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DRYING KINETICS OF THIN LAYER PEA PODS USING TRAY DRYING

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ABSTRACT

In the present study, efforts have been directed to possible utilization of the pea pods, not only from the point of preservation and waste management, but as a profitable adjunct to the food processing industry. In this connection, an experimental study was performed to determine the drying characteristics of pea pods in a laboratory scale tray dryer at a constant air velocity of 0.5m/s and temperature of 70°C. Pea pods were dried for 7 hrs. Drying curve was prepared and results indicated that maximum drying took place in falling rate period. Three different thin layer drying models were compared with respect to their coefficient of determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) was selected to better estimate the drying curves. The entire models were showed a good fit to the drying data. However, the (Page) drying model was showed a better fit to the experiment data among other models.

Keywords: Pea pods, tray drying, drying curve, thin layer, falling rate, drying model.

INTRODUCTION

Pea is among the most important crops of the temperate climatic regions satisfying the purpose of both human consumption and animal feeding. Pea is a forage plant and grows either alone or in combination with small grains and used for green forage, hay, silage, haylage, dehydrated feed and grain, as well as in the form of green manure (Mmihailović, et.al., 2005). The pea is the small spherical seeds of the pod fruit *Pisum sativum*. Each pod contains several peas. Peapods are botanically a fruit since they contain seeds developed from the ovary of a (pea) flower. Pea pods are rich in minerals, vitamins, fibre, pigments etc. Peas are consumed as a legume or vegetable throughout the world. Its pods are usually discarded or used as animal feed. Pea pods have good nutritional value and hence different value added foods can be prepared by using pea pods. However, as it is seasonal in nature its availability is limited only to some part of the year, which creates the need for its preservation.

Drying is a process to remove water or other liquid from the solid material till an acceptable low value of moisture is achieved (McCabe et.al., 1993). According to several authors the word ‘‘drying’’ is used to describe the process of water removal naturally on exposure to the sun (Brennan, 1994) whereas ‘‘dehydration’’ as the artificial drying carried out in controlled conditions (Potter, 1998). Drying is probably the oldest method of food preservation. Earlier foods such as meat, fish, fruits and vegetables were preserved using sun-drying techniques (Brennan, 1994). Now days, drying are regarded not only as a preservation process, but also as a method for increasing value added foods. Among foodstuffs, particular attention has been given to drying of fruits and vegetables. Variety of products can be obtained which can be incorporated in breakfast cereals, bakery, confectionery and dairy products, soups, purees and others (Ramos). Hence drying is an essential, most widely used and a primary method for preservation of agricultural products. As the pea pods have good amount of moisture (water activity was 0.98 at 25°C), its storage is difficult. Therefore, the waste is just dumped and allowed to decay. The material easily spoils when exposed to the air and emits a very foul odour. It also provides a breeding place for a variety of pests, which are hosts of many disease-causing organisms. Increasing landfill costs and societal concerns about solid waste have generated interest in finding an economical outlet for such by-products. Such a great amount of pea pod waste could become a serious environmental problem and a waste of resources. This was significant for the reason that the pea pods can be best dried without much quality degradation and the dried product can be used as a good source of fibre and other nutrients and hence find great scope in incorporating the dried pea pods in various food products such as biscuits, muffins and cakes, soup mixes, etc., thereby increasing the nutritional value of the foods and at the same time utilizing the waste in a best possible way. Thus, it would be of great benefit to produce dried functional ingredients from these product waste streams, as a good way and a challenge to disposing of the waste without effecting the environment. Therefore, mathematical models are used that can describe suitable drying mechanisms and predict water removal rates (Özdemir, 1999). Lot of literature is available on drying behavior of agricultural products including sweet potato slices, garlic slices, pistachio, grape, rough rice, black tea, banana and prickly pear peel (Kamil et.al, 2006). However there is a lack of information available concerning pea pods. This paper aims at studying the drying characteristics of pea pods and its nutritional composition during tray drying.

MATERIAL AND METHODS

SAMPLE COLLECTION

Fresh peas were purchased from local market and were sorted and collected.

EXPERIMENTAL SET UP

The laboratory scale batch type Tray dryer is used.

