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SYNTHETIC MATHEMATICAL MODELING OF CARROT CUTS DRYING AND ITS CONSUMED ENERGY BY MICROWAVE METHOD

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ABSTRACT

In this research, drying synthetic of carrot cuts were investigated and modeled in microwave drying method (in powers 90 , 180 , 360 , 60 and 900 w).Modeling was applied via 12 models and their fitting quality were measured. After drying experiments, color changes (Lab), rehydration and vitamin C were measured in the samples studied , as well as the energy used in drying experiments with different powers were calculated. Comparing models indicated that was more fit to estimate humidity changes and describing carrot drying behavior .Results also showed that the role important of microwave power in drying process in which increasing power cause to reduce drying time, the least and the most consumed energy were related to power 90 w and 360, 600w respectively.

Keywords: Synthetic, mathematical modeling, microwave, carrot cuts

INTRODUCTION

Carrot is one of the most important vegetables used by men around the world. This vegetable is a pre-producing factor of vitamin A due to having rich sources of beta carotene **(Singh *et al*, 1999)**. Also this vegetable has high cellulosic contents and is used in the form of raw, cooked and salty too. High use of vegetables and fruits around the world has caused innovation of various methods for processing and preserving this food product. One of the most general methods is drying and then storing it **(Akpinar *et al*, 2006).** Drying operation is one of the most important operations in industrial processes of food. This method is one of the oldest methods for preserving food products and this shows that appearance has high importance in food processes **(Motevalli *et al*, 2009).** Drying fruits and vegetables is one of the oldest and widest methods for preserving food and is the most important processes for preserving the quality of food products. The main aim of drying agricultural products is to decrease the moisture so that these products can be preserved for a long time. With decreasing microbial and enzymatic activities and decreasing the rate of chemical interactions the time of preserving product will increase and with remarkable decreasing of their weight and volume the costs of packaging, storing and transporting will decrease too**(Akpinar *et al* ,2006).** In common industrial dryers with hot air since the heat conduction is low the energy efficiency will decrease and more time is necessary for drying. Regarding these issues today other drying methods have been considered such as drying by micro wave **(Zirjani *et al*, 2006).**Contrary to other methods in which the heat must come to the depth from the surface, in this method the heat is produced inside the food product. The study of in kinetics investigation and modeling the drying process of thin layer of carrot with vacuum microwave indicated that drying on the basis of dry weight usually happens in constant intensity and in descending stage and the curves of practical and theoretical moisture ratio were in fit. In drying carrot by three methods of micro wave, halogen lamp and hot air methods reported that with increasing the power of micro wave the time of drying will decrease. Also drying with micro wave in comparison with hot air can decrease the time of drying to 98% along with producing a dry crop having high quality **(Abassi Surki *et al*, 2009)**.
In the test of color and re-absorption of water it is proved that the samples dried by micro wave had higher quality than the samples of other methods. in drying carrot cuts with 3 methods of micro wave, hot air and freezing found that drying with micro wave is very good method and the quality properties of the crop such as re-absorption of water, vitamin C , color and texture properties of the crop will be improved **(Tein *et al*, 1998)**. In investigating the energy consumption of drying the beads of pomegranate with micro wave reported that the least level of energy consumption is obtained in drying with the power 200 watts. They also reported that drying process is influenced by the power of micro wave and the primary moisture of the product so that with increasing the power of micro wave the rate of drying will increase **(Motevvali *et al*, 2009)**. Also in other studies of the leaves of spinage were dried by micro wave and by convection method and the combination of micro wave and convection and the influence of them on the time of drying, the evaporation rate and the changes of color were investigated and compared **(Karaaslan *et al*, 2008).** The aim of this study is to investigate the influence of drying with micro wave on the quality of dried carrot, to investigate kinetics of drying with micro wave, to select the best model for describing the process of drying carrot with micro wave and to compute the level of its energy consumption.

MATERIAL AND METHODS

Preparing Samples and Measuring Moisture

The carrot for this daily study was purchased from the local market of Gorgan and was preserved in refrigerator. In any turn of daily test the samples were removed from the refrigerator and they were cleaned and washed and then skinned. Then the samples were cut to the thickness 3+_0/015 millimeters and were prepared. The samples 100 grams were dried with the precision 0/001 grams after preparing and weighing by scale A&D GF-6100 Japan using Oven (Iranfater electronic U670) in temperature 1+_ 105 degrees of centigrade's for 15 hours for determining the content of moisture (MC) so that no changes in weight was observed between two weightings. Then the primary moisture content was obtained in terms of wet weight. The moisture contents on the wet and dry basis were obtained with equations 1 and 2:

Equation 1: on the wet basis

$$MC_{w.b.} = \frac{m1 - m2}{m1} \times 10$$

Equation 2: on the dry basis

$$MC_{d.b.} = \frac{MC_{w.b.}}{100 - MC_{w.b.}} \times 10$$

In which:
$MC_{w.b}$ is the content of moisture on the wet basis, MC $_{d.b}$ is the content of moisture on the dry basis, m1 is the weight of samples before drying (gram) and m 2 is the weight of sample after drying (balancing moisture)(gram).

