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RESEARCH PAPER

Moisture Sorption Characteristics of Ready-to-eat Chicken Wheat Crisps Prepared Using Resistant Starch and Chicken Powder with Wheat Flour

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ABSTRACT

Fibre and protein enriched chicken wheat crisps were evaluated for their adsorption behaviour at a temperature range of 5 °C - 40 °C and a water activity range of 0.1-0.9. Sigmoid type II isotherm was obtained for the product and the sorption data was fitted to 3 models namely Brunauer–Emmett–Teller (BET), Guggenheim–Andersen–de Boer (GAB), and Peleg model. Each model was statistically evaluated by means of root mean square (per cent) and coefficient of determination (R2). Peleg and GAB gave the best fits for the moisture sorption data evaluated on the basis of regression analyses and goodness of fit. Surface area of adsorption was evaluated using parameter values obtained from the BET model and the surface area decreased with increase in temperature. Equilibrium moisture content at a particular water activity and isosteric heat of sorption were seen to decrease with increasing temperature. We conclude that the chicken wheat crisps can be stored at 25 °C for a better shelf life.

Keywords: Moisture sorption; Isosteric heat; Chicken wheat crisps; Resistant starch

1. INTRODUCTION

Consumer demand for healthy food products has increased in the past decades. Convenience foods category needs to provide healthy and tasty options to the consumers as the lifestyle and working pattern of today's consumer leaves them with very less time for cooking, etc. Ready-to-eat category of convenience foods mainly include snack items such as biscuits, crackers, crisp bread, chips, extruded products to name a few. One concern for such on-the-go products is their nutritional composition. They are mainly high in fat, low in fibre and protein. Any improvement in this area will be beneficial for today's health-conscious consumer. Main concern of the on-the-go products is that they provide taste and satiety in between the main meals. Hence, the food industry must make a conscious choice while choosing to develop products. Resistant starch is a new type of low calorie (2 kcal/g) functional food ingredient providing variety of health benefits to consumers. It benefits special groups of people, meanwhile the ordinary consumers can also gain health benefits[1]. This ingredient has been incorporated in various foods and found to be sensorially accepted by consumers[2-6]. Chicken wheat crisps were developed as a convenient ready-to-eat product. The developed product can be compared to the crisp-bread, crackers and matzo products from the western countries and khakhra from India. One main characteristic for these products is the low moisture content, which directly effects their crispness or hardness.

Moisture sensitive foods such as this are susceptible to sensory and quality changes with any change in their environment and if left open, they become stale and soggy. Water migration and diffusion one of the most important factors for the moisture sensitive foods. Also, enzyme activity and rancidity occurs with increase in water activity[7]. The sorption behaviour of various foods have been studied and modelled extensively over recent years[8]. Sorption isotherm is a plot of equilibrium moisture content of product at a given temperature versus water activity[9]. Moisture sorption isotherms of food products are useful thermodynamic tools for the prediction of interaction between food components and water[10]. Also these are known to be of great significance in design, modelling and optimisation of many processes involved in product processing, development and storage conditions[11].

Sorption isotherms act as a very vital tool for food technologists as they can be used to predict possible changes relating to stability of food, that occur during storage and are used to find suitable storing conditions and packaging material[12], offering help to optimise or maximise retention of colour, flavour, texture, nutrients and biological stability[9]. These can also be used to investigate structural features of a food product such as specific surface area, pore volume, pore size distribution, and crystallinity[9]. Many authors have pointed out the importance of this data in drying, aeration, predicting of stability and quality during packaging and storage of food[13-17].

The adsorption isotherms of salted cracker[7] and oatmeal cookies and oat flakes[18] have been reported. Rakshit[19], *et al.* studied the moisture sorption characteristics of wadi, a legume based indian traditional condiment and established suitable

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storage conditions. Rhim[15], *et al.* studied the sorption characteristics of freeze-dried rice porridge. Wani and Kumar[20] studied the sorption behaviour of an extruded snack.

Determination of heat of sorption is essential for the modelling of various food processes and its storage. Additionally, it can also be utilised in estimation of energy requirements of food drying and also provides significant evidence about the state of water in food products[21].

The present study was undertaken to study the adsorption behaviour of chicken wheat crisps made up of wheat flour, resistant starch (RS, Himaize™260) and chicken powder. Numerical optimisation of the product has been reported elsewhere (patent pending). Chicken powder used helps in improvement of nutritional quality of the product as it is a good source of protein.

2. MATERIALS AND METHODS

2.1 Determination of Initial Moisture Content of FDCP

The initial moisture content of chicken wheat crisps was determined using the gravimetric method as described by AOAC[22].

2.2 Determination of Equilibrium Moisture Content

Equilibrium moisture content (EMC) of chicken wheat crisps was determined at 5 °C, 25 °C, and 40 °C by the static gravimetric method. Saturated salt solutions of lithium chloride, magnesium chloride, potassium carbonate, magnesium nitrate, sodium nitrite, sodium chloride, potassium chloride were used to obtain a_w between the ranges 0.1 to 0.9. Toluene was placed in desiccators with RH $\geq$ 70 per cent to avoid mold growth[23]. All the chemicals used were of analytical grade. The desiccators were placed in thermostatically maintained incubators at the mentioned temperatures for a period of 24 h to bring the salt solutions to a stationary temperature. Approximately 1 g of sample was placed in previously weighed glass bottles with the stopper lids. The bottles were weighed periodically until the difference in two successive readings was $\leq$ 1 mg.

