With respect to the importance of the food drying process and obtaining a product with the desired quality and appropriate marketing, optimization of the operational conditions seems to be essential in order to

produce dried onion with minimum shrinkage and maximum rehydration capability, which has not been studied so far. Therefore, in this research, in addition to the investigation of onion drying kinetics in terms of temperature and time changes, the effects of these two parameters and their combination on moisture content, rehydration, and shrinkage of dried onion are studied. Furthermore, Mathematical modeling of this process is investigated using the surface-response method which includes the simultaneous influence of changes in drying temperature and time on moisture content, rehydration, and shrinkage of dried onion.

2- Materials and methods

White onion was used for all experiments. In order to perform all the experiments in identical conditions, onions are selected manually. All of the onions were placed in a refrigerating room at 4°C with a relative humidity of 17% for two weeks prior to experiments so that the storage conditions would be kept the same for all samples before drying. To start the experiments, the required numbers of onions were taken out of the refrigerating room and kept at room temperature for 2 hours, until they adapt to room conditions. Then they were layered and cut into circular pieces, 3 cm in diameter using a mold.

A batch cabinet dryer containing three perforated trays was used for drying the samples. In this device, the air velocity was constant and equal to 1.5 m/s. The thermal condition was variable and the operational temperature could be tuned with a built-in thermocouple.

12 experiments were performed at 4 temperatures of 60, 70, 80, and 90°C. The experiments were repeated 3 times at each temperature and experimental results were recorded. The obtained experimental results include the samples moisture contents on a wet and dry basis, shrinkage, and rehydration.

In order to investigate drying kinetics and moisture content, a dimensionless moisture ratio (MR) parameter was used that can be obtained from the following equation:

$$MR = \frac{X_t - X_e}{X_0 - X_e} \qquad (1)$$

Where X_0 is the initial moisture, X_e is the equilibrium moisture, and X_t is the moisture at time t.

To calculate the rehydration parameter, the dried sample is placed in a hot water bath at 100°C for 10 minutes. Then, the amount of rehydration is calculated by the equation presented below:

$$R' = \frac{M}{M_0} \qquad (2)$$

Where R' is the rehydration, and M and M_0 are the sample weight after and before placing it in the hot water bath, respectively.

The shrinkage percentage is expressed by equation (3):

$$\%S = \frac{V_0 - V_d}{V_0} \times 100 \qquad (3)$$

Where S is the shrinkage amount, and V_d and V_0 are the sample superficial volume

after and before drying, respectively.

One of the common methods for measuring the samples volume is sample submergence in a solvent. Thus, in choosing the solvent it should be kept in mind that the chosen solvent must be organic, does not react with the sample components, and has a lower density than the sample, so that the sample is fully submerged. Considering what is mentioned above, toluene or heptane are appropriate solvents for measuring the samples volume. Using a solvent such as toluene, the sample superficial volume is given by equation (4):

$$V = V_f - \frac{M_{t+s} - M_f - M}{\rho_s} \qquad (4)$$

Where V_f is the beaker volume, M_{t+s} is total mass of (the beaker, sample, and toluene), M_f is mass of the beaker, M is mass of the sample, and ρ_s is the toluene density.

The obtained experimental data including moisture content, shrinkage, and rehydration were analyzed via random factorial scheme. Comparison of the data average was carried out with the help of the multi amplitude test of Duncan. The Mstatc-Ver ½ Software was used for this purpose. The time and temperature combined effects on the moisture content, shrinkage, and rehydration of the samples were modelled using the surface-response fitting method. The Minitab Release 11.12 Software was used for surface-response fitting.

