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Research Article
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Thin Layer Drying Characteristics of Sweet Potato Starch Based Films and Mathematical Modelling

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Abstract

Drying kinetics of sweet potato starch based films was studied at different temperatures (45, 50, 55 and 60°C). Films were prepared by casting technique and were dried in hot air oven. In declining rate period, moisture transfer from films was described by applying the Page's model, and the rate constant (k) was calculated. Results indicated that removal of moisture from these thin films was fast in initial hours and with increase of temperature as well. The effect of temperature on rate constant (k) was interpreted according to Arrhenius law. The rate constant increased (0.000–0.002 h^{-1}) with the drying air temperature.

Keywords: Sweet potato; Films; Drying kinetics; Page's model

Nomenclature: E: Activation Energy (kJ mol^{-1}); k: Rate Constant (h^{-1}); MR: Moisture Ratio (dimensionless); M: Moisture Content at any given Instant (kg water/kg dry solids); m_e: Equilibrium Moisture Content (kg water/kg dry solids); m_o: Initial Moisture Content (kg water/kg dry solids); n: Dimensionless Coefficient; R: Universal Gas Constant (8.314 kJ $mol^{-1}K^{-1}$); T: Absolute Temperature (K); t: Time of Rehydration or Dehydration (h)

Introduction

The production of plastics has been increasing considerably due to the extensive growth of world population. Plastics are becoming part and parcel of our day to day life and as a result plastic industry has emerged as a rapidly expanding industry in the past several decades. There is 4% growth in plastic production annually, creating hundreds of tons of residues daily [1]. Over the past century the topic of "green chemistry" has gained increased attention. In order to solve the problems generated by plastic waste, particularly by disposable commodities, many efforts have been made to develop environment friendly materials [2,3]. The treatment of waste plastics has become a serious problem because of the difficulty of ensuring reclaimed land and burning by incineration [4]. The industry is now facing ecological and legislative issues for handling plastic raw materials and finished products [5]. Currently, the most part of raw material used for packaging are from petroleum-based polymers, such as polyethylene and polystyrene. The utilization of biodegradable packaging materials has the greatest potential in countries where landfill is the main waste management tool. Natural bio polymeric films are totally biodegradable and are derived from renewable raw materials and these properties make them advantageous over synthetic polymers. They can be used effectively as an alternative to synthetic plastics. Biopolymers have also desirable overall mechanical and barrier properties [6].

Agriculture-derived biopolymers, such as proteins and polysaccharides, appears as an interesting alternative to synthetic plastics for some applications, especially those with a short life-time, such as food packaging and add values to agricultural products [7-10]. Starch a renewable source, appears to be the best raw material of biodegradable polymer with low cost [11]. Starch from different sources has been studied as a potential film-forming agent, including that from potato and barley [12], wheat [13], tapioca [14], and rice [13]. Maize starch [13-16] is a low-cost renewable material containing 15-30% (w/w) amylose and 70-85% (w/w) amylopectin [16] and is used in many applications including the food, pharmaceutical and medical industries, both in its native powdered form and in modified forms [13]. Amylose is primarily responsible for the film-forming ability and functional properties of starch-based films due to its recrystallization behavior after processing. Amylose forms strong and flexible films whereas amylopectin produces weak and brittle ones [17,18]. The basic process for preparation of films involves evaporation of solvent from polymer solution and thus forming solid coating on substrate. The effect of a specific drying condition depends on various characteristics of the raw material such as the presence of preexisting gel phase or the occurrence of thermal gelation during drying. The drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behavior and for optimizing the drying parameters [19,20].

Sweet potato (*Ipomoea batatas Lam.*) is an important source of carbohydrate for the people in Asia. It is rich in B-carotene, fiber and potassium ion etc. and is widely used in ready-to-eat foods. Roots and tuber crops are grown throughout the world in hot and humid regions. Roots and tubers contain 70-80% water, 16-24% starch and trace quantities (<4%) of proteins and lipids. Sweet potato (*Ipomoea batatas Lam*) is one of the most economically important species of tropical root and tuber crops, which can grow in great abundance on marginal soils [21]. These are rich in starches (58–76%, on a dry basis) and its starches have properties similar to those of potato starch [22-24].