Drying with Micro Wave

In this process the samples 100±0.05 grams were prepared and were dried by micro wave (LG-solarDOM, Australia). Drying was performed in intensities 90, 180, 360, 600 and 900. In order to investigate the kinetics of drying and to draw the related curves the prepared samples were placed in oven after weighing and recording the weight. In successive times every 10 minutes to the first 2 hours and then 30 minutes for the method of hot air and in time intervals every 300 seconds (90 watts), 180 seconds (180 watts), 90 seconds (360 watts), 60 seconds (600 watts) and 30 seconds (900 watts) for micro wave the samples were removed from dryer and were weighed and then they were placed in dried again. This action was repeated until the sample reached the constant weight **(Abbasi Souraki *et al*, 2009**).

Investigating Kinetics of Drying Carrot

Moisture Ratio

In the most researches the kinetics of drying has been reported on the basis of moisture ratio index. The reason is decrease of spread and arranging the data. Also in this study the equation 3 was used for computing moisture ratio of celery leaves during the process of drying.

Equation 3:

$$MR = \frac{Mt - Me}{M0 - Me}$$

In which:
M_R is moisture ratio (without dimension), M_t is the sample moisture on the basis of dry weight in time t, M_0 is the primary moisture on the dry basis, M_e is the content of balancing moisture on the dry basis.

Drying Rate (DR)

The rate of drying is computed by equation 4.

Equation 4:

$$DR = \frac{(m_0 - m_1) \times 60}{(t_2 - t_1) \times m_2}$$

In which:
DR is the rate of drying, m_0 is the weight of sample in time t_1, m_1 is the weight of sample in time t_2, m_2 is balancing moisture and t_1 is the primary time.

Dry Modeling

For mathematical modeling of drying samples the moisture ratio during drying was used (equation 3). The models of curve of drying carrot were selected on the basis of recommended models by the authors worked in this regard. They have been brought in table 1. The ratio of moisture obtained during the test with 12 models among the standard models of drying was compared. These equations are derived from the relationship between the changes of moisture content and the time of drying.

Table1 Selected models for describing the process of drying carrot

Power	Model Constant	χ2	R2	RMSE
90	K=0.0022, a=0.999, b= -0.000638, n=1.305	0.00016	0.9990	0.00012
180	K=0.004, a1.020, b=-0.000179, n=0.848	0.00008	0.9999	0.00075
360	K=0.000385, a=0.987, b= -0.000121, n=1.022	0.00001	0.9999	0.0036
600	K=0.004740, a=0.982, b= -0.000248, n=1.012	0.00004	0.9990	0.00530
900	K=0.0075, a=1.002, b= -0.000565, n=1.142	0.00006	0.9989	0.01210

After computing MR, 12 models were added to the acquired data from different stages of drying in order to obtain the best model and their coefficients using the non linear regression and the software Excel. Among 3 criteria of determination factor (R2) the square of K (X2) and square medium root of date error (RMSE) were used for evaluating the best model. The criteria of selection the best model of describing the manner of drying were the most amount of R2 and the least amount of RMSE. Then the selected coefficients (equation constants) were placed in relation with variables used in drying process using Solver in software Excel. So the general equation was obtained which was able to predicate the specifications of drying carrot cuts in tested conditions. Three criteria of correlation factor (R2), K (X2) and RMSE were used for confirming the presented model. They are computed by equations 5 and 6:

Equation 5:

$$x^2 = \frac{\sum_{I=1}^{N}(MR_{expt} - MR_{prei})^2}{N - m}$$

Equation 6:

$$RMSE = (\frac{1}{N}\sum_{I=1}^{N}(MR_{Pre,i} - MR_{exp,r})^2)^{\frac{1}{2}}$$

In which $M_{rexp,I}$ is the ith test data of drying rate, $M_{rpre,I}$ is predicated data of drying rate, N is the number of observations and m is the number of constants of the equation of drying rate. All steps and tests in this study were performed 3 times. The results of the influence of temperature and power of drying on the time of drying were investigated three times by completely random design with temperature treatment of dryer in 3 temperatures 50, 60 and 70 degrees of centigrade and 5 levels of power 90, 180. 360, 600 and 900. The average treatments were compared by software SAS (version 9/3, 2011) and Duncan Test (α<0.05).