3- Results and discussion

3.1- Drying kinetics and moisture content

Analysis of the experimental data shows that onion drying occurs only in the falling rate zone. Drying rate can be defined as moisture content on dry basis in unit of time. Drying rate decreases with time in four experimental temperatures, a result of the decrease in moisture content as time passes (Fig. 1). An increase in operational temperature in a certain time, leads to a decrease in the moisture content of the samples since the evaporation rate increases with increasing temperature (Fig. 2).
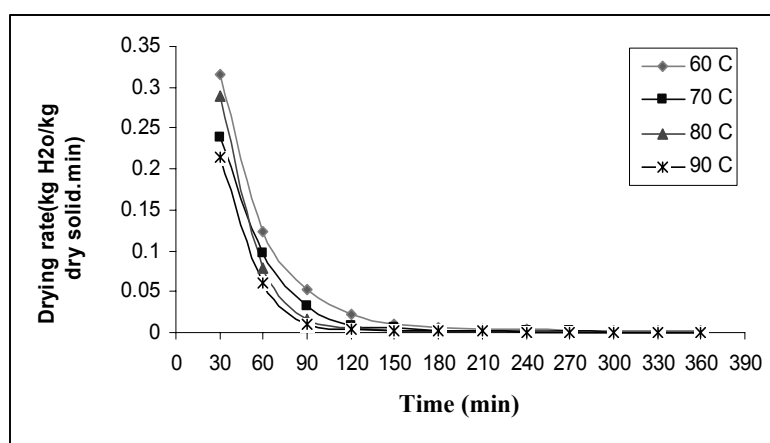

Figure 1. Influence of air temperature on the drying rate of samples in different times
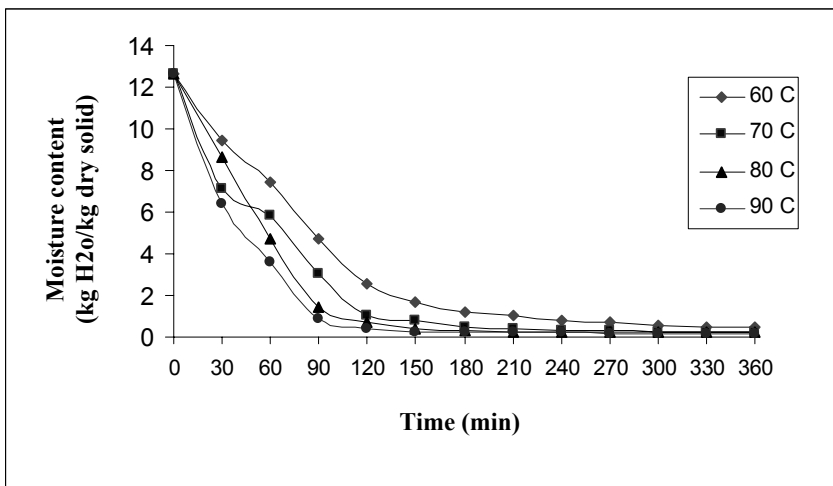
Figure 2. Dependence of moisture content on the drying time and temperature of samples

The results of variance analysis of moisture content are listed in Table 1. In this table, degree of freedom and sum of squares for each factor are estimated according to the number of considered levels and the obtained experimental data. In the 4th column, the ratio of sum of squares for each factor to its degree of freedom is given as mean square. F-value quantity is equivalent to the ratio of mean square of each factor to the error value shown in the fifth row and fourth column (mean square of error) of the table. It is a criterion for accepting the effectiveness assumption of each factor. Probability values have been determined from special tables with respect to the values of some of the above mentioned parameters. Probability values in the final column must be less than 5% for accepting the effectiveness assumption. So the results of this column in Table 1 show that temperature, time, and their combined effect have a reasonable impact on the moisture content of the samples.

Table 1. Effect of different parameters on moisture content with respect to variance analysis

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
Temperature	3	49.25	16.42	20.88	0.00
Time	11	850.82	77.35	98.38	0.00
Time and Temperature	33	48.22	1.46	1.86	0.01
Error	96	75.48	0.79	_	_
Total	143	1 023.77	_	_	_

Fig. 3 shows the temperature effect on moisture content. The moisture content of the samples decreases with temperature, so that the most and least moisture content on dry basis, i.e. 2.721 and 1.148, belong to the sample dried at 60°C and 90°C, respectively. Using meaningful letters on the base of Least Significant Difference (LSD) comparative analysis method, the differences between the obtained results of each level are also shown on this figure. As usage of different letters of a, b and c, which are named decreasingly from higher to a lower amount, indicates that their corresponding temperature levels (60°C, 70°C and 90°C) have a meaningful difference with each other, but as moisture content decreases mildly at higher temperatures, at 80°C the value of this parameter is close to the value of its adjacent levels. Thus the combined letter of ab is used to characterize this level.

