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RESEARCH PAPER

Modelling of sorption isotherms of blanched and unblanched spinach leaves

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SUMMARY :

A study was conducted to determine the effect of blanching on moisture adsorption and desorption characteristics of spinach by static gravimetric method. Different saturated salt solutions were prepared to provide constant relative humidity environments. Four spinach samples (Unblanched, Unblanched dried, Blanched and Blanched dried) were kept at 3 temperatures (30^{0}C, 40^{0}C and 60ºC) with corresponding five relative humidity levels (10.95 to 92.31%). It was observed that EMC of spinach increased with increase in relative humidity at constant temperature also at constant ERH, EMC decreased with increase in temperature. The adsorption EMC was lower than the desorption EMC for all the samples at all temperature and relative humidity ranges. The blanched dried spinach exhibited lowest EMC than other samples. Sorption data was modeled by using Henderson equation to develop guideline for moisture sorption process. Both constant of equation found to be dependent on temperature. The relation between constant was expressed by a polynomial equation.

KEY WORDS : Spinach, Sorption sothorms, ERH, EMC, Mathematical modeling

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Spinach (*Spinacia oleracea*) is an important leafy vegetable commonly grown in India. It contains 91.40% moisture, 3.6% carbohydrate, 2.2% protein, 2.2% fibre, 0.4% fat and rich source of vitamin A, iron and calcium (Anonymous, 2009). Shelf life of spinach is shorter due to its high moisture content. Therefore, to increase shelf life of spinach, its moisture should be removed which can be done by dehydration and stored at particular temperature and relative humidity. However, changes in flavor and textural alterations may occur during storage of dried food products. These changes are particularly influenced by moisture content of material, relative humidity and storage conditions. Hence, knowledge of such transformation factors is important for predicting the various storage conditions of particular material (Velez-Ruiz *et al.*, 2004).

EMC is defined as moisture content of hygroscopic material in equilibrium with a particular environment in terms at temperature and relative humidity. The corresponding relative humidity is known as equilibrium relative humidity (ERH). Material can attain EMC either by losing the moisture (desorption isotherm) or by gaining the moisture from surrounding (adsorption isotherm). Thus with the knowledge of the moisture sorption isotherms of vegetable plant, it is possible to predict the maximum moisture that the plant can be allowed to gain during storage. Sorption isotherms are an extremely valuable tool for scientists because they can be used to predict potential changes in biological material's stability. The adsorption isotherm data can be used for a storage method determination while the desorption isotherm data can be used for drying analysis (Daniel and Wanderley, 2004).

Mathematical modeling of sorption process is known to be important for the design of processing equipments and optimization of storage and drying conditions. Work has been conducted on the study of sorption isotherms of different medicinal plants like tow mint, aroma leaves, calendula leaves and so on (Kouhila *et al.*, 2007; Silva *et al.*, 2004; Velez-Ruiz *et al.*, 2004). However sufficient information about vegetable like spinach appears to be lacking. A study was, therefore, undertaken for blanched and unblanched spinach. This information will be useful in identifying the most shelf-stable product of spinach and appropriate packaging materials.

EXPERIMENTAL METHODS

About 10 kg of fresh spinach was purchased from a local market. Air tight glass containers of 350 ml capacity each, five analytical salts namely lithium chloride (LiCl), magnesium chloride ($MgCl_{2)}$, sodium bromide (NaBr), sodium chloride (NaCl) and potassium nitrate (KNO_3) with purity 99.9% were used.

Sample preparation :

Fresh spinach leaves were thoroughly washed and rinsed with potable water. The washed leaves were randomly selected, divided into two portions and cut into irregular shapes of about 3 cm^3 size. One portion was used as it is *i.e.* as unblanched while second portion was blanched by dipping the sample in boiling water (100 ± 2ºC) for 1.5 min. and then immediately cooling in water (Chakraverty and De, 1981). The half part of each of unblanched and blanched portion was sun dried for 6 hr. to get the four samples namely unblanched spinach, unblanched dried spinach, blanched spinach and blanched dried spinach leaves. After determining moisture content (%d.b.) of all these samples by oven method (105^0C for 24 h), they were used for sorption study. Unblanched and blanched spinach portions were used for desorption study while unblanched dried and blanched dried spinach portions were used for adsorption study.