Quality Properties

Color

In order to investigate the color of samples the software ImageJ2x was used so that firstly some images were prepared under similar conditions from the surface of dried samples with high quality. Then the color parameters L, a and b were obtained by the software. Each step of test was repeated 5 times. Then color difference of product in relation with primary product (EA) was computed by equation 7. The component L determines the level of brightness or darkness of the product and is in the range 0-100. The number 100 shows the white color and 0 shows the black color. The positive amounts of A show the color of red and 0 shows the color of gray and negative amounts show the color of green. For the component b if it is positive it means yellow color and if it is negative it means blue.

Equation 7:

$$[\Delta^{1/2} + (\Delta b)^2]E = (\Delta L)^2 + (\Delta a)^2$$

Rehydration Ratio (RR)

In this test the dried samples of carrot firstly were weighed and then 5 grams of them were submersed in breaker containing 200 milliliters distillated water in the laboratory temperature so that no addition in weight is observed (approximately 15 hours). Then the samples were removed from the distillated water and were spread on the filter paper so that the surface water was removed. Then the samples were weighed again and finally the capacity of rehydration was computed by equation 8.

Equation 8:

$$RR = \frac{m_{AR}}{m_{BR}}$$

In which:
RR is the rehydration ratio, m_{RA} is the weight of sample after dehydration and m_{BR}(g) is the weight of sample after dehydration (g).

Vitamin C

The amount of vitamin C in samples was computed by the method of titration 2 and 6- dichlorophenolandophenol. In this test some specific amounts of net vitamin C was solved in 100 milliliters distillated water in order to prepare standard solution. For determining the amount of vitamin C in the observer sample some specific amounts of standard solution were titrated with indophenols so that the pale red color (pink) was obtained. The extraction was performed using acid acetic 99/5% manufactured by the company of Doctor Mojallali. For extraction first the samples were placed in 100 milliliters acid acetic and then they were mixed by glass mixer and finally the extraction obtained was separated by filter paper for conducting titration. The titration of extract obtained was performed by chlorophenol too.

Computation of Consumed Energy

For computing consumed energy after each test the time during which the unit was on is noted and regarding to the specified consumed power the consumed energy of each test was computed according to equation 9.

Equation 9*:*

$$W = P \times t$$

In which:
W is consumed energy in terms of watt-hour, P is consumed power of micro wave in terms of watt and t is the time during which the unit was on in terms of hour.

RESULTS AND DISCUSSION

The Influence of the Power of Microwave

Figure 1 indicates the changes in moisture content in different powers. As indicated with increasing the power of microwave the time of drying decreases because with decreasing air pressure the temperature of water evaporation decreases and the moisture inside product is removed in lower temperature. Also the required time for decreasing specific amount of moisture depends on the operation conditions so that in power 900 watts about 500 seconds and in power 90 watts about 2750 seconds time was necessary for moisture to be removed from the sample completely.

