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Moisture sorption characteristics of red cherry pepper (*Capsicum annum var. cerasiforme*) of Sikkim

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ABSTRACT

Moisture sorption experiments were conducted for red cherry pepper using static gravimetric method. Four different saturated salt solutions corresponding to different relative humidity in the range of 23.2 – 75.5% at 20°C were used in the present study. Four sorption models viz., GAB, Halsey, Oswin and modified BET were tested to fit the experimental data. It was observed that the values of statistical parameters of the models viz., coefficients of regression R^2 was in the range of 0.95 - 0.98, average percent error E was in the range of 6.935% – 10.378%, and X^2 was in the range of 0.0006 – 0.0012 and *RMSE* was in the range of 0.013 -0.024. Almost all the models showed coefficients of regression R^2>0.95 and E ≤10% which indicated that all the models can be considered as acceptable for predicting equilibrium moisture content of red cherry pepper. However, out of all the tested models, Oswin model showed the lowest values of E (6.935%), χ^2(0.0006), second highest value of R^2 (0.972) and hence can be regarded as the best fit model to predict the sorption behaviour of red cherry pepper.

1. Introduction

Red Cherry pepper (*Capsicum annum var. cerasiforme)* which is locally known as *dallae khorsani*, is one of the important cash crops of Sikkim and Darjeeling hills. They are small, round shaped, fleshy and heavily seeded. They are green in color in early stage of fruiting and turn red when fully matured. It derives its name from its cherry like shape and appearance. Most cherry peppers are not more than 0.75 – 1.5 inch in diameter. It is an excellent source of vitamin A and C, (Hailu and Derbew, 2015). Due to its high moisture content (about 85% w.b.), shelf life of cherry pepper in ambient condition is limited to 7 - 10 days in ambient conditions in Sikkim (Huirem et al., 2018). This makes it rare and costly during the off season. Hence, preservation of cherry peppers is of considerable importance both to the farmers as well as to the consumers. Controlling the moisture content during the processing of foods is an ancient method of preservation. This is achieved by either removing water, or binding it such that the food becomes stable to both microbial and chemical deterioration. For this reason much attention has been given to the sorption properties of foods.

A moisture sorption isotherm describes the relationship between the water activity (aw) and equilibrium moisture content for a food product at a constant pressure and temperature (Getahun et al., 2020). The knowledge and understanding of moisture sorption isotherms for foods is of great importance in food science and technology for many problems such as the design and optimization of processing as for instance in drying, for assessing packaging problems, for modeling moisture changes which occur during drying and for predicting shelf life (Aviara, 2020).

Several researchers have investigated moisture sorption characteristics of different fruits, vegetables, spices at various temperatures (Getahun *et al.,* 2020). These moisture sorption data can be modeled using many empirical and semi empirical equations that have been proposed in the literature. Since the moisture sorption of food materials represent the hygroscopic properties of various constituents, it is difficult to have a unique mathematical model whether

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theoretical or empirical that describes accurately the sorption isotherm in the whole range of water activity and for various types of food. There is few published information on sorption characteristics for red cherry pepper. Therefore, the present study was taken up to investigate the moisture sorption characteristics, and to suggest the best fit model for predicting the sorption behaviour of red cherry pepper.

2. Materials and Methods

1. Preparation of sample

Fresh mature red cherry peppers (*Dallae*) were procured from local market (Ranipool, India). The samples were stored under refrigerated conditions until further experiments. The samples were washed, wiped dry and their weighed using a digital electronic balance (Contech, India) with an accuracy of ±0.001. Chilli pods of relatively uniform size and weight were used in the experiments. The average equivalent diameter of samples as measured by a micrometer was determined as 2.9 cm. Initial moisture content of cherry peppers were measured using infrared moisture analyzer (SatoriusM35, India). Chemical salts were procured from MERCK, India.