Different authors [25-27] reported that the film-forming method and drying process conditions influence film performance. Rindlav et al. [28] reported that crystallinity degree of potato starch edible film is dependent on the temperature, the air humidity and the time that elapses during drying from gel to film. The study of drying properties

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of edible film in relation to its kinetics is a subject of greater importance due to the need of a complete characterization of the film to evaluate advantages and disadvantages of its application in relation to food shelf life. The aim of the present study was to assess the effect of different temperatures on the drying rate of thin layer films.

Material and Methods

Isolation of starch

Starch was isolated from sweet potato as per the method described by Singh et al. [29]. Sweet potato were washed, peeled and shred. Shreds were put into plain and chemical added water containing various combinations of chemicals (0.2% potassium metabisulphite (KMS), combination of 0.5% citric acid and 0.1% KMS and 0.5% citric acid and 0.2% KMS) to improve the color of starch. The starch precipitate was transferred to trays and dried in an oven at 40°C to a moisture content of 8-10% (wet basis).

Preparation of starch films

The starch films were prepared according to the method described by [30]. The films were prepared through the casting technique using a film-forming solution containing 5% of sweet potato starch. Glycerol at concentrations of (10% on dry starch basis) was used as plasticizer. The mixture (5% dry starch+95% water+10% glycerol on dry starch basis) was heated to 70°C-80°C temperature on hot plate and constant stirring was done for 10 minutes by magnetic stirrer. Mixture was cooled and passed through vacuum pump to remove bubbles and poured (hot) about 25ml homogenously onto the high density poly propylene (HDPP) plastic trays (9 × 9 × 2 cm). The trays containing the film forming solution were then dried in an oven at different temperature 45, 50, 55 and 60°C till the equilibrium was achieved. The dried films were peeled off the trays and kept in air tight polyethylene bags.

Drying kinetics

To determine the drying kinetics, sweet potato films were dried on plastic trays in an oven (M/s. Linco, Ambala, India). The drying oven was equipped with an electrical heater, a fan, and temperature indicator. The airflow was uniform. An approximately 25 ml sample tray was uniformly spread on trays. Samples were removed periodically after 10 min and weighed by an electronic balance up to two decimal places. The films were dried up to the level, until equilibrium moisture content was reached. When drying was completed, the average moisture content of each sample was analyzed according to the hot air oven method. Experiments were performed to determine the effect of process variables on drying kinetics. The variables examined were the temperature 45, 50, 55 and 60°C.

Statistical evaluation

The series of drying experiments at different conditions such as different temperatures (45, 50, 55 and 60°C) at constant air velocity. The results obtained from correlation and regressions comparing the estimates of random and systematic errors were evaluated based on F-value at a probability level of 5%.

Results and Discussion

Drying rate

The typical drying rate curves at different drying temperatures are shown in Figure 1. The variation of moisture content with drying time was obtained at each drying temperature. From these results, drying rates were calculated and plotted against time. The drying rates were computed using a Lagrangian numeric differentiation technique utilizing three data points. It was observed that the drying rate decreased continuously throughout the drying period. The drying of films took place in the falling rate period. Similar types of observations on the thickness reduction of films with respect to temperature have also been studied by other workers [31].

Selection of the drying model

The convective drying of biological materials in the falling rate period is a diffusion-controlled process and may be represented by Fick's second law of diffusion. Various types of mathematical models have been used to describe drying of foodstuffs, ranging from theoretical models based on classical diffusion theory and simplified forms of these to purely empirical models [32-34]. However, the non-Fickian models have been observed during drying of viscoelastic food materials where both relaxation and diffusion affect mass transfer [35]. One equation that has been used successfully to describe drying behavior is Page's equation as below:

$$MR = (m-m_e) / (m_o-m_e) = \exp(-kt^n) \quad (1)$$

The linear form of Eq. (1) is

$$In [-In (MR)] = In (k) + n In (t) \quad (2)$$

Linear regression of Equation (1) was carried out using the least squares technique and the coefficients were determined. The values of the coefficients are reported in Table 1. As seen in Figure 1-3, Page's equation adequately described the drying of sweet potato starch based films over selected range of drying air temperatures. The coefficient of determination was greater than 0.976 and standard errors were less than 0.053 in all the cases, as shown in Table 1.

Temp (°C)	k	N	R^2	Standard Error
45	0.00098	1.574	0.988	0.035
50	0.00145	1.568	0.9768	0.053
55	0.00199	1.543	0.9892	0.04
60	0.00226	1.559	0.9854	0.051

Table 1: Value of coefficients of Eq. (2).