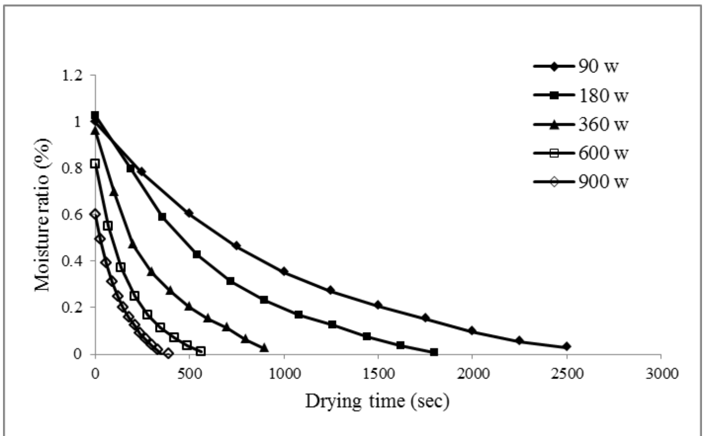

Figure 1 the graph of the influence of power on the time of drying

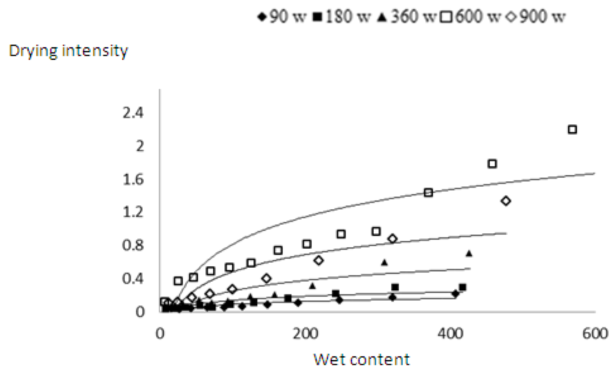

Figure 2 the graph of the influence of power on the rate of drying

Regarding figure 2 with decreasing moisture content the rate of drying decreases because the moisture must be transmitted from the center of sample to the surface and then it must be evaporated. The rate of micro wave beam is the most important factor in controlling quality properties of the product during drying. The influence of drying rate of micro wave on quality properties of the dried carrot cuts was meaningful.

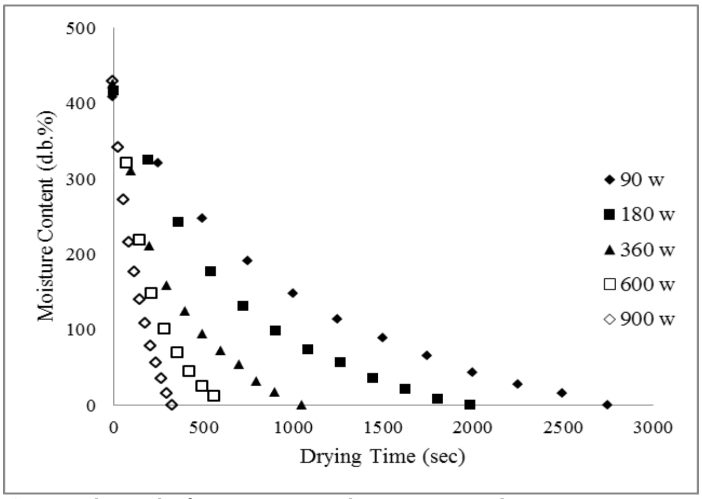

Figure 3 The graph of moisture ratio in drying process with micro wave

Also figure 3 indicates the moisture ratio graph in drying process of mint with micro wave. As indicated the influence of power of micro wave on moisture ratio is meaningful too. Results obtained were in accommodation with the results of the study of **Akpinas *et al* .(2006)**, **Doymas et al. (2006)**, and **Dortay and Zhu (2009).**

Measuring Color

The results and the amounts obtained by the tests of colors indicated that drying in different powers of micro wave was meaningful for color parameters L, a and b of dried carrot samples in the level 5%. The results of this test were in accommodation with the results of other studies. The amounts of measuring color parameters L, a and b have been indicated in table 2.

Table2 the amounts of rehydration ratio in dried samples

	Microwave power				
Color Index	90	180	360	600	900
L	39.13 [a]	38.44 [a]	33.82 [c]	32.77 [c]	34.2 [b]
a	25.87 [a]	24.75 [a]	23.98 [c]	23.13 [c]	24.95 [a]
b	25.42 [a]	24.75 [a]	19.30 [b]	18.47 [b]	22.63 [b]

Rehydration Measurement

Investigating the results of the tests related to rehydration indicated that there is no meaningful difference among different powers of drying ($\alpha<0.05$).
In general case it is accepted that the amount of rehydration depends on the degree of degradation of structural cell. Because the hydration process and its amount has direct relation with texture of the product and the level of porosity it can be deduced that the power of micro wave beam has more influence on the texture of the sample in higher powers and has caused more porosity in it. Also among all dried samples the most amount of rehydration is related to drying samples in power 600 watts of micro wave. It can be a reason for more degradation of texture and creating more porosity in dried samples in this power with micro wave. The results of the tests of rehydration have been indicated in table 3.

Table 3 the amounts of rehydration ratio in dried samples

	Microwave Power (W)				
Drying Treatment	90	180	360	600	900
Rehydration (%)	[a]5.93	6.22 [a]	6.48 [a]	6.75 [a]	6.7 [a]

Vitamin C

The amounts obtained by the tests of measuring vitamin C have been indicated in table 3. In these tests the most amount was related to dried samples in 90 watts and the least amount was related to dried samples in 900 watts. The reason can be unfavorable influences of high powers of dryer and higher power of beam in higher levels. The results showed that there is meaningful difference between power 90 watts and the other powers of dryers in the level 5%. The results of this test were in accommodation with the results of the tests of **Doymaz *et al*. (2006)**.