Fig. 4 shows the time effect on the moisture content. There is a reduction in moisture content as time passes; furthermore, there is no considerable statistical variation in the moisture content of the samples after the 120th minute.

In this study, the surface-response fitting method was used in order to study the combined effect of time and temperature on the dried sample characteristics. Fig. 5, which shows the surface response of moisture content on dry basis, implies that the moisture content of the samples decreases with increasing time and temperature, although the time variations of the moisture content is less in the final stages of the drying process. Fig. 6 shows the contour lines of the moisture content in different drying times and temperatures. It is obvious that drying time decreases with increasing temperature.
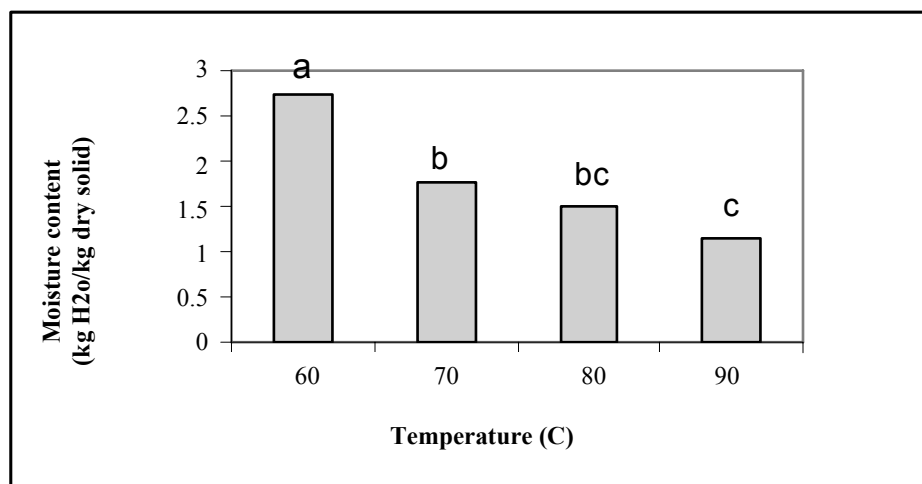

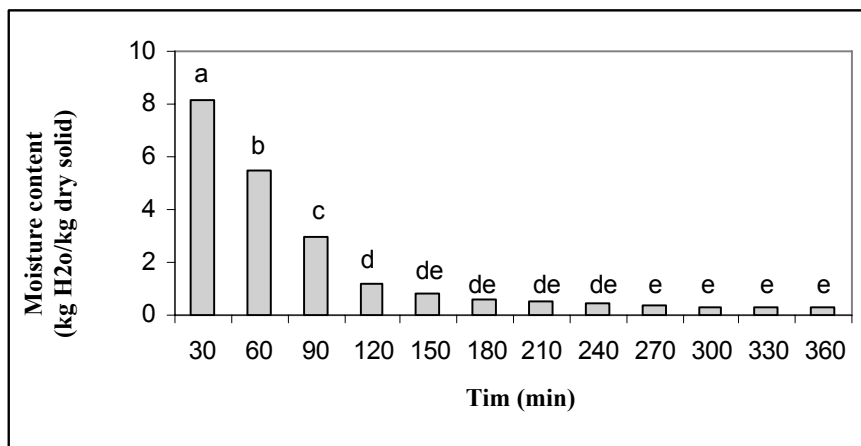**Figure 3.** Temperature effect on the moisture content of samples

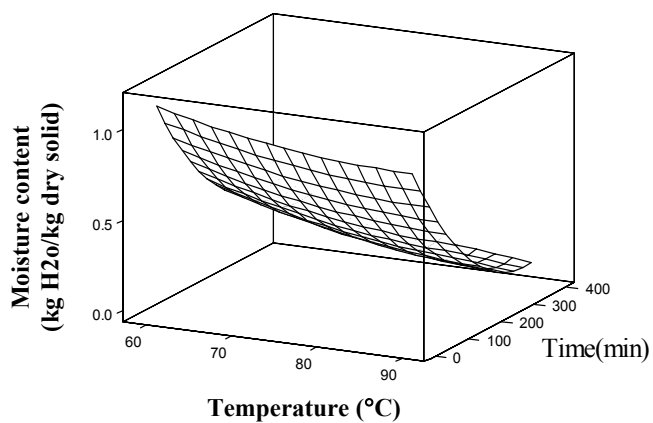**Figure 4.** Time effect on the moisture content of samples

