Development of moisture isotherms for Momordica charantia and Carica papaya

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Abstract: Safe moisture of a product is important in drying of agricultural products to prevent it from deterioration. The equilibrium moisture content (EMC) is an important parameter in modeling and simulation of drying process. The objectives of this research are to develop an EMC curve for Agricultural Products, such as bitter gourd (*Momordica charantia*) and papaya (*Carica papaya*), and to test the suitability of mathematical models of modified Henderson's equations. The study is performed on the basis of adsorption of moisture content, at three temperatures (30°C, 40°C & 50°C) and four relative humidity (Rh) (10%, 30%, 50% and 80%). Salt solutions with concentrations were used to maintain Rh. The statistical analysis was done to find the best model and the significant difference between observed and calculated values were tested by coefficient of regression value and Reduced Chi squared test. EMC curve is developed for Bitter gourd and Papaya. The constants of mathematical models of Bitter gourd are estimated as N= 3.9, C=15.336 and $K=1.05\times10^{-7}$ and for Papaw as N= 15.3, C=13.75 and $K=3.433\times10^{-29}$. The modified Henderson's equation was found to be the most appropriate model to describe the adsorption EMC isotherm equations of the given Agricultural products.

Keywords: Equilibrium moisture content, adsorption, isotherms, Mathematical model

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1 Introduction

Drying, the removal of water from products is a necessary operation in many industries for the purpose of preserving product quality or adding value to the products. The main purpose of agricultural product drying is often to reduce loss and to maintain product quality during subsequent storage and delivery. Drying process is the most important appropriate technology which can preserve and improve the quality and quantity of the final product successfully (Henderson and Perry, 1976; Erteken and Yaldiz, 2004; Hossain and Bala, 2007).

Fundamental relationship between equilibrium moisture content and relative humidity of a food at a given temperature is presented through sorption isotherm. Moisture sorption characteristics of food material are important in designing, modelling and optimization of many post-harvest handling processes such as drying, storage and aeration (Bala, 1997; Palipane and Driscoll, 1993; Akanbi et al., 2006).

Many researchers have developed mathematical, theoretical, semi-theoretical and empirical equations to describe the sorption isotherms of food material (Guillard et al., 2013). lglesiasis and Chirife (1995) reviewed 73 isotherm equations, both theoretical and experimental, and their use for fitting sorption isotherms of food products. None of these equations described accurately the sorption isotherm over the whole range of relative humidity and for different types of food materials.

However, most products can be represented by some of available equations and one of these equations was given below. Grains and related products are often represented by the slightly complicated Modified Henderson Equation (Equation (1)) (ASAE, 2000;

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Rahman, 2007). Different constants must be used for each product and temperature of interest. Dey and Nelson (1965) modified Henderson equation to describe wheat up to 70% relative humidity. Adsorption and desorption isotherms of macadamia in-shell nuts at nine relative humidity levels and six temperatures ranging from 11% to 97% and 20°C to 60°C respectively were established using the gravimetric static method (Palipane and Driscoll, 1993). The relative humidity defined by these equations is commonly called the equilibrium relative humidity (ERH). Thus, ERH is the relative humidity for equilibrium between air and specific product at a given temperature.

$$ERH = 1 - \exp[e - K(t + c)M_e^N] \qquad (1)$$

where, ERH = Equilibrium relative humidity, decimal; M_e = Equilibrium moisture content, %, dry basis; t = temperature, °C; K, N, C = constants determined for each material.

The available information on sorption equilibrium moisture content for bitter gourd and papaya is scarce and does not cover the entire range of temperature and moisture content of practical application. This study was focused to determine unknown constant of adsorption isotherm for bitter gourd and papaya at different temperatures to fit the experimental data to some selected mathematical model (modified Henderson's equations).

2 Materials and methods

2.1 Sample preparation

Freshly harvested Bitter gourd and Papaya were sliced with 2 mm thickness and pretreated with $NaHCO_3$ and lime respectively to avoid discoloration (Onayemi and Badifu, 1987). Both samples were initially dried at the 60°C to reduce the moisture content below the level of sorption study.