Determination of sorption isotherms :

The setup for sorption study consists of air tight glass container with metal lid equipped with saturated salt solution and air oven. For sorption study of samples, saturated salt solutions were prepared (Silva *et al.*, 2004; Zomorodian and Tavakolil, 2007), which gave relative humidity in the range of 10.95 to 92.31% at constant temperatures (Table 1). Each of 100ml of above prepared saturated salt solution was filled in different glass containers and kept at constant temperatures (30, 40 and 50^0C) in oven for 24 h for obtaining constant relative humidity (Kouhila *et al.*, 2007). After completion of equilibration process, each samples of four type of above prepared spinach leaves (1 g each for desorption and adsorption study) were kept in glass container holder. After hermitically sealing the containers, they were again kept in oven for EMC determination till constant weight of samples was reached (Alakali *et al.*, 2009). Each sample had taken around 10 h to reach constant weight. Each experiment was replicated thrice. After obtaining constant weight of each sample, its EMC (% d.b) was determined by using standard air oven method at 105^0C for 24 h (AOAC, 1990).

Modelling of sorption isotherms :

Henderson equation was used to model the sorption isotherm for all the samples of spinach as shown in following equation :

$$1 - ERH = e^{-cTM_e^n} \qquad (1)$$

here, ERH is equilibrium relative humidity (decimal), Me is equilibrium moisture content (%d.b.), T is temperature (^{0}C) and c and n are constant depend on crop type.

The equation (1) was rearranged in the form of equation (2) and (3).

$$\log(1 - ERH) = cTM_e^n \qquad (2)$$

$$\log\left[\frac{-\log(1 - ERH)}{T}\right] = \log c + n \log M_e \qquad (3)$$

It was considered that linear regression analysis (Microsoft excel 2007) of $\log\left[\frac{-\log(1 - ERH)}{T}\right]$ against $\log M_e$ gives value of co-efficients (c & n) of Henderson equation.

EXPERIMENTAL FINDINGS AND ANALYSIS

The initial moisture contents of unblanched, blanched, unblanched dried and blanched dried spinach leaves were observed, 91.00, 91.80, 3.52 and 2.27% (w.b.) respectively. Equilibrium moisture contents (EMC) with equilibrium relative humidity (ERH) for all the types of spinach is shown in Table 1. It can be seen that EMC of spinach sample increased with increase in ERH at a given temperature. Also it was observed that at a particular ERH, EMC of spinach samples decreased with increase in temperature. This might be due to spinach samples became less hygroscopic with increase in temperature at constant relative humidity. Similar trends were observed for maytenus leaves (Daniel and Wanderley, 2004); tow mint (Kouhila *et al.*, 2007) and calendula leaves (Silva *et al.*, 2004).

EMC of blanched spinach sample always exhibited less EMC than unblanched spinach sample at that particular relative humidity (Table 1). This might be due to availability of higher moisture in the container at higher relative humidity levels. These observations are in line with the findings of Velez-Ruiz *et al.* (2004), Kouhila *et al.* (2007), Alakali *et al.* (2009). Blanched and blanched dried spinach gave lower EMC as compared to unblanched and unblanched dried spinach, respectively. The

EMC's of blanched spinach were lower than unblanched, because of its less hygroscopic nature, which may be due to the hot water blanching which lead to gelatinization of chlorophyll in the leaves possibly creating a less hygroscopic polymer network around the blanched dried spinach surfaces. The same trend was observed for ginger by Alakali *et al.* (2009).