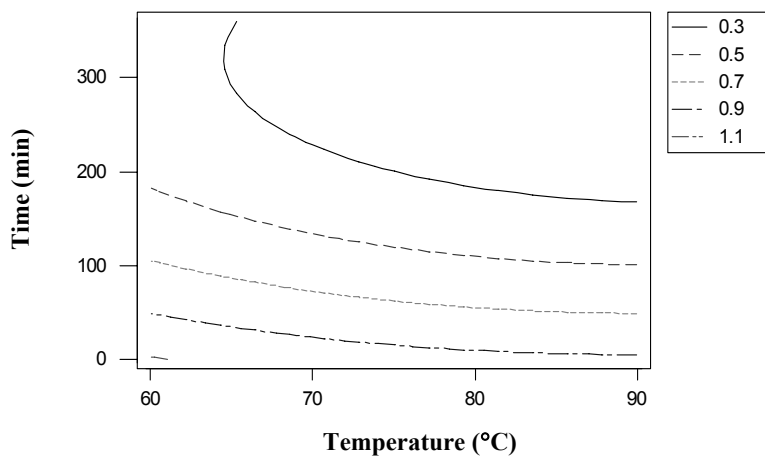**Figure 5.** Surface response of moisture content on wet basis versus time and temperature

Figure 6. Contour lines of moisture content on wet basis at different drying times and temperatures

3.2- Shrinkage

With respect to variance analysis of shrinkage which is listed in Table 2; time and temperature have a reasonable impact on the value of the dried samples shrinkage ($P<0.05$), but their combined effect is not meaningful ($P>0.05$).

Fig. 7 shows the effect of temperature on shrinkage value. The increasing effect of temperature on the value of shrinkage is obvious. Furthermore, according to meaningful letters there is a considerable difference in shrinkage value among each of the four temperature levels.

Fig. 8 shows time effect on shrinkage value. The highest and lowest shrinkage value, i.e. 92.79% and 33.10%, belong to the sample placed for 360 and 30 minutes in the dyer,

respectively. Furthermore, there is a considerable statistical difference in the value of shrinkage among the dried samples at primary times.

With respect to Figs. 7 and 8, there is an obvious increasing trend in the value of shrinkage, while time and temperature increase. Actually, the increase in time and temperature increases the amount of heat given to food material which results in a decreasing moisture content of the sample. Therefore, contractile stresses occur in the cellular structure of the food material which intensifies shrinkage. However, the value of shrinkage becomes constant at the final stages of the drying process, which is the result of the sample structure stabilization made by a firm layer formed on its surface.

Table 2. Effect of different parameters on shrinkage with respect to variance analysis

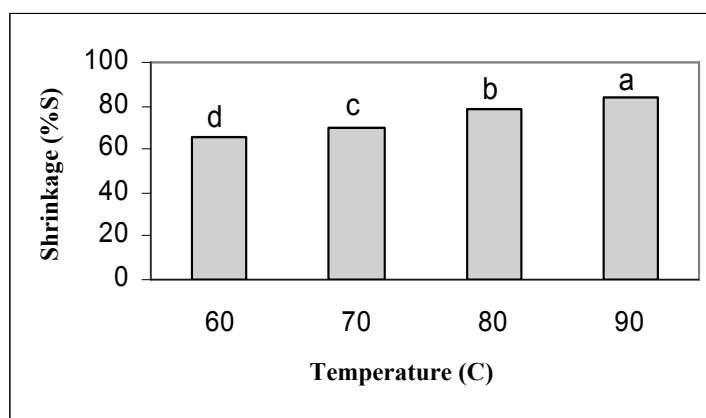| Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
Temperature	3	85.42	28.47	25.62	0.00
Time	11	83.91	7.63	6.86	0.00
Time and Temperature	33	40.39	1.22	1.10	0.35
Error	96	106.69	1.11	_	_
Total	143	316.41	_	_	_