2. Experimental procedure

Clean cherry peppers were taken for moisture sorption studies. Moisture sorption experiments were conducted using static gravimetric method (Labuza, 1984). Four saturated salt solutions corresponding to give different relative humidity in the range of 23.2 -75.5% were used. The salt solutions used and their corresponding relative humidities at different temperatures are given in Table 1. Cherry pepper samples were weighed and placed in containers, inside desiccators containing saturated salt solutions. Samples were kept in triplicate inside the desiccators. The desiccators were stored at a temperature of 20±2°C. Samples were weighed at 7 days interval.

Equilibrium was reached when the sample weight difference between two successive measurements was less than the 0.001 g. The time required for equilibrium was 4 weeks or more depending on relative humidity and temperature of the samples. Water activity was calculated from equilibrium Relative humidity (ERH) using the formula ERH=aw x 100

3. Modeling of Experimental Data

Although several mathematical models exist to describe water sorption isotherms of food materials, no single equation gives accurate results throughout the whole range of water activities, and for all types of foods (Lomauro *et al.,* 1985). It was noted by many researchers (Labuza 1975; Van den Berg & Bruin 1981) that no sorption isotherm model could fit data over the entire range of relative humidity because water is associated with the food matrix by different mechanisms in different water activity regions. Of the large number of models available in the literature, some of those more commonly used for vegetables and peppers were best described by the Guggenheim-Anderson-de Boer (GAB) model, Modified Brunauer, Emmett and Teller (BET) model, Oswin equation and Halsey equation which were shown in Table 2 (Kaymak-Ertekin & Gedik 2004; Kaymak-Ertekin & Sultanoğlu 2001). These models were selected for the present study and experimental data of all samples were fitted to these four sorption models.

Table 1. Saturated salt solutions with corresponding equilibrium relative humidity

Salt	Average equilibrium relative humidity at 20°C, %
Sodium chloride	75.5
Sodium nitrate	65.3
Magnesium chloride	33.6
Potassium acetate	23.2

Ref: *Sahay and Singh (2001)*

Table 2 Equations describing the sorption isotherm

Name of the models	Equations	References
Modified BET	$M = \frac{a}{(1 - brh)}$	Modified BET,1996
GAB	$M = \frac{M_o CK a_w}{(1 - Ka_w)(1 - Ka_w + CKa_w)}$	Van den Berg, 1985
Halsey	$a_w = e^{(-k/M^n)}$	Halsey, 1948
Oswin	$M = k\left[\frac{a_w}{1 - a_w}\right]^n$	Oswin, 1946

Where *C, K, k, a, b* and *n* are constants in sorption isotherm models, a_w is water activity, *M* is the equilibrium moisture content (dry basis) and M_o is the monolayer moisture content (dry basis).

For determination of model coefficients, these models were fitted to the experimental data using Lab fit curve fitting software V7.2.48. The statistical criteria used to evaluate the goodness-of-fit of each model were coefficient of determination (R^2), reduced chi square (χ^2), root mean square error (*RMSE)* and average percentage error(*E).* For good quality fit, R^2 value of the selected model should be highest and χ^2, *RMSE* and *E* values should be less than10%. (Getahun *et al.,* 2020). The above parameters were calculated using the following equations.

$$\chi^2 = \frac{1}{N-z}\sum_{i=1}^{N}(M_{exp,i} - M_{pre,i})^2 \quad \text{...Eq. (1)}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(M_{exp,i} - M_{pre,i})^2\right]^{1/2} \quad \text{... Eq.(2)}$$

$$E = \frac{100}{N}\sum_{i=1}^{N}\frac{|M_{exp,i} - M_{pre,i}|}{M_{exp,i}} \quad \text{... Eq.(3)}$$

where, $M_{exp,i}$ the experimental equilibrium moisture content, $M_{pre,i}$ is the predicted equilibrium moisture content, χ^2 is reduced chi square, *RMSE* is root mean square error, *E* is average percentage error, *N* is number of readings and *z* is number of constants in the model.