2.3 Modelling of Sorption Models

The experimental sorption data obtained for chicken wheat crisps was fitted to 3 sorption models as shown in Table 1. Among the chosen models Brunauer–Emmett–Teller (BET) is a two parameter), Guggenheim–Andersen–de Boer (GAB) is a three parameter and Peleg is a four parameter model. The model fitting was carried out using the software curve expert (version 1.38).

All the equations were converted into linear form. The moisture sorption data were analysed and fitted to different equations either in the whole range of isotherm or part of it. The goodness of fit for each equation was evaluated in terms of coefficient of determination (R^2) and by per cent root mean square (% RMS):

$$RMS\% = \sqrt{\left(\frac{1}{n}\sum_1^n\left(\frac{M\exp - Mcal}{M\exp}\right)^2\right)} * 100 \tag{1}$$

where n denotes the number of observations.

Table 1. Sorption isotherm models for fitting experimental data

Model	Equation	Constant	Reference
BET	$X = \frac{X_m \times C \times a_w}{(1-a_w)\times(1+(C-1)\times a_w)}$	X_m, C	Brunauer[38], *et al.*
GAB	$X = \frac{X_m \times C \times K \times a_w}{(1-k\times a_w)\times(1+(C-1)\times k \times a_w)}$	X_m, C, k	Van den Berg and Bruin[31]
Peleg	$X = (a\times a_w{}^b)+(c\times a_w{}^d)$	a, b, c, d	Peleg[39]

2.4 Surface Area of Adsorption

The water surface area, S_0 in m^2/g of solid, was determined using the Eqn. (2) as described by Labuza[24].

$$S_0 = X_m * N_0 * A_{water} * \left(\frac{1}{M_{water}}\right) \tag{2}$$

where X_m = monolayer value in g adsorbed/g solid, M_{water} = mol. Weight of water = 18 g/mole, N_0 = Avogadro's no. = 6 x 10^{23} molecules/mole, A_{water} = area of water molecule = 10.6 x 10^{-20} m^2.

2.5 Heat of Sorption

The isosteric heat of sorption is the total heat of sorption of water from the material minus the heat of vapourisation of the water[25] (Eqn. (3)). The Slope obtained from a plot of $ln(a_w)$ vs T^{-1} (°K), was used to determine the value for q_{st}. The Claussius–Clapeyron equation (Eqn. (4)) was used to calculate the net isosteric heat of water sorption (Qst, kJ/mol) as described by Bell and Labuza[26]:

$$q_{st} = Q_{st} - \Delta H_{vap} \tag{3}$$

$$Q_{st} = -R\frac{\partial(In\, a_w)}{\partial(T^{-1})} \tag{4}$$

where R is the universal gas constant (8.314x10^{-3} kJ/mol K) and a_{w2} and a_{w1} are the water activity values at temperatures T_2 and T_1, respectively. The isosteric heat of sorption is a differential molar quantity derived from the temperature dependence of the isotherms. The isosteric heat is invariant with temperature, and it is required that the measurement of sorption isotherms be performed at two or more temperature values[25]. The a_w values at various moisture content levels were calculated using the GAB model.

3. RESULTS AND DISCUSSION

3.1 Sorption Isotherm

Adsorption isotherms of chicken wheat crisps obtained at 5 °C, 25 °C, and 40 °C are shown in Fig. 1. The isotherm was type II sigmoidal at all temperatures. Such an isotherm is characteristic of high carbohydrate foods[7,19]. The initial moisture content of chicken wheat crisps was 2 per cent.

The sorption isotherms demonstrate an increase in equilibrium moisture content with increasing water activity, at one particular temperature. This can be explained as an

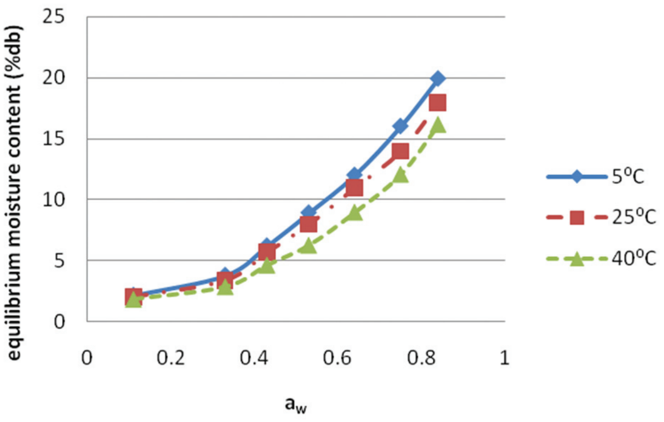

Figure 1. Moisture sorption isotherms of chicken wheat crisps at different temperatures.

increase in the vapour pressure of water within the foods with any increase in the surrounding vapour pressure[27]. Also, the EMC at a particular water activity was observed to decrease with increase in temperature throughout the a_w range studied.

At $a_w < 0.4$, a gradual increase in equilibrium moisture content with increasing a_w was observed. This reflects sorption of water by the starch-based