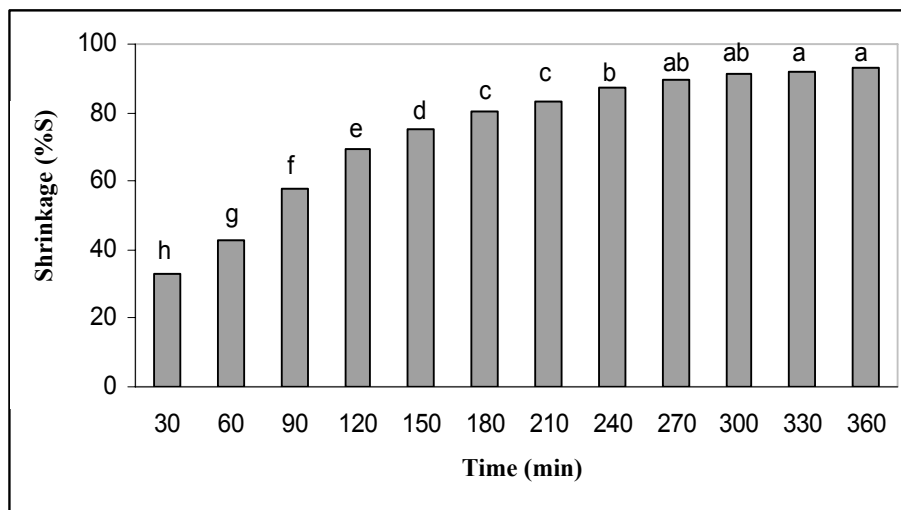**Figure 7.** Temperature effect on value of shrinkage

Figure 8. Time effect on value of shrinkage

With respect to Fig. 9 which shows the surface response of shrinkage value with time and temperature, shrinkage increases with increasing time and temperature and finally gains a constant value.

Fig. 10 shows the contour lines of shrinkage value at different times and temperatures. Required time for reaching a certain value of shrinkage increases with decreasing temperature.
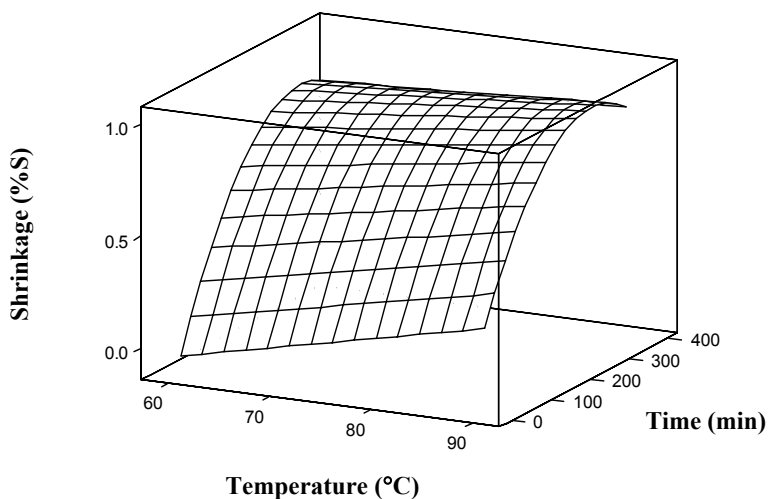

Figure 9. Surface response of shrinkage value versus time and temperature
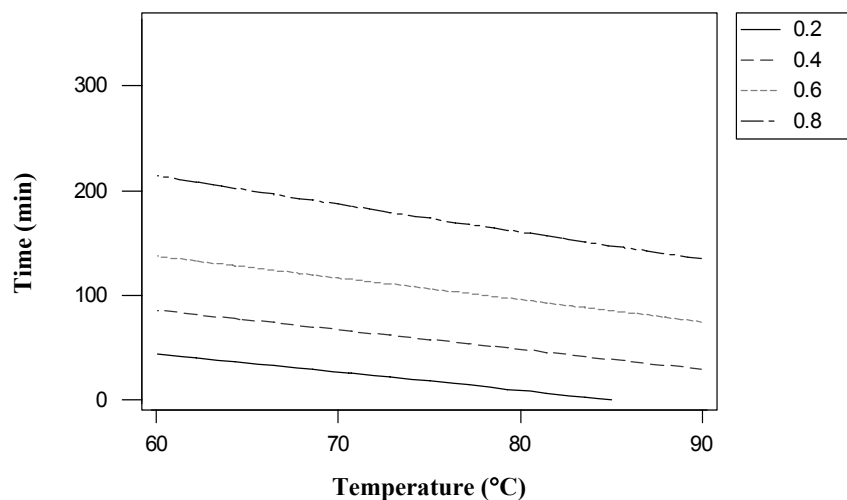
Figure 10. Contour lines of shrinkage value at different drying times and temperatures