3. Results and Discussion

1. Desorption Isotherms

The experimental results of equilibrium moisture contents(EMC) for red cherry peppers at various each water activity(a_w) values are presented in Table 3..From Table 3, it can be observed that the EMC values ranges from 12.196 – 35.3 % dry basis for water activity range of 0.232 – 0.755. Fig. 1 shows the sorption isotherm for red cherry peppers at 20°C.

Table 3. Equilibrium moisture content (% dry basis) of red cherry peppers at 20°C

Water activity, a_w	Average Equilibrium moisture content, % db
0.232	12.196
0.336	13.533
0.653	31.475
0.755	35.300

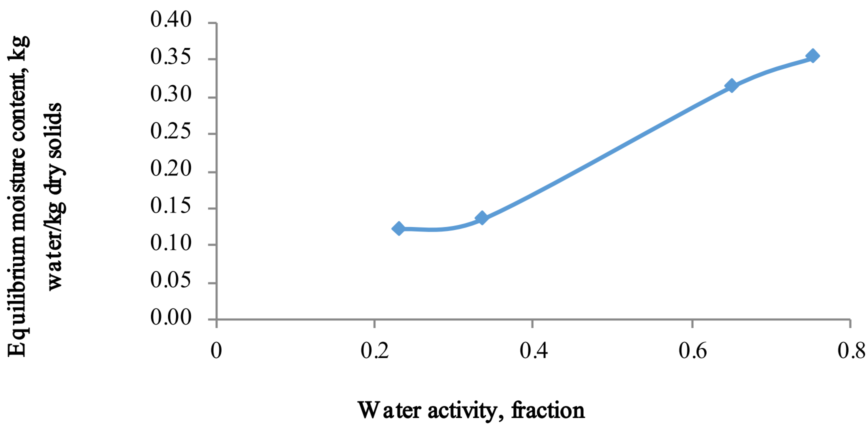

Fig 1. Desorption Isotherm of red cherry pepper at 20°C

The sorption isotherm gives the characteristic sigmoidal curve, typical of the many sorption isotherms of food (Iglesias & Chirife, 1982).According to the BET classification (Brunauer et al., 1940) thisdesorption curve obtained at 20°C is type II. The equilibrium moisture content decreased with a decrease in water activity/relative humidity at constant temperature.This may be due to the tendency of the food material to lower vapor pressure when decreasing the relative humidity of air (Moreira *et. al.,* 2008). Similar effect has been reported by Kaymak-Ertekin and Sultanoğlu (2001) during sorption studies of green and red peppers. No reported literature was available for comparison of sorption data of red cherry peppers at the studied temperature. Hence, the results were comparedwith sorption data of red peppers and chilli peppers at higher temperature of 30°- 65°C as reported by Kaymak-Ertekin and Sultanoğlu (2001) and Getahun *et al.* (2020) respectively. The equilibrium moisture contents reported by these investigators were found to be lower than the observed experimental data due to higher temperature.

2. Fitting of Sorption Models to Experimental Sorption Data

The coefficients of the four sorption models tested at 20°C were obtained from the Labfit software and are reported in Table 4. From Table 4, it can be observed that the values of statistical parameters of the models viz., coefficients of regression R^2in the range of 0.95 - 0.98, average percent error, E,in the range of 6.935% – 10.378%, and χ^2 in the range of 0.0006 – 0.0012 and $RMSE$ in the range of 0.013 -0.024. A value of average percent error of 10 or less was considered as a good fit (Wang & Brennan,.1991).Almost all the models showed coefficients of regression R^2>0.95 and E ≤10% which indicated all the models can beconsidered as acceptable for predicting the equilibrium moisture content (EMC) of red cherry pepper. However, out of all the tested models, Oswin model showed the lowest values of E (6.935%), χ^2(0.0006), second highest value of R^2 (0.972) and hence can be regarded as the best fit model to predict the sorption behaviour of red cherry pepper