2.2 Experimental procedure

The cylindrical airtight glass bottles (60 mm diameter and 80 mm height), containing saturated salt solutions (Table 1) for maintaining Relative humidity and toluene for controlling mould growth, were placed in temperature controlled heat chambers.

Three temperature controlled chambers were fabricated (20×300×400 mm^3). Regulator was used to control the temperature inside the chamber as 30°C, 40°C and 50°C. Insulation sheets were used to minimize the heat loss. Inside arrangement was prepared to put twelve experimental units inside each chamber.

Table 1 Saturated salt solutions used in sorption experiments for different Relative humidity (Greenspan, 1977)

Name of the salt	Relative Humidity		
	30°C	40°C	50°C
Lithium chloride	0.113	0.112	0.111
Magnesium chloride	0.323	0.318	0.314
Magnesium nitrate	0.513	0.487	0.464
Ammonium sulfate	0.806	0.799	0.792

Samples were replicated three times. Duplicate samples of different type of agricultural products (~3 g) suspended over the saturated salt solutions in the glass bottle and the bottles were made air tight with lid. The glass bottles were placed in the drying camber at a desired constant temperature and allowed to equilibrate with the environment inside the glass bottles. The weight of each sample was checked initially 12 hours interval until weight change was less than 0.01 mg. The moisture content of each sample was then determined by drying in a ventilated air own at 105°C for 24 hours (Gravimetric method) (Misra, 1972; Naviglio et al., 2010).

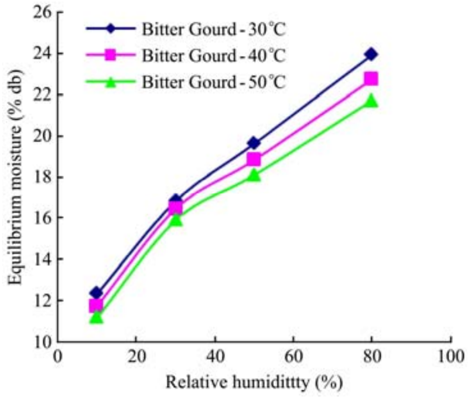
2.3 Model fitting

Selected models are used for fitting the experimental data for adsorption isotherms for bitter gourd and papaw. The unknown constants of the equation were mathematically estimated. The Chi-squared test was done to determine the significance difference between observed and calculated values at 5% significant level. The regression analysis was done for testing the developed isotherm.

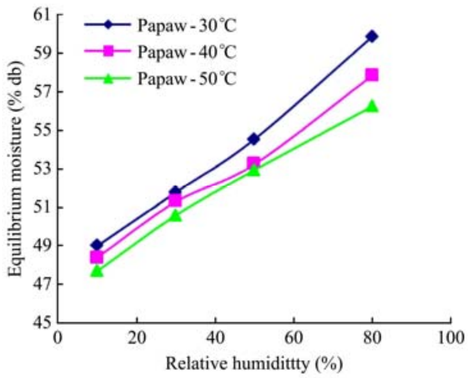
3 Results and discussion

The experimental adsorption equilibrium moister contents for bitter gourd and papaya for different relative humidity at the temperatures of 30°C, 40°C and 50°C are presented in Figure 1(a) and 1(b)respectively.

All isotherm curves followed the same shape. Higher equilibrium moisture contents were found at the lower temperature at the same relative humidity. The reason may be that as temperature increased the vapor pressure of the moisture within the product increased and hastened the transfer of moisture from product to the air. Hossain and Bala (2000) were observed same behavior of isotherm for red chilies.



(a) Bitter gourd



(b) Papaya

Figure 1 Experimental adsorption isotherms for bitter gourd and papaya for different relative humidity at different temperature

The constants of the modified Henderson’s equation were derived for bitter gourd and papaya and the values were given in the Table 2.

Table 2 Developed constant for mathematical models

Agricultural product	Constants		
	N	C	K
Bitter Gourd	3.9	15.36	1.05×10^{-7}
Papaya	15.3	13.75	3.434×10^{-29}

Using the above developed constants, the equilibrium moisture content values for bitter gourd and papaya were calculated. The calculated values and the observed values of the experiment is given in Table 3 and 4 for bitter gourd and the papaya respectively.

