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Studies on Kinetics of Moisture Removal from Spinach Leaves

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Abstract

Spinach (Spinacia oleracea) is an important green leafy vegetable. Spinach is a rich source of vitamins particularly riboflavin, niacin, folic acid, minerals as iron, zinc and dietary fiber. Reduction of the moisture content to reduced water activity allows more shelf life of the dehydrated product for safe storage over an extended period. Drying kinetics of untreated spinach leaves were analyzed mathematically at the dehydration temperature of 50°C, 60°C, 70°C and 80°C in a convective type dryer. The results reflected that the increase in air temperature significantly reduced the drying time of spinach leaves. The dehydration data was statistically analysed to obtain best fit among all available models, which includes Page; Modified Page; Newton; Logarithmic; Two term exponential; Henderson and Pabis; Modified Henderson and Pabis; Hii, Law and Cloke; Modified Page equation-II; Two term and Diffusion approximation. The adequacy of applied dehydration models for goodness of fit were evaluated on the basis of coefficient of multiple determinations (R^2), reduced chi-square (χ^2) and root mean square error (RMSE). The fitted model described the dehydration process adequately as per found higher R^2 (>95%), lower χ^2 and RMSE. It was found that the drying processes took place in a falling rate period. The effective diffusivity found in the range of 2.150-9.710x10^{-12} m^2/s for the isothermal dehydration of untreated spinach with the activation energy value of 50.851 KJ/mol.

Keywords: Spinacia; spinach; dehydration; drying; dehydration model.

1. Introduction

Spinach (*Spinacea oleracea*) is a cool season annual either eaten raw, boiled or baked into various delicacies. It is a rich source of vitamins, minerals and dietary fibers (Ozkan et al, 2007; Nisha et al, 2005). Chlorophyll is the major pigment and accountable for green coloration of spinach leaves. Its colour changes from bright green during improper processing due to the conversion of chlorophyll to pheophytin. Drying is the reduction of the moisture content to a level, which allows safe storage over an extended period. Also, it brings about substantial reduction in weight and volume, minimizing packaging, storage and transportation costs (Doymaz, 2004, 2007). Fitting of mathematical models on experimental readings of drying data and simulation of drying curves under different conditions is important to obtain a better control of this important unit operation for overall improvement of quality of final product. Models are often used to study the variables involved in the process prediction, drying kinetics of the product and optimize the operating parameters and conditions (Garau et al, 2006; Madamba et al, 1996). Therefore, it was considered important to conduct studies on the drying characteristics of spinach leaves.

2. Materials and Methods

The present work was carried out in the Food Engineering and Technology Department, located at Sant Longowal Institute of Engineering and Technology (SLIET), Longowal, Punjab. Spinach leaves (Palak RNG-All Green Akshit) were harvested during early morning from local farm of nearby Longowal village. Fresh and undamaged leaves were sorted, washed to remove foreign matter such as dust, dirt, chaff and immature leaves using tap water. Drying behaviour of spinach leaves were investigated at four different isothermal temperatures (50, 60, 70 and 80 ^{0}C) in a developed cabinet dryer. The change in the weight was recorded with the developed on line automatic monitoring system. As per preliminary experimentation the dehydration process was carried out for three hours duration. The obtained dried samples at different temperatures were subjected for further studies.

2.1 Mathematical model fitting of drying curves

Moisture content of samples during dehydration was expressed on dry weight basis for fitting of selected eleven dehydration models (Table 1). The Moisture ratio was calculated with the moisture content values at specific time, initial and equilibrium moisture content. Evaluation of drying rate is very useful in understanding the mechanism of moisture movement within the leaves as well as to the surrounding environment. The experimental data was interpreted by means of a non-linear regression analysis using the Quasi-Newton method. Coefficient of multiple determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) values were determine and used to find the goodness of fit for different fitted dehydration models.

Table 1: Fitted dehydration models with representation in form of mathematical expression.

Sl. No.	Mathematical expression	Dehydration Models	Nomenclature
1.	MR= exp(-kt)	Newton or Lewis	MR - Moisture Ratio t - time, sec a, b, c, g, h, n - constants k,ko,k1 - model coefficients L - half-leaf thickness, mm
2.	MR= exp(-ktn)	Page	
3.	MR= exp(-(kt)n)	Modified Page	
4.	MR= a exp(-kt) + (1-a) exp(-kat)	Two Term exponential	
5.	MR= a exp(-kt)	Handerson and Pabis	
6.	MR= a exp(-kt) + c	Logrithemic	
7.	MR= a exp(-kt) + (1-a) exp(-kbt)	Diffusion Approach	
8.	MR= aexp(-k0t) + b exp(-k1t)	Two term	
9.	MR = a exp(-kt) + b exp(-gt) + c exp(-ht)	Modified Henderson and Pabis	
10.	MR= exp(-k(t/L2)n)	Modified Page equation-II	
11.	MR = a exp(-ktn)+ c exp(-gtn)	Hii, Law and Cloke	