SAMPLE PREPARATION

The seeds were separated from the pea pods. The pea pods were then cleaned and weighed with the help of a digital electronic balance having an accuracy of 0.01g. In 2kg peas, pea pods weighed 750gms. To determine the initial moisture content of the sample, the pea pods were subjected to oven drying at 130˚C for one hour. Also the water activity was determined at 25˚C Aqua Lab water activity meter.. The weighed sample was spread on to tray subjecting to drying in a tray dryer at temperature of 70°C for two hours, at a constant air velocity of 0.5m/s. The sample was weighed after every 10 minutes until the drying rate became constant. Finally the sample was allowed to cool in a dessicator, and then weighed. Water activity was now calculated for the dried sample.

DRYING ANALYSIS

MOISTURE CONTENT

$$Mc = \frac{(Mi\text{-}Md)}{(Mi)} x100$$

Mi is the mass of sample before drying and *Md* is the mass of sample after drying.

DRYING RATE (RD):

$$Rd = \frac{(Mi\text{-}Md)}{t}$$

Moisture ratio is given by,

$$MR = \frac{(M\text{-}Me)}{(Mo\text{-}Me)}$$

where MR is the dimensionless moisture ratio, M, Me and Mo are the moisture content at any time, the equilibrium moisture content and the initial moisture content in kg respectively. The equilibrium moisture content (Me) was assumed to be zero for this experiment because it is very small as compared to Mo.

THEORY OF MATHEMATICAL MODELING

A mathematical model is a mathematical analog of the physical reality, describing the properties of a real system in terms of mathematical variables and operations. Development of model is necessary to investigate the drying characteristics of pea pods. Due to the super growth and availability of the computing power, mathematical models have become more realistic and this have in turn led to rapid rise in the use of such models in product, process, and equipment design and research (Sablani et.al., 2006). There are two types of thin-layer models in use: diffusion models and empirical models. The accuracy of diffusion models to predict moisture content depends on assumptions concerning the geometry, moisture diffusivity and temperature profile of a piece of food. The diffusion models need more computation time and computer memory than the simpler empirical models. According to Bruce 1985, for stimulations of deep-bed drying, simpler models are considered to be useful than the diffusion models where economy of computation is concerned, while the later being more accurate and allow internal moisture movement to be modeled. However empirical models are more applicable for control technology of drying, as computation requires lesser time. Therefore, it was decided to look at widely used simpler models (Perry et.al., 1984). In this study, the experimental drying data of pea pod at temperature of 70˚C were fitted into 3 commonly used thin-layer drying models, listed in Table 1. Page's model has been widely used to describe drying behaviour of a variety of biological materials.

Table 1: Mathematical thin-layer models fitted to experimental data

Model Name	Model Expression	Reference
Page	MR=exp(-kt^n)	Page (1949) in Bruce (1985)
Wang and Singh	$MR=1+at+bt^2$	Wang & Singh (1978)
Exponential two terms model	MR□ □ a.exp(-k.t) □ □ (1-a)exp(-k.a.t)	Togrul & Pehlivan (2003)

Thin layer equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalize drying curves. For modeling thin layer drying for agricultural products, the material is first subjected to a constant relative humidity and temperature conditions and the moisture content of the material at any time is measured and is then correlated to the drying parameters (Midilli et.al., 2002). To select the best model for describing the drying curve during drying process the thin layer drying equations in Table 2 were tested. The reduced chi-square (χ^2) and the root mean square error (RMSE) were calculated using following expressions (Navneet et.al., 2012):

$$R^2 = \frac{\sum_{i=1}^{n}(MR_i \quad MR_{pre,i}) \cdot \sum_{i=1}^{n}(MR_i \quad MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^{n}(MR_i \quad MR_{pre,i})^2\right] \cdot \left[\sum_{i=1}^{n}(MR_i \quad MR_{exp,i})^2\right]}}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{Exp,i} - MR_{Pre,i}\right)^2}{(N - Z)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{Pre,i} - MR_{Exp,i})^2}$$

Where MR_{Exp}, i is the i[th] experimental moisture ratio, MR_{Pre}, i is the i[th] predicted moisture ratio, N is the number of observations and n is the number of constants. In this study, the nonlinear regression analysis was performed with statistical software, Origin Pro 8.5.1 (Origin Lab, Massachusetts). The higher values of R^2 and lower values of the χ^2 and RMSE indicates the goodness of the fit (Akpinar et.al., 2003, Gunhan et.al., 2005 and Yaldiz et.al, 2001).