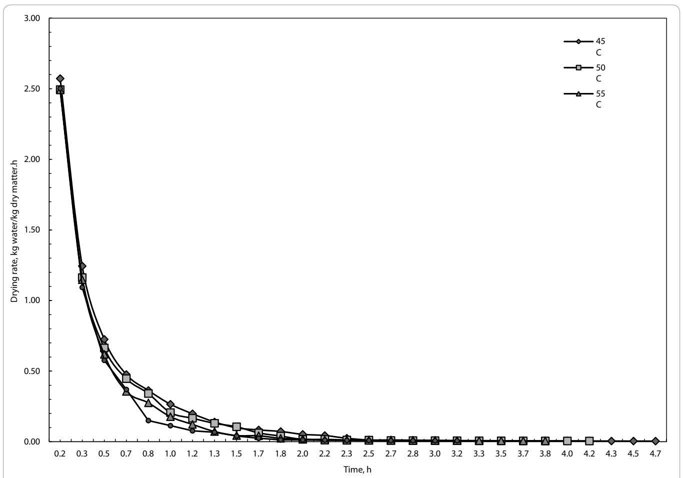

Figure 1: Effect of temperature on drying rate of sweet potato starch based films.

Effect of temperature variables on drying characteristics

It was observed that the total time of drying reduced significantly with the increase in the temperature of hot air. As the temperature increases the drying reduced. The rate constant (k) increased (0.000-0.002) with the drying air temperature. The results suggested that the Arrhenius law might be applicable to relate the dependence of the rate constant on drying air temperature. The relationship is given by the following equation:

$$k = k_o \exp(-E/RT) \quad (3)$$

The computed values for activation energy for films were 26.89 kJ mol^{-1}. Plots of ln MR against drying time showed a linear relationship (Figure 3) and verify the dependence of drying air temperature.

Conclusion

Drying took place in the falling rate period, and Page's model was found to describe well the drying behavior of sweet potato starch based films. The drying rate constant was related to temperature using the Arrhenius relationship. It would be possible to attain faster drying with increased drying temperature up to 60°C with reduced time. Drying took place entirely in the falling rate period.

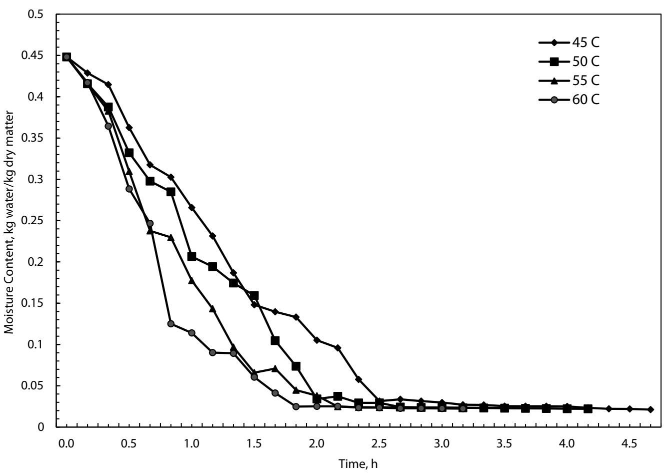

Figure 2: Effect of temperature on moisture content of sweet potato starch based films.

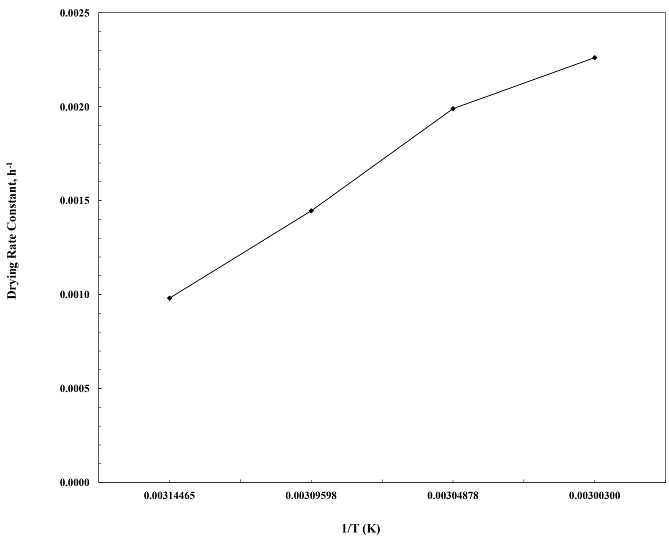

Figure 3: Temperature dependence of drying rate constant of sweet potato starch films.

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