2.2 Effective moisture diffusivity and Activation Energy

Fick's second law of diffusion has been widely used to describe the drying process during for most biological materials and can be used for calculating the activation energy (Sharma & Prasad, 2001). The diffusion equation is solved considering spinach leaves as infinite slab, assuming one dimensional moisture movement, no volume change, constant temperature and negligible external resistance (Crank, 1975). The Simplified form, (Doymaz, 2007; Madamba et al, 1996) by taking the first term

$$MR = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff}\, t}{4L^2}\right)$$

Where, D_{eff} is the effective diffusivity (m^2/s), L is the half thickness ($2x10^{-4}$m) of the leaf (m). MR is the moisture ratio and t is drying time in seconds.

The average effective moisture diffusivity was calculated by taking the arithmetic mean of the effective moisture diffusivities that were estimated at various levels of moisture contents during the course of drying. The dependence of average effective moisture diffusivity on drying air temperature was obtained by an Arrhenius-type relationship

$$D_{eff} = D_O \exp\left(\frac{-E_a}{R(T+273.15)}\right)$$

Where D_0 is the Arrhenius factor (m^2/s), E_a is the activation energy for the moisture diffusion (kJ/mol), *R* is the universal gas constant (kJ/mol K), and *T* is drying air temperature (^0C).

3. Results and Discussion

3.1 Drying characteristics of spinach leaves

The variation of moisture ratio (MR) with drying time at different temperatures is shown in Fig 1. Moisture content and MR decreased continuously with drying time. Moisture reduction found to be temperature dependent and slow at lower temperature and took more time as compared to drying at higher temperatures. Fig. 1 depicts the variable time taken by the process to achieve the equilibrium moisture content and found to have only one fifth of total dehydration time at 80^{O}C as compared to time taken to achieve the similar moisture content at 60^{O}C. Also at 70^{O}C the dehydration time taken by the process was only 60 minutes as compared to at least 150 minutes time taken either at 50 or 60^{O}C.

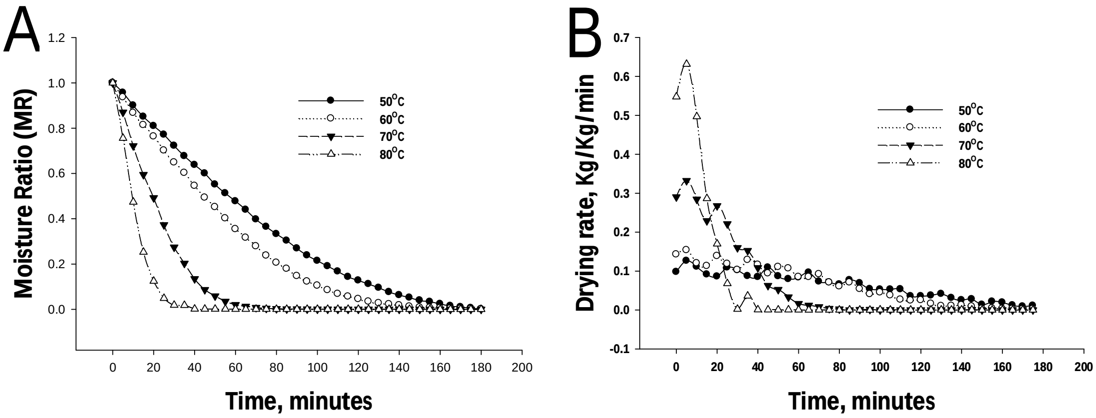

Fig. 1: Temperature dependent moisture ratio vs drying time (A) and drying rate vs drying time (B) curve.

Rate of drying was found to be governed by the process of diffusion process and reflected the temperature dependent. With the changes in temperature, changes in the drying rate could be observed (Fig. 2). Drying rate has found to increase and adjusted to peak before reduction continuously throughout the rest of the drying period. Also it is evident that drying rate was higher at higher temperature with faster removal of moisture. The results were found in agreement with the studies earlier carried out for other different leafy vegetables (Ozkan et al, 2007; Kaya and Aydin, 2009) and for other biomaterials (Bozkir, 2006; Doymaz, 2007). Considering the temperature dependent variable nature of dehydration process, attempts have been made to get the advantage of higher dehydration rate of drying the spinach at higher considered temperature ($\geq$70^{O}C) in initial phase of dehydration and to maintain the product quality by lowering the dehydration temperature ($\leq$60^{O}C) during the later phase also to reduce the effective dehydration time by one and half to two hours in order to make the process more economical. This may pave the way for the development of on-line dehydration equipment for getting the product more cheaply and at the same time effective and timely utilization of this valuable highly perishable product to reduce the loss further.