DETERMINATION OF WATER ACTIVITY

The water activity of pea pods was determined at 25˚C (±0.2˚C) using an electronic dew point water activity meter, equipped with a temperature-controlled system which have a temperature stable sensing device. The equipment was first calibrated with saturated salt solutions in the range of interest of the a_w. For each determination, duplicates readings were obtained, and the average value was reported. The accuracy of about ± $0.003a_w$ is given by this meter under these conditions (Fontana, 2002).

RESULTS AND DISCUSSION

DRYING CURVES

A rapid drying was observed in dimensionless moisture content. The instantaneous moisture content rapidly decreases as the drying time increases. The variations of drying rate during drying time obtained in this experiment are shown in Fig 2.

It is apparent that the drying rate decreased continuously throughout the drying time. Also the moisture ratio decreased incessantly (Fig. 1). At the beginning of the drying process, the drying rate was very high, but decreased with moisture ratio reduction. However, during the drying process the surface does not remain in a saturated condition as the movement of water to the surface is not sufficient to maintain saturation. Subsequently, the surface is not in a condition of equilibrium which results in lowering of the drying rate (Brennan, 2002). Earlier studies on aromatic plants also showed similar results (Belghit et.al, 2000 and Akpinar, 2006). As indicated in these curves, there was no constant rate period in drying and almost all the drying process took place in falling rate period and was started from the initial moisture content (88.91 %, dry basis) to final moisture content (3.846 % dry basis). Similar results were obtained from the earlier studies on different vegetables (Akpinar, 2004, Akpinar, 2004, Doymaz, 2006 and Doymaz et.al., 2006).

Fig. 1 Tray Dryer

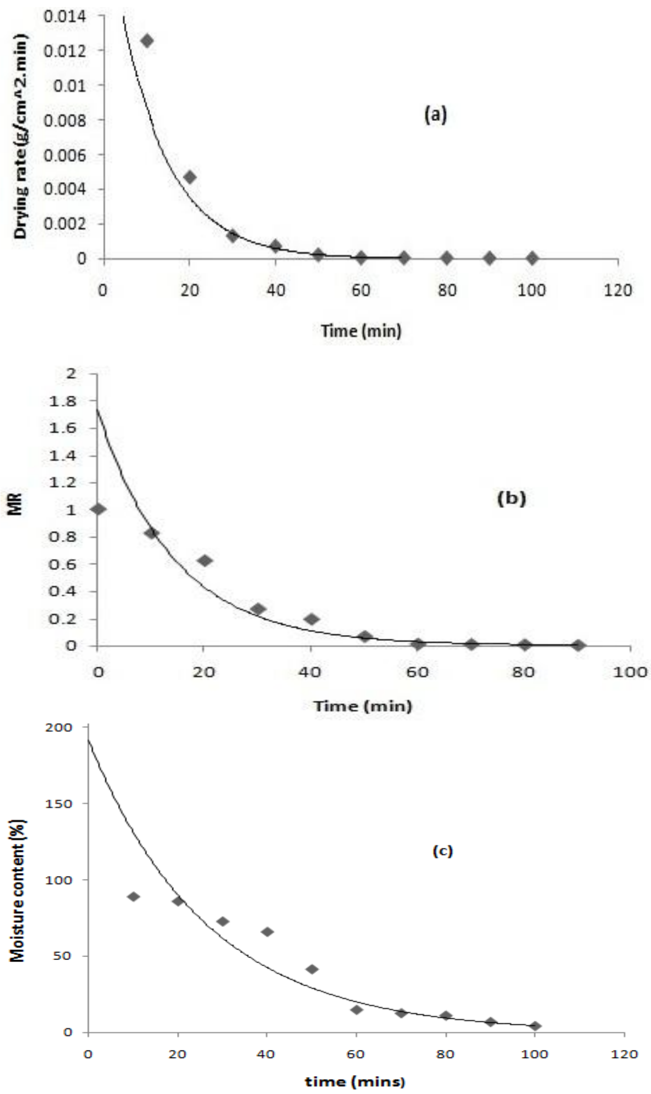

Fig.2 Drying curves (a) Variation of drying rate with drying time, (b) Variation of Moisture ratio with drying time, and (c) Variation of Moisture content with drying time