3.3- Rehydration

With respect to variance analysis of rehydration which is listed in Table 3, time and temperature and their combined effect have a reasonable impact on the rehydration of the samples ($P<0.05$).

Fig. 11 shows the temperature effect on the rehydration of samples. There is no considerable statistical difference among temperatures 70, 80, and 90°C.

With respect to Fig. 12 which shows the time effect on rehydration, the highest and lowest value of rehydration, i.e. 4.038 and 1.449, belong to the sample placed for 360 and 30 minutes in dryer, respectively.

Table 3. Effect of different parameters on rehydration with respect to variance analysis

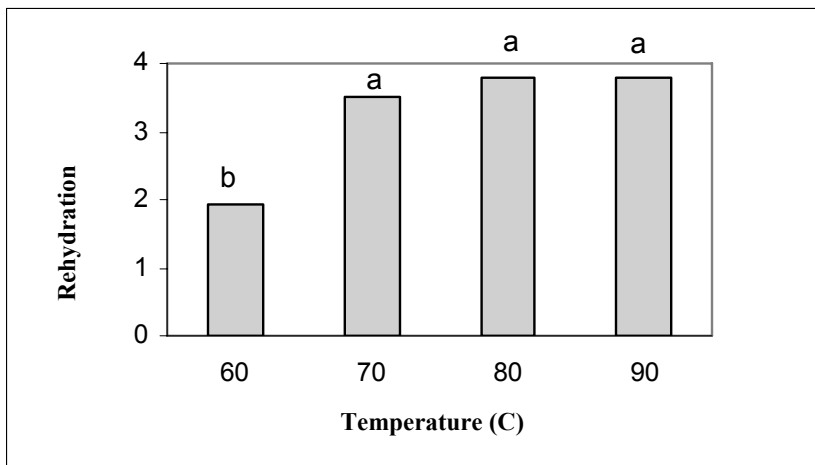| Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob.
Temperature	3	7 656.27	2 552.09	107.37	0.00
Time	11	52 941.28	4 812.84	202.47	0.00
Time and Temperature	33	3 265.03	98.94	4.16	0.00
Error	96	2 281.93	23.77	_	_
Total	143	66 144.51	_	_	_

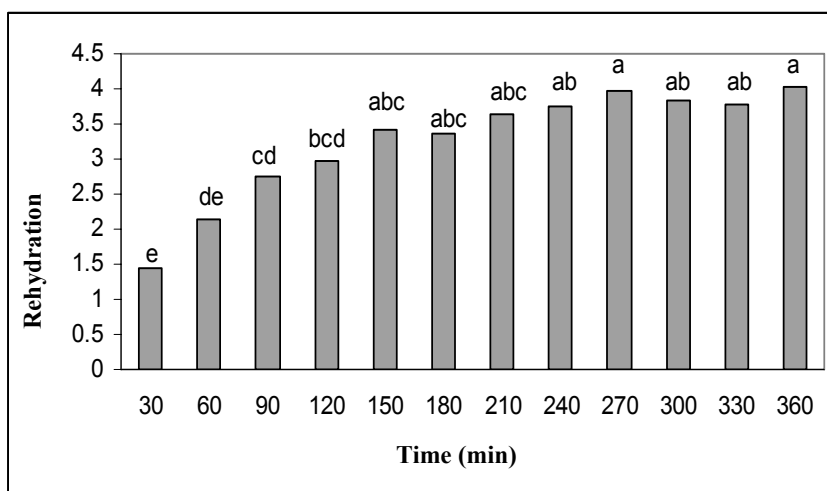**Figure 11.** Temperature effect on value of rehydration

Figure 12. Time effect on value of rehydration

With respect to Figs. 11 and 12, rehydration has an increasing trend with increasing time and temperature since these two parameters have an increasing effect on the samples shrinkage which makes the cellular structure of the samples more porous.

