JMBFS

Journal of Microbiology, Biotechnology and Food Sciences

International peer-reviewed scientific online journal

Published by Faculty of Biotechnology and Food Sciences

STATISTIC MODELING OF DRYING KINETHIC OF SPINACH LEAVES USING MICROWAVE AND HOT AIR METHODS

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doi: 10.15414/jmbfs.2015.4.6.554-559

ARTICLE INFO

Received 8. 4. 2015
Revised 12. 5. 2015
Accepted 21. 5. 2015
Published 1. 6. 2015

Regular article

OPEN ACCESS

ABSTRACT

The target of this study was to model of spinach leaves drying using microwave and hot air dryer. This test performed in combination treatment of temperatures (50°C, 60°C, and 70°C) and microwave (90, 180, 360, 600 and 900w) in 3 replications. Sample moisture measured within drying. All the results were fitted and analyzed with 8 mathematical models base on 3 parameters including determination (R2), Chi square(X2), root mean square errors(RSME). Results also revealed that temperature and microwave power effectively reduce the drying time when increase. Drying occurs in degrading stage; moreover the comparison of results exhibited that Page and Two sentences models were fitted appropriately to estimate moisture changing and drying description. Regarding all the results, it is cleared that microwave method is an appropriate method in spinach drying as a result of reducing drying temperature and its high efficiency.

Keywords: Kinetic, microwave, spinach, hot air

INTRODUCTION

Drying of fruits and vegetables is one of the so-called and well reputed methods in preservation and keeping quality of foodstuffs. The main target in drying of agriculture products is reduction of moisture to a level at which long shelf life becomes possible, besides decrease of enzymatic, microbial and chemical activities, along with increase of shelf life lead to diminish their weight and volume and facilitates transportation (**Akpinar *et al*, 2006**). The history of dried products in Iran refers to ancient times, predominant changes have occurred in processing of food products. Common industrial dryers due to low heat transfer, drying time lengthen thus nowadays other methods of food drying such as microwave have been considered (**Zirjani *et al*, 2010**). Unlike other drying methods at which heat must penetrates from surface to depth, in modern methods heat takes place in inner parts of foods. New methods in improvement and development of food stuffs have led to create standard combined drying methods. Spinach, *Spinacia oleracea*, is Iran native vegetable and has acceded from Iran to other parts of the world in the beginning of first anno domini century so that spinach has been cultivating in china and Spain in 12^{th} century. Spinach is rich in Vitamin C and B_3 and therefore can be regarded as an important drug in treating of diseases. **Doymaz et al. (2006)** found that in drying of thin layers of mint in cabinet drying at 35°C-60 °C, increase of temperature remarkably causes to diminish drying time of mint leaves and increase of drying intensity, furthermore the most suitable models in data analyzing. In another study spinach leaves (50g) and moisture (%9.1 base on dry weight) dried in microwave using 8 microwave powers in range of 90-1000w up to a constant moisture. Obtained results revealed that energy consumption has been constant in power range between 350-1000w while considerably increased at 60w and 190w. From the viewpoint of color and ascorbic acid amounts, the best quality reached at 750w, furthermore the least energy consumption occurred at combination of 750w and 350s (**Ozkan *et al*, 2007**). In comparison and investigation of drying behavior of parsley leaves in a traditional sun drying method and convection dryer at 56°C, 67°C, 85°C, and 93°C with convection race of 1m/s observed that in cyclic drying plots, constant race is impossible and drying process accompany with reduction of moisture per hour. Obtained results also fitted with Newton, page, modified page 1^{st} and 2^{nd}, Henderson and Pabis, Logarithmic, two sentences, Verma et al, Vang and sing. These models' efficiency investigated by comparing of their obtained results at which both Verma et al and Page model showed good fitness with data obtained from drying of parsley leaves. **Doymaz *et al* .(2004).** Found that in drying of carrot thin layers with 0.5cm thickness at 50°C, 60°C, 65°C and 70°C and air race 0.5-1cm/s, Page model fitted in best levels. This study aims at study of kinetic of drying spinach leaves and process modeling with practical and regression in different temperatures and powers of microwave.

MATERIAL AND METHODS

Spinach in fresh form purchased from native market of Goragan city, Golestan province of Iran and placed in refrigerator. In each replicate, samples cleansed and their extra parts (including useless leaves and stems) removed.

Drying with hot air and microwave

In order to preparing of spinach samples in hot air oven, samples placed in cleaned and dried containers made of aluminum and 50±0.05g of spinach weighed with balance model A&D GF-6100, Japan and 0.001g accuracy, then dried at 50°C, 60°C, and 70°C and their weights recorded when no weight difference observed between two consecutive weighing. In microwave process also, 50 ± 0.2 g of spinach weighed and dried with microwave model solar Dom, Australia in 90w, 180w, 360w, 600w and 900w. In order to investigation of drying kinetic and drawing of its curves, samples prepared, weighed and placed in the oven. To dry samples with Hot air drying method continuous 10m time intervals at 1st two hr. and then 30m time intervals after that applied and for microwave drying method combination of time intervals and powers as 300s and 90w, 180s and 180w, 90s and 360w, 60s and 600w, 30s and 900w applied. It must be mentioned that weighing continued up to reach to a constant weight.

Data fitting method

In most researches, kinetic models have reported base on moisture index due to diminish scattering. Equation 1 used in current study in order to calculate moisture ratio of spinach leaves.

Equation (1):

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

In which;

MR= moisture ratio (dimensionless)
M_t= moisture ratio base on dry weight
M_0= initial moisture base on dry weight
M_e= the amount of balance moisture base on dry weight

Moisture measurement

Samples (50g) of spinach weighed with balance model A&D GF-6100, Japan. 0.001 Accuracy, then dried in oven model Fater electronic U670, Iran at 105°C±1 for 15 hr. when no weight difference observed at two consecutive weighing, initial moisture measured base on wet weight.

Moisture base on wet weight

Equation (2):

$$MC_{w.b.} = \frac{m_1 - m_2}{m_1}$$

Moisture base on dry weight

Equation (3):

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

In which;
$MC_{w.b}$= moisture percent base on wet
$MC_{d.b.}$= moisture percent base on dry

m_1= sample weight before drying (g)
m_2= sample weight after drying (g)

Table 1 Different describing models of spinach drying

N.O.	Model equation	Model name	Reference
1	*MR= exp(-kt^n)*	page	Page, 1949
2	*MR= exp(-kt)*	Newton	Westerman et al, 1973
3	*MR= a exp(-kt)*	Henderson ,Pabis	Henderson ,Pabis, 1961
4	*MR= a exp(-kt)+ c*	Logarithmic	Toghrol and Pahlevan, 2004
5	*MR= a exp(-kt^n)+ bt*	Midili	Akpinar et al, 2003
6	*MR= a exp(-kt)+ b exp(-lt)*	Two sentences	Henderson, 1974
7	*MR= a exp(-kt)+ (1-a) exp(-gt)*	Verma et al	Verma et al, 1985
8	*MR= 1 + at + bt^2*	Wang and Sing	Wang and sing, 1978

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}$$

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp,t} - MR_{pre,i})^2}{N - m}$$

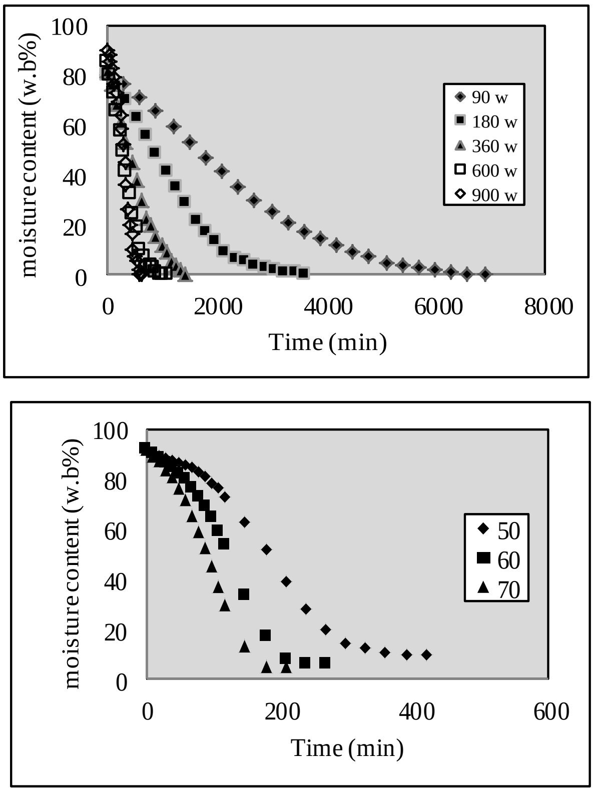
$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2\right)^{\frac{1}{2}}$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,t})$$

In which;
$MR_{exp,i}$ is experiment data of drying intensity.
$MR_{pre,i}$ is predicted data of drying intensity.
N is the number of observation.
M is drying constant.

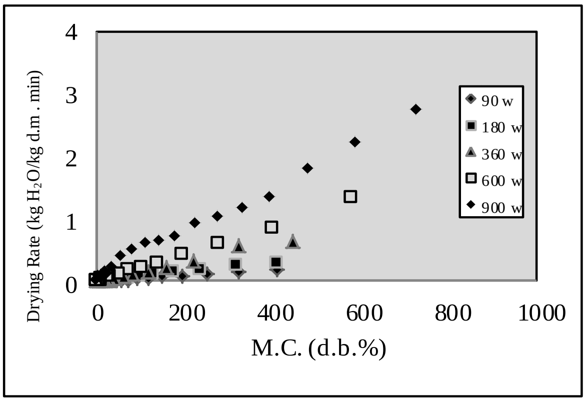
RESULTS AND DISCUSSION

Drying gradient is high in the beginning of drying process but during time occurring of wrinkle diminish moisture content and therefore drying gradient reduces, besides required time for reduction of a certain amount of moisture depends on operation conditions so that at 70°C less time is needed in comparison with 50°C.

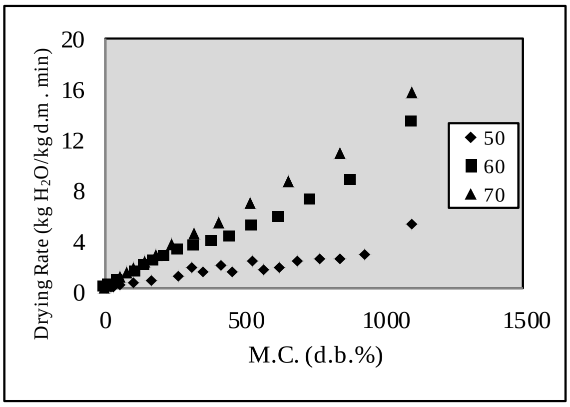


(a) (b)
Figure 1 Changes of moisture amount in drying process a) hot air b) microwave

Moisture reduction starts from surface layer, then heat transferring from center to surface begins and transfer of moisture from surface to center continues. In this stage, drying intensity is quick due to water evaporation close to sample surface, while intensity diminishes as a result of moisture reduction. In fact, moisture must transfer to surface and then vapor. Constant evaporation takes place in equal race of water transferring to surface and surface evaporation where constant temperature is available. Furthermore, increase of microwave power; reduce drying time as a result of air pressure reduction and thus removing moisture product in lower temperature.



(a)



(a)

(b)

Figure3 Intensity of drying a) hot air b) microwave

As it has shown in figure 3, drying intensity is more in the beginning stages of process causes to conclude this fact that being high of evaporation intensity of spinach leaves. Resistance versus water transferring to product surface due to wrinkle occurring in the final stages of drying decelerates drying race. In all treatments, Page model acceptably fitted with moisture amount during drying. These results were in agreement with **Akpinar *et al*.(2003) and Akpinar *et al*.(2006).**

Table 2 statistical results of different models in hot air drying

Model	Temperature	MBE	RMSE	χ^2	R^2
	50 ° c	0.003504	0.0231688	0.057969589	0.99221394
Page	60 ° c	3.608059407	0.033027	1.227006876	0.984732118
	70 ° c	-0.51547	0.134425	4.694984	0.99255772
	50 ° c	0.015758	0.0297968	0.058443356	0.99221212
Newton	60 ° c	0.009596842	0.102604	0.281406055	0.982877874
	70 ° c	-0.23897	0.06317	3.589139283	0.96909344
	50 ° c	0.015758	0.0297968	0.061226373	0.99221212
Henderson and Pabis	60 ° c	1.39098E+17	10.94007664	10.94007664	0.982877874
	70 ° c	-0.78143	0.202222	5.294553	0.9690934
	50 ° c	-0.69166	0.7521292	8.874053691	0.9922121
Logarithmic	60 ° c	1.38916E+17	0.725203	10.93950182	0.982877874
	70 ° c	-0.88022	0.229847	5.579516	0.9690934
	50 ° c	0.003503	0.0231681	0.05796948	0.99221396
Midili	60 ° c	1.36272E+17	0.724875	10.93752058	0.878992048
	70 ° c	-0.78123	0.202171	5.2939	0.84558274
	50 ° c	0.015758	0.0297968	0.061226373	0.99221212
Two sentences	60 ° c	0.009596842	0.102604	0.297039725	0.982877874
	70 ° c	-0.23897	0.06317	3.788536	0.96909344
	50 ° c	0.015758	0.0297968	0.061226373	0.99221212
Verma et al	60 ° c	0.009596841	0.102604	0.297039725	0.982877874
	70 ° c	-0.23897	0.06317	3.788536	0.96909344
	50 ° c	-2.40849	2.4265324	14.69677999	0.9558548
Veng and sing	60 ° c	7.38411E+61	2.396992	16.99931286	0.972800384
	70 ° c	-2.95947	0.743991	9.935815	0.9942134

Table 3 statistical results of different models in microwave

Model	Power	MBE	RMSE	χ^2	R^2
Page	90 w	0.018665	0.043465	0.160561175	0.9784807
	180 w	-0.2223003	0.2374096	3.952935036	0.967369
	360 w	-0.11887716	0.143524731	5.51503452	0.9090943
	600 w	-0.38093385	0.40963881	4.179931	0.99258204
	900 w	0.026119515	0.140649596	2.842724307	0.8655734
Newton	90 w	-0.00412	0.009599	0.174032449	0.976052
	180 w	-0.25454	0.273195	4.121412465	0.976977
	360 w	-0.145739659	0.179394131	5.75436044	0.9205264
	600 w	-0.30983621	0.33039539	3.880141	0.98446057
	900 w	-0.08252542	0.087517864	3.295072757	0.9779166
Henderson and Pabis	90 w	-0.79212	0.853696	13.8959889	0.976052
	180 w	-0.82362	0.86964	5.720104983	0.97698
	360 w	-0.747924362	0.871144193	9.03756829	0.9205264
	600 w	-0.84169154	0.88479551	5.102838	0.98446057
	900 w	1.94119E+24	0.826588356	7.203450645	0.977917
Logarithmic	90 w	-0.78619	0.846961	13.83782881	0.976052
	180 w	-0.8264	0.872563	5.72895938	0.97698
	360 w	-0.749351745	0.872730848	9.0444245	0.9205264
	600 w	-0.8368523	0.87931845	5.090085	0.98446057
	900 w	1.9423E+24	0.82657884	7.203413182	0.977917
Midili	90 w	0.083171	0.17206	0.858798182	0.9338386
	180 w	-0.2447855	0.2622346	3.867385937	0.974444
	360 w	-0.033904473	0.108880653	5.41979277	0.8069778
	600 w	-0.83490623	0.87734372	5.762144	0.87994373
	900 w	0	0.253774795	4.692202387	0.9978383
Two sentences	90 w	-0.00412	0.009599	0.174032449	0.976052
	180 w	-0.2545449	0.2731953	4.121412465	0.976977
	360 w	-0.145739663	0.179394136	5.75436044	0.9205264
	600 w	-0.30983621	0.3303954	3.880141	0.98446057
	900 w	-0.08252542	0.087517863	3.295072757	0.9779166
Verma et al	90 w	-0.00412	0.009599	0.174032449	0.976052
	180 w	-0.2545449	0.2731953	4.121412465	0.976977
	360 w	-0.145739662	0.179394135	5.75436044	0.9205264
	600 w	-0.30983622	0.3303954	3.880141	0.98446057
	900 w	384.3039457	0.087517864	3.295072757	0.9779166
Veng sing	90 w	-2.51754	2.590803	21.95919659	0.976052
	180 w	-3.3317352	3.4253052	11.47327118	0.98446
	360 w	-6.758728714	8.579059056	21.6269293	0.9205264
	600 w	-5.08672336	5.49273978	12.78715	0.98446057
	900 w	5.01089E+79	2.564808009	12.49978725	0.998373

Table 4 constant amounts of models in different intensities of hot air drying

Model	Temperature	a	b	g	c	n	k (min^{-1})
page	50 ° c	_	_	_	_	1.04589085	0.010729282
	60 ° c	_	_	_	_	0.952337601	0.015600785
	70 ° c	_	_	_	_	1.66241951	0.000160175
Newton	50 ° c	_	_	_	_	_	0.01393267
	60 ° c	_	_	_	_	_	0.019703684
	70 ° c	_	_	_	_	_	0.011060275
Henderson and pabis	50 ° c	1.00007226	_	_	_	_	0.013931663
	60 ° c	0.001	_	_	_	_	0.001
	70 ° c	0.0001	_	_	_	_	0.0001
Logarithmic	50 ° c	0.001	_	_	0.001	_	0.01
	60 ° c	0.0001	_	_	0.0001	_	0.0001
	70 ° c	0.1	_	_	0.0001	_	0.01
Midili	50 ° c	0.903741733	1.0911E-05	_	_	1.04585287	0.01188383
	60 ° c	0.006381507	0	_	_	0.395887665	0.005700071
	70 ° c	0.006381507	0	_	_	0.395887665	0.005700071
Two sentences	50 ° c	0.093727226	_	_	_	_	0.07798006
	60 ° c	0.097941454	_	_	_	_	0.105768658
	70 ° c	0.069734552	_	_	_	_	0.08216765
Verma et al	50 ° c	0.910410162	_	0.10143114	_	_	0.00532229
	60 ° c	0.909721888	_	0.10203958	_	_	0.011532913
	70 ° c	0.910752447	_	0.10112767	_	_	0.002234282
Veng and sing	50 ° c	0	0.00000001	_	_	_	_
	60 ° c	0	0.00000001	_	_	_	_
	70 ° c	0.00011	0.00001	_	_	_	_

Table 5 constant amounts of models in different intensities of microwave drying

Model	Power	a	b	c	g	n	k (min^{-1})
Page	90 w	_	_	_	_	0.8656975	0.002763482
	180 w	_	_	_	_	0.8657	0.001727641
	360 w	_	_	_	_	0.8657	0.00483663
	600 w	_	_	_	_	1.30711102	0.000182
	900 w	_	_	_	_	0.3948926	0.206116683
Newton	90 w	_	_	_	_	_	0.000877865
	180 w	_	_	_	_	_	0.000571529
	360 w	_	_	_	_	_	0.001807272
	600 w	_	_	_	_	_	0.001642841
	900 w	_	_	_	_	_	0.004901795
Henderson and pabis	90 w	0.001	_	_	_	_	0.00289
	180 w	0.0001	_	_	_	_	0.0001
	360 w	0.0001	_	_	_	_	0.00289
	600 w	0.00343	_	_	_	_	0.003429916
	900 w	0.0001	_	_	_	_	0.000289
Logarithmic	90 w	0.001	_	0.0001	_	_	0.001
	180 w	0.001	_	0.001	_	_	0.001
	360 w	0.001	_	0.001	_	_	0.001
	600 w	0.001	_	0.001	_	_	0.001
	900 w	0.0001	_	0.0001	_	_	0.0001
Midili	90 w	24.50582865	0	_	_	0.3958877	0.005700071
	180 w	0.308241504	0	_	_	0.959032	0.002600211
	360 w	24.50582865	0	_	_	0.39588767	0.005700071
	600 w	0.006381507	0	_	_	0.395888	0.005700071
	900 w	4.29693E-05	0	_	_	1.7585651	0.870030399
Two sentences	90 w	0.023945138	_	_	_	_	0.018552889
	180 w	0.020220124	_	_	_	_	0.014277018
	360 w	0.029529943	_	_	_	_	0.03105925
	600 w	0.035056577	_	_	_	_	0.023849
	900 w	0.048270774	_	_	_	_	0.052029703
	90 w	1.02541163	_	_	0	_	0.00085611
	180 w	1.025411728	_	_	0	_	0.000557365

Verma et al	360 w	0.966182159	_	_	0.0532525	_	6.6097E-06
	600 w	0.968533712	_	_	0.05163814	_	1.86E-05
	900 w	0.953048115	_	_	0.063808	_	0.001999782
	90 w	1.00E-05	0	_	_	_	_
	180 w	0.00011	0.00000001	_	_	_	_
veng abd sing	360 w	0.00109999	0	_	_	_	_
	600 w	0.001099992	0	_	_	_	_
	900 w	0.000011	0.0000001	_	_	_	_

CONCLUSION

Obtained results showed that drying of spinach leaves with hot air lengthen due deceleration of evaporation, long time is required in order to completely removing of moisture where itself causes to degrade of quality in final product.Application of microwave revealed that microwave energy not only quickly separate water but enhance structural properties in comparison with hot sir method. Results also exhibited that temperature of dryer and microwave power effects importantly on spinach drying. Increase of temperature and power of dryer, drying time reduced, drying process took place in descent stage. Page and two sentences models were suitable in estimation of moisture changes and description of drying behavior of spinach leaves.

Acknowledgement: This work was funded by European Community under project no 26220220180: Building Research Centre „AgroBioTech".

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