EVALUATION OF THE MATHEMATICAL MODELS

During drying, the moisture content data at the different time intervals were converted to a dimensionless parameter called as moisture ratio and then the variations of moisture ratio with drying time at drying temperatures of 70° C were fitted to the selected thin-layer drying models i.e. Page, Wang and Singh, and Exponential two terms as listed in Table 1. Also the criteria used to estimate goodness of the fits (R^2, RMSE and χ^2) and the constants in models (a, b, n and k) are presented in these **Table 2**.

Table 2: Modeling of moisture ratio according to drying time for pea pods.

Model	Coefficients	R^2	χ^2	RMSE
Page	k=0.00302 n=1.73795	0.9938	8.35614*10^-4	0.00131 0.12829
Wang and Singh	a= -0.02629 b= 1.66822*10^-4	0.9780	0.00298	0.00112 1.38034*10^-5
Exponential two terms model	a= 2.16923 k= 0.06236	0.9899	0.00136	0.09994 0.0037

Based on these criteria, the highest R^2 and the lowest RMSE and χ^2, the best model was selected. From the Table 2, R^2, RMSE and χ^2 values were varied between 0.9780–0.9938, 0.00001 – 0.1282 and 0.000835–0.0029, respectively. However, among the three mathematical drying models, the Page model resulted in the highest values of R^2 (0.9938) and the lowest values of χ^2 (8.35614*10^-4) and RMSE (0.0000138). This indicated good fit of Page model compared to other models, as shown in Table 2. Page model is found to be good for fitting the drying curves, and as functions of the drying conditions, various model parameters were correlated (Queiroz et.al., 2004). Statistical analysis of experimental data showed that temperature was the main factor affecting drying rate.

To validate the developed model, the experimental data were plotted against the predicted values. The results showed smooth and good scatter of the data points around the fitted line. This confirms the goodness of the developed model to estimate the moisture content of pea pods in a tray drying. **Figure 3** show the observed moisture ratio versus predicted moisture ratio.