Fig. 13 shows the surface-response of the rehydration value. The rehydration value increases with time and temperature, however, temperature has no considerable effect at final temperatures.

Fig. 14 shows the contour lines of the rehydration value at different times and temperatures of drying. The required time for reaching a certain value of rehydration decreases with increasing temperature.
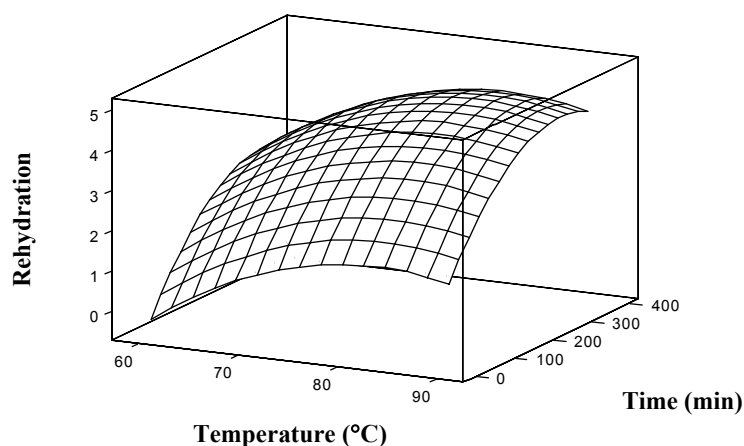
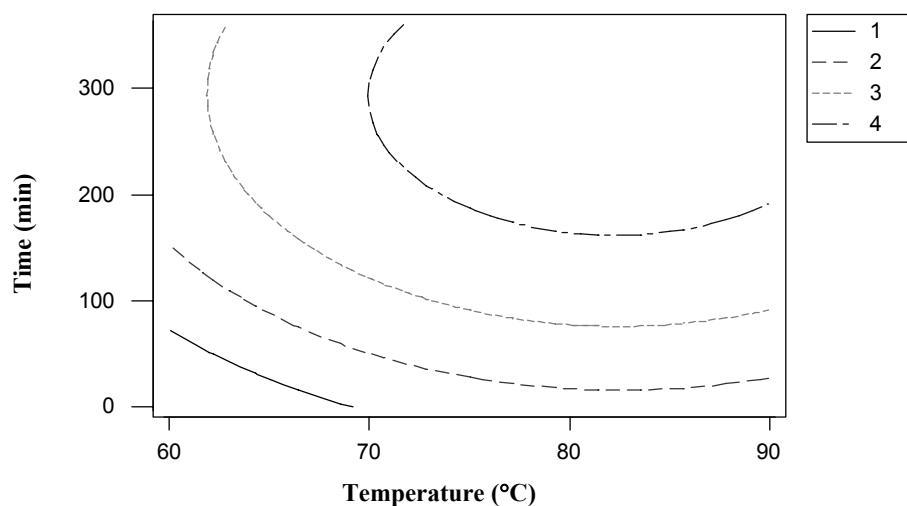**Figure 13.** Surface response of rehydration value versus time and temperature

Figure 14. Contour lines of rehydration value at different drying times and temperatures

Conclusion

Statistical analysis of the experimental data shows that time, temperature, and their combined effect have a reasonable impact on the moisture content and rehydration of dried onion (P<0.05). However, the combined effect of time and temperature on the value of shrinkage is not meaningful. With respect to the results, increasing drying time and temperature leads to a decrease in the moisture content. With increasing these two parameters, contractile stresses occur in the cell wall structure since the amount of heat given to food material increases. Therefore, the porosity of the dried samples increases leading to an increase in shrinkage and rehydration value. With respect to the contour lines plotted, there is a reduction in the time of drying with increasing drying temperature.

References

1. Kaymak-Ertekin, F. and Gedik, A., "Kinetic modeling of quality deterioration in onions during drying and storage," *Journal of Food Engineering*, 68, 443 (2005).

2. Sharma, G.P., Verma, R.C., and Pathare, P.B., "Thin-layer infrared radiation drying of onion slices," *Journal of Food Engineering*, 67, 361 (2005).