Fig. 2 shows the comparison of the experimental data with the predicted equilibrium moisture contents by Oswin model. From this figure, it can be observed that Oswin model is fitting closely to the experimental data in the studied water activity range. Similar type of modelling for desorption behaviour of red chili pepper has been carried out by Seid & Hensel (2012) in the temperature range of 30°-70°C. According to them, GAB model was found to be the best fit model with an E value of 5.95% and R^2 value of 0.99 for the water activity range of 0.11 – 0.92. Similarly, Getahun *et al.,* (2020) has reported, GAB model to be the best fitted model for green chili pepper whereas Oswin model for brown and red chili variant. Kaymak-Ertekin and Sultanoğlu (2001) modeled the desorption behaviour of green and red peppers in the temperature ranges 30°-60°C. They reported Halsey model to be the best fit model for their experimental water activity range of 0.11-0.9 with E value of 3.716 %. Hence, it can be inferred that the best fit desorption model varies with the temperature and water activity range studied even for similar type of food product. It may be attributed to variation in shape of the products studied.

Table 4: Estimated sorption model constants and statistical parameters for red cherry peppers during desorption

Sl. No.	Model	Temperature, 20°C
1.	**Oswin**	
	k	0.212
	n	0.488
	E, %	6.935
	R^2	0.972
	RMSE	0.017
	χ^2	0.0006
2.	**GAB**	
	M_o	0.715
	C	2.085
	K	0.306
	E, %	7.761

	R^2	0.983
	RMSE	0.013
	χ^2	0.0007
3.	**Modified BET**	
	a	0.105
	b	0.949
	E, %	10.378
	R^2	0.949
	RMSE	0.024
	χ^2	0.0012
4.	**Halsey**	
	K	0.063
	N	1.51
	E, %	7.427
	R^2	0.961
	RMSE	0.024
	χ^2	0.0008

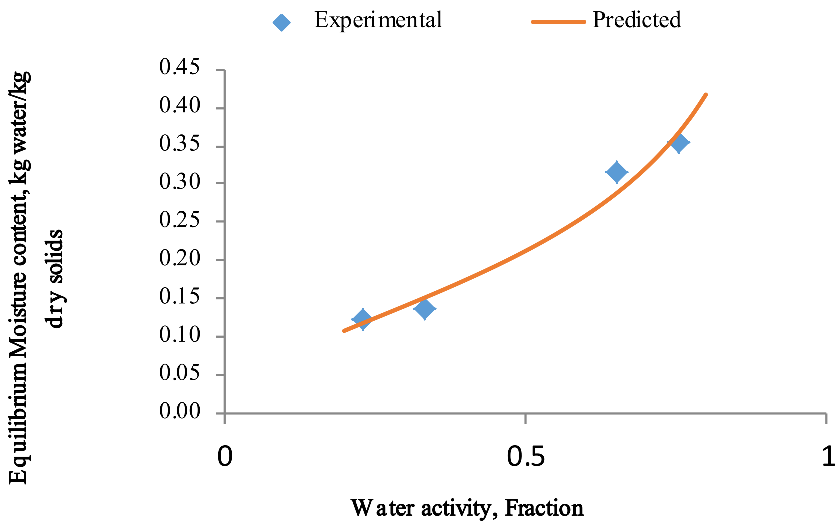

Fig 2. Comparison of the experimental EMC with the predicted EMC by Oswin model.

4. Conclusions:

The present study focused on modelling of moisture sorption characteristics of red cherry pepper. The study revealed that the equilibrium moisture content of red cherry pepper decreased with decrease in relative humidity at constant temperature. Type II moisture sorption isotherm was observed. Based on the model fit statistics, all the selected models were found to be suitable for predicting the moisture sorption behavior of red cherry pepper. However, the Oswin model can be recommended as best fit model due to its most desirable statistical parameters. The findings of this study would be useful for storage, and handling of red cherry pepper.

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