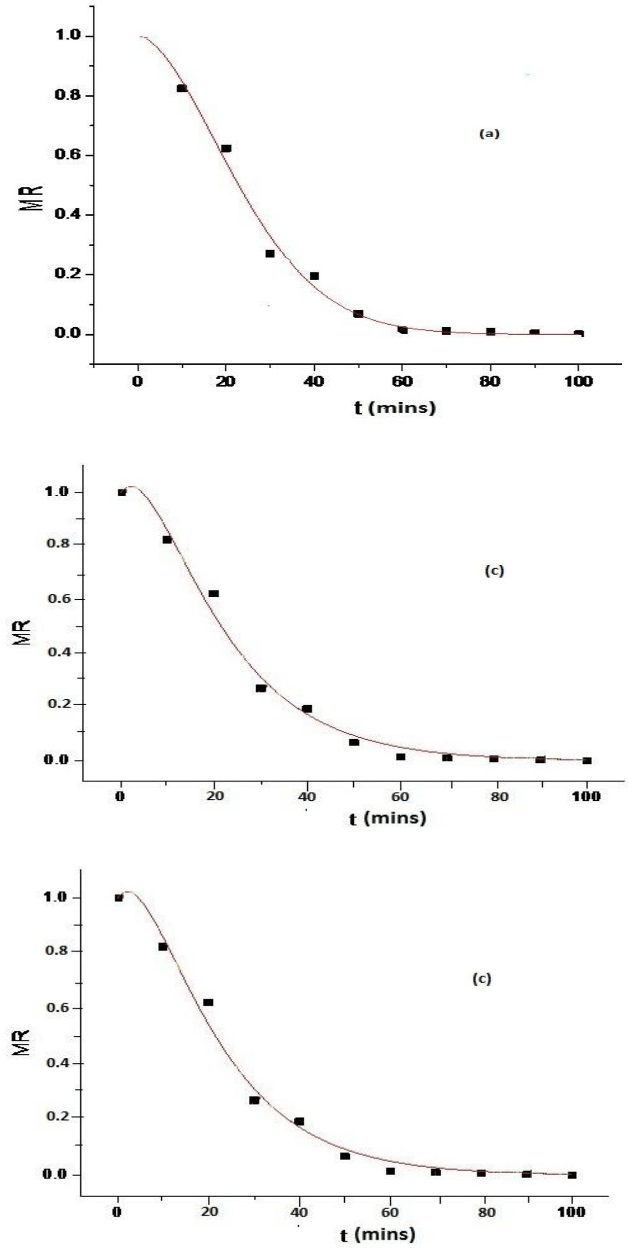

Fig.3. Comparison of experimental (■) and calculated ( ) dimensionless moisture content of pea pods

VARIATION OF THE WATER ACTIVITY WITH DRYING

The use of water activity help in predicting the storage behavior of pea pods, which is beneficial to determine apart from moisture content, just to be more assure about the chances of the pea pods to gain or loss any moisture on exposure to ambient relative humidities (Chirife et.al, 2006).

Drying considerably reduces the water activity of the material (Doymaz et.al., 2006). The graph was plotted between water activity v/s time and water activity v/s moisture content. The time was in minute and the water activity was determined at 25˚C (Figures 4).

The water activity reduces as the drying time increases, as the available free moisture content continues to reduce on tray drying .Also there is a linear relation between water activity variation and variation of moisture content. This is in agreement with the findings of Chirife et al. (2006).

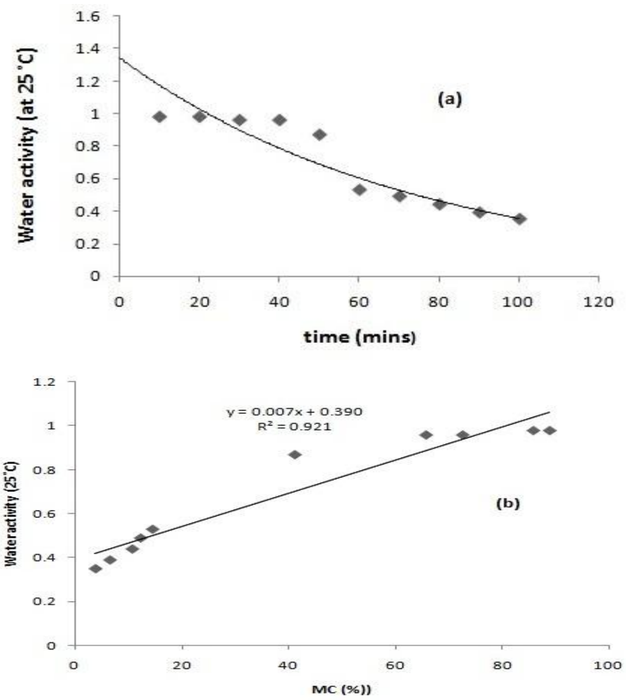

Figure 4 – Correlation between (a) water activity (25 ºC) and drying time, and (b) water activity (25 ºC) and % moisture.

CONCLUSIONS

In the present study, drying behavior of the pea pods was investigated under tray drying. Out of the three models fitted, Page model shown the best outcomes as this resulted in a high correlation coefficient (R^2), and values of low chi-square (χ^{22}) and root mean square error (RMSE), which was found to be adequate in describing the thin layer drying characteristics of pea pods in a tray drying.
Also, drying of pea pods offers numerous advantages. Not only it is a promising solution for food waste management but also the abundantly available inexpensive pea pods can serve as a pool house of nutrients and can be used in the developing countries to combat micronutrient deficiencies by incorporating pea pod powder to prepare various value added food products. However, preparation of such value added products and to ascertain their acceptability needs investigation.

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