Table 3 Calculated and tested value for bitter gourd

RH (%)	30°C		40°C		50°C	
	Tested value	Calculated value	Tested value	Calculated value	Tested value	Calculated value
10	12.3	12.9	11.8	12.3	11.2	11.8
30	16.8	17.7	16.4	16.8	15.9	16.1
50	19.6	21.0	18.8	19.9	18.1	19.1
80	23.9	25.9	22.7	24.6	21.7	23.6

Table 4 Calculated and tested values for Papaya

RH (%)	30°C		40°C		50°C	
	Tested value	Calculate value	Tested value	Calculate value	Tested value	Calculate value
10	49.0	47.9	48.4	47.2	47.7	46.7
30	51.8	51.8	51.3	51.1	50.6	50.6
50	54.5	54.1	53.2	53.4	52.9	52.8
80	59.9	57.1	57.8	56.4	56.2	55.8

The regression R^2 value and Chi Squared value shows that there is no significant difference between tested values and calculated values for Modified Henderson’s equation as all the calculated chi square values are lower than the chi square value at 5% significant level.

Table 5 Regression R^2 value and Chi squared value of calculated and the observed data

Temperature °C	R^2 value		Calculated chi square value		Chi square value at 5% significant level
	Bitter gourd	Papaya	Bitter gourd	Papaya	
30	0.9528	0.9984	0.3015	0.1907	
40	0.933	0.9948	0.2294	0.0686	3.8140
50	0.9212	0.9920	0.2276	0.0263	

Misra (1972) find adsorption isotherm for Indian red chili to the Henderson (1952) equation and found reasonable agreement between the predicted and experimental data. The calculated and experimentally tested adsorption moisture isotherms by modified Henderson’s equation are shown in Figure 2 and 3 for bitter gourd and papaya respectively.

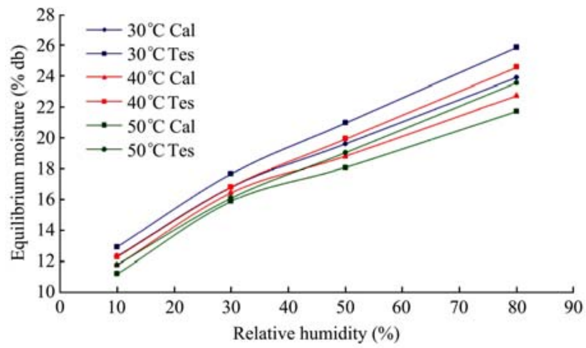


Figure 2 Calculated and tested adsorption isotherm using modified Henderson’s equation for bitter gourd

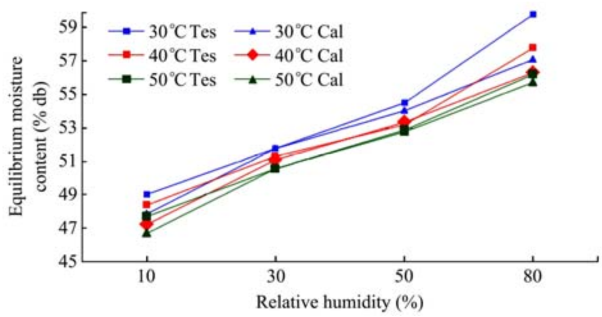


Figure 3 Calculated and tested adsorption isotherm using modified Henderson’s equation for papaya

4 Conclusion

Equilibrium moisture content model and Modified Henderson’s equation were used to fit the experimental adsorption moisture data in the different relative humidity values at the different temperatures. The constant values of the modified Henderson’s equation are estimated for bitter gourd as N=3.9, C=15.336 and $K=1.05\times10^{-7}$ and for papaya as N=15.3, C=13.75 and $K=3.433\times10^{-29}$. The modified Henderson’s equation is recommended for the prediction of the adsorption isotherms for bitter gourd and papaya.

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