3. Sharma, G.P., Verma, R.C., and Pathare, P., "Mathematical modeling of infrared radiation thin layer drying of onion slices," *Journal of Food Engineering*, 71, 282 (2005).

4. Praveen Kumar, D.G., Ramesh, M.N., and Umesh Hebbar, H., "Suitability of thin layer models for infrared–hot air-drying of onion slices," *Journal of Food Technology*, 39, 700 (2006).

5. Bondaruk, J., Błaszczak, W., and Markowski, M., "Effect of drying conditions on the quality of vacuum-microwave dried potato cubes," *Journal of Food Engineering*, 81, 306 (2007).

6. Bouraout, M., Richard, P., and Durance, T., "Microwave and convective drying of potato slices," *Journal of Food Process Engineering*, 17, 353 (1994).

7. Maskan, M., "Microwave/air and microwave finish drying of banana," *Journal of Food Engineering*, 48, 169 (2000).

8. Lewicki, P. P., "Design of hot air drying for better foods," *Trends in Food Science & Technology*, 17, 153 (2006).

9. Mongpraneet, S., Abe, T., and Tsurusaki, T., "Accelerated drying of welsh onion by far infrared radiation under vacuum conditions," *Journal of Food Engineering*, 55, 147 (2002).

10. Ratti, C., "Hot air and freeze-drying of high-value foods: A review," *Journal of Food Engineering* 49, 311 (2001).

11. Yongsawatdigul, J. and Gunasekaran, S., "Microwave-vacuum drying of cranberries: Part II. Quality evaluation," *Journal of Food Processing and Preservation*, 20, 145 (1996).

12. Garcia-Pascal, P., San Juan, N., Melis, R., and Mulet, A., "Morchella esculent (morel) rehydretion process modeling," *Journal of Food Engineering*, 72, 346 (2006)

13. Machado, M.D.F., Oliveira, F.A.R., Gekas, V., and Singh, R.P., "Kinetics of moisture uptake and soluble solids loose by puffed breakfast cereals immersed in water," *International Journal of Food Science and Technology*, 33, 225 (1998).

14. Park, K.J., Vohrikova, Z., and Bord, F.P.R., "Evaluation of drying parameters and desorption isotherms of garden mint leaves (Mentha Crispal)," *Journal of Food Engineering*, 51, 193 (2002).

15. Abdel-Kaber, Z.M., "Study of some factors affecting water absorption by faba beans during soaking," *Food Chemistry*, 53, 235 (1994).

16. Farid, M., "Misconceptions in the analysis of heat and mass transfer in drying and frying," In Proceedings of *The Int. Drying Symposia*, Beijing, China, (2003).

17. Mayor, L. and Sereho, A.M., "Modeling shrinkage during convective drying of food materials," *Journal of Food Process Engineering* 61, 373 (2004).

18. 18. Ruiz-López, I. I. and García-Alvarado, M. A., "Analytical solution for food-drying kinetics considering shrinkage and variable diffusivity," *Journal of Food Engineering*, 79, 208 (2007).

19. Ratti, C., "Shrinkage during drying of foodstuffs," *Journal of Food Engineering*, 23, 91 (1994).

20. Clements, G., Bon, J., Carcel, J.A., Garcia-Pascual, P., and Mulet, A., "Meat shrinkage during drying," proceedings of *The 8th Int. Cong. on Engineering and Food*, Mexico, (2000).

21. Panyawong, S. and Devahastin, S., "Determination of deformation of a food product undergoing different drying methods and conditions via evolution of a

shape factor," *Journal of Food Engineering*, 78, 151 (2007).

22. Queiroz, M.A. and Nebra, S.A., "Theoretical and experimental analysis of the drying kinetics of bananas," *Journal of Food Engineering*, 47, 127 (2001).

23. Rahman, M.S., Perera, C.O., Chen, X.D., Driscoll, R.H., and Potluri, P.L., "Density, shrinkage, and porosity of Calamari Mantle meat during air drying in a cabinet dryer as a function of water content," *Journal of Food Engineering*, 30, 135 (1996).

24. Zogzos, N.P., Maroulis, Z.B., and Marino-Kouris, D., "Densities, shrinkage and porosity of some vegetables during air drying," *Dryinrg Technology*, 12 (7), 1653 (1994).