Table 4 the amounts of vitamin C in dried samples (mg100g-1)

	Microwave Power (W)					
Drying Treatment	Control	90	180	360	600	900
Vitamin C	68.1a	61.17b	52.41c	51.24c	51.05c	49.17c

Modeling the Process of Drying with Hot Air and Micro Wave

In this step the experimental data of drying carrot in different powers were obtained by selected theoretical and experimental models. The results obtained by fitting of models tested in all treatments indicated that the Midili model has acceptable fitting with the moisture content in different treatments. Although the amounts of indexes of model selection had good fitting with the other models in most cases the level of fitting of Midili model had amounts of R2 higher than 0/99 and their RMSE was lower than other models. Although the amount of RMSE in most models was close to each other in other model there is more spread in RMSE. For evaluating fitting of mentioned models with data of the test two indexes RMSE and MBE must be the least in addition to higher R2 for the best fitting. The other authors reported similar results.

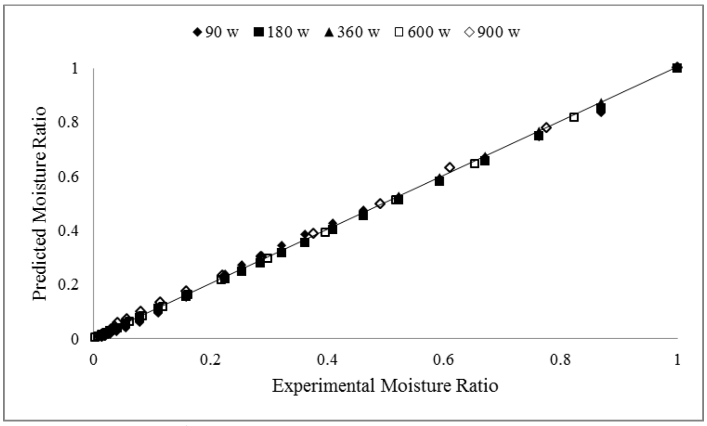

Figure 4 the graph of real and computed moisture ratio in the Midili model

The Amount of Consumed Energy

One of the very important factors in designing and evaluating dryers is the level of consumed energy. Drying with micro wave is one of the cheap methods and consumes energy less than other dryers. Carrot cuts are dried in different powers. The least amount of energy consumed was for power 90 watts with the amount 0/068 kwh and the highest amount was for the power 360 watts and 600 watts with the amount 0/105 kwh so that the amount of consumed energy in power 360 and 600 watts was approximately 1/5 times consumed energy in 90 watts.

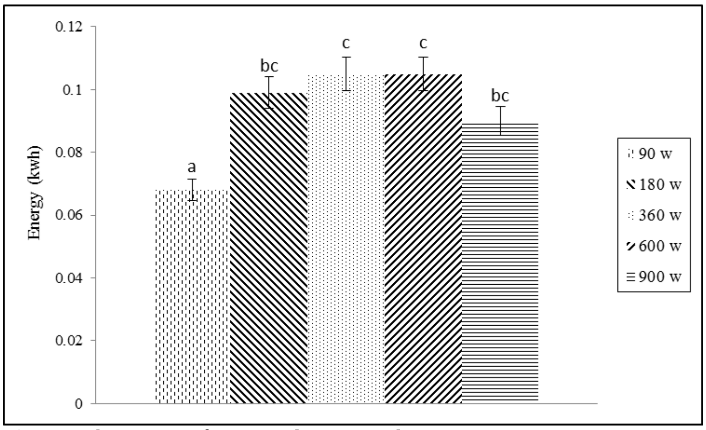

Figure 5 the amount of consumed energy in drying carrot cuts

CONCLUSION

In this study kinetics of drying thin layer of carrot with micro wave, modeling the process, quality properties of final dried samples and the amount of consumed energy of drying process were all investigated. The results showed that using the energy of micro wave causes improvement of structural properties of product in addition to rapid separation of water of the product but in high rate it can create some undesirable changes in samples. Also, the power of micro wave has main influence on the drying rate of carrot and with increasing the power of dryer the drying time will decrease and the process of drying happen in descending stage. The results of fitting of 12 selected mathematical models indicated that the model of Midili. was the best model for describing the behavior of drying carrot. According to the results of qualitative tests drying in high powers especially in 900 watts has more negative influence on dried samples. In the tests of color it is indicated that the samples dried in 90 and 180 watts had higher quality. The most amount of rehydration was for samples dried in the power 600 watts in micro wave. The most amount of vitamin C was for samples dried in the power 90 watts and the least amount was for 900 watts. The least amount of consumed energy was for drying in 90 watts and the highest was for 360 and 600 watts.

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