Henderson equation constants for desorption and adsorption isotherms for unblanched and blanched spinach

Table 1 : Desorption and adsorption equilibrium moisture contents of spinach leaves at different temperature and relative humidity levels

Temperatures (^{0}C)	Equilibrium relative humidity (ERH) (%)	Desorption EMC (% d.b)		Adsorption EMC (% d.b)	
		Unblanched	Blanched	Unblanched	Blanched
30	11.28	7.77	6.16	4.59	4.10
	32.44	10.98	9.86	10.09	9.78
	56.04	19.99	16.86	17.00	15.18
	75.09	28.25	24.37	22.98	21.24
	92.31	45.64	43.88	41.10	40.50
40	11.21	6.66	4.93	4.10	4.05
	31.60	9.9	9.74	9.27	7.80
	53.2	19.09	15.84	15.02	14.49
	74.68	27.46	22.21	20.71	18.65
	89.03	42.87	41.46	40.19	37.49
60	10.95	4.39	3.70	3.07	3.07
	29.26	8.96	7.41	6.17	5.15
	49.66	16.03	13.57	12.49	10.35
	74.50	23.71	20.72	18.65	15.46
	86.13	38.42	35.79	35.04	32.48

Table 2 : Henderson equation constants for desorption and adsorption isotherms for unblanched spinach leaves

Temperatures (^{0}C)	Henderson equation constants unblanched spinach leaves					
	Desorption isotherm			Adsorption isotherm		
	c	n	R^2	c	n	R^2
30	0.0263	1.328	0.9986	0.0277	1.352	0.9905
40	0.0269	1.224	0.9931	0.0297	1.212	0.9606
50	0.0230	1.230	0.9820	0.0329	1.041	0.9701

Table 3 : Henderson equation constants for desorption and adsorption isotherms for blanched spinach leaves

Temperatures (^{0}C)	Henderson equation constants for blanched spinach leaves					
	Desorption isotherm			Adsorption isotherm		
	c	n	R^2	c	n	R^2
30	0.0308	1.260	0.9941	0.0329	1.3150	0.9773
40	0.0280	1.231	0.9693	0.0339	1.1470	0.9594
50	0.0278	1.140	0.9785	0.038	0.9783	0.9562

Table 4 : Relation between Henderson equation constants for Desorption and adsorption isotherms for spinach leaves

Desorption isotherm (unblanched leave)	$c = -9x\ 10^{-6}T^2 + 0.0007T + 0.0143$ ($R^2 = 1$)
	$n = 0.0004T^2 - 0.0354T + 2.068$ ($R^2 = 1$)
Adsorption isotherm (unblanched dried)	$c = -1x\ 10^{-6}T^2 + 0.0003T + 0.0201$ ($R^2 = 1$)
	$n = 0.0002T^2 - 0.0267T + 1.99$ ($R^2 = 1$)
Desorption isotherm (blanched leave)	$c = 9x\ 10^{-6}T^2 - 0.0009T + 0.05$ ($R^2 = 1$)
	$n = -6x\ 10^{-5}T^2 + 0.001T + 1.281$ ($R^2 = 1$)
Adsorption isotherm (blanched dried)	$c = 3x\ 10^{-6}T^2 - 0.0001T + 0.0341$ ($R^2 = 1$)
	$n = 0.0003T^2 - 0.0363T + 2.1536$ ($R^2 = 1$)

leaves shown in Table 2 and Table 3. It can be seen that co-efficient of determination was higher (R^2> 0.95) indicated that Henderson equation satisfactorily described sorption characteristics for all the spinach samples. The constant 'c' was almost equal indicated that there was no much effect of temperature on sorption process but there might be possibility of higher variation with higher temperature variation in sorption process. The constant 'n' was decreased with increase in temperature for both adsorption and desorption process for all the samples. This effect might be depending on moisture transfer or moisture diffusion properties of leaf (Silva *et al.*, 2004). Therefore, relation between these co-efficients with temperature was expressed by using polynomial equation (R^2=1) as shown in Table 4.

Conclusion :

EMC of spinach increased with increase in relative humidity at all temperatures, while it decreased with increase in temperature at all relative humidity levels. Also, blanching greatly affected the adsorption and desorption characteristics of spinach. Blanched dried spinach exhibits lowest EMC at all temperature and relative humidity ranges. Henderson equation satisfactorily (R^2 >0.95) described moisture sorption characteristics for all the samples of spinach.

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