3.2 Mathematical model fitting of drying curves

The moisture content data at the different drying air temperatures were converted to the more useful moisture ratio for curve fitting using different dehydration models (Table 1). Best model was identified to describe the process of dehydration on the basis of higher coefficient of multiple determinations (R^2) and lower values of reduced chi-square (χ^2) and root mean square error (RMSE) (Doymaz, 2007; Roberts et al, 2008; Vega et al, 2007). On comparison two term exponential, page, modified page, modified page eq II, Hii and logarithmic models gave better fit than other models. Fitted models gave R^2 values of more than 0.985 with RMSE and χ^2 values were less than 26.82×10^{-3} and 13.690×10^{-4}, respectively. This shows the process of dehydration could be described in a better way by these models out of selected eleven models.

3.3 Effective moisture diffusivity and Activation Energy

The average effective moisture diffusivity (D_{eff}) was calculated by taking the arithmetic mean of the effective moisture diffusivities determined at various levels of moisture contents during the course of drying. The D_{eff} found to be varied in the range of $2.150\text{-}9.710 \times 10^{-12}$ m^2/s within the selected temperature range, which supports for food materials. D_{eff} value was found temperature dependent and increased logarithmically with the increase in temperature (Kaya and Aydin, 2009; Ozkan et al, 2007; Marquez et al, 2006; Fernando et al, 2008 and Vega et al, 2007).

The dependence of average effective moisture diffusivity on drying air temperature was obtained by an Arrhenius-type relationship. The activation energy for spinach leaves was found to be 50.851 KJ/mol and moisture diffusivity or diffusivity constant at 273 K found was $8.636 \times 10^{-4} m^2/s$. These values are comparable to that of different leafy vegetables dill leaves, 35.05kJ/mol, parsley leaves, 43.92kJ/mol and pepper, 39.70kJ/mol during drying (Vega et al, 2007).

4. Conclusion

Dehydration kinetics of Spinach (*Spinacia oleracea*) leaves revealed the reduction in moisture is temperature dependent and temperature alters the duration of drying time. The drying process fell in falling rate period with the some variations in initial adjustment phase. The combination temperature method not only reduces the cost of production but also ensure effective and timely utilization of this highly perishable valued green leafy vegetable. Two term exponential, page, modified page, modified page eq II, Hii Law and Cloke and logarithmic models could be used to describe the process of dehydration adequately as per fitting parameters. The dehydration process requires the activation energy of at least 50.851 KJ/mol with the diffusivity constant of 8.636×10^{-4} m^2/s.

References

[1] A Kaya, and O Aydın (2009), An experimental study on drying kinetics of some herbal leaves, *Energy Conversion and Management*, **50**, pp. 118–124.

[2] A Vega, P Fito, A Andre and R Lemus (2007), Mathematical modeling of hot-air drying kinetics of red bell pepper (*Var lamuyo*), *Journal of Food Engineering*, **79**, pp. 1460–1466.

[3] C Marquez, A Michelis and S Adrian Giner (2006), Drying kinetics of rose hip fruits (*Rosa eglanteria L*), *Journal of Food Engineering*, **77**, pp. 566–574.

[4] G Sharma, and S Prasad, (2001), Drying of garlic (*Allium sativum*) cloves by microwave-hot air combination, *Journal of Food Engineering*, **50**, pp. 99-105.

[5] I Doymaz (2004), Drying kinetics of white mulberry, *Journal of Food Engineering*, **61**, pp. 341–346.

[6] I Doymaz (2007), Air-drying characteristics of tomatoes, *Journal of Food Engineering*, **78**, pp. 1291–1297.

[7] I Ozkan, B Akbudak and N Akbudak (2007), Microwave drying characteristics of spinach, *Journal of Food Engineering*, **78**, pp. 577–583.

[8] J Crank (1975), *The mathematics of diffusion* (2nd ed) Oxford, London: Clarendon Press.

[9] J Roberts, D Kidd and O Padilla-Zakour (2008), Drying kinetics of grape seeds, *Journal of Food Engineering*, **89**, pp. 460–465.

[10] M Garau, S Simal, A Femenia, and C Rossello (2006), Drying of orange skin: drying kinetics modeling and functional properties, *Journal of Food Engineering*, **75**, pp. 288–295.

[11] O Bozkır (2006), Thin-layer drying and mathematical modeling for washed dry apricots, *Journal of Food Engineering*, **77**, pp. 146–151.

[12] P Madamba, R Driscollb, and K Buckleb (1996), The Thin-layer Drying Characteristics of Garlic Slices, *Journal of Food Engineering*, **29**, pp. 15-97.

[13] P Nisha, R Singhal and A Pandit (2004), A study on the degradation kinetics of visual green colour in spinach (*Spinacea oleracea L*) and the effect of salt therein, *Journal of Food Engineering*, **64**, pp. 135–142.

[14] W Fernando, A Ahmad, S Abd and Y Shukor Lok (2008), A model for constant temperature drying rates of case hardened slices of papaya and garlic, *Journal of Food Engineering*, **88**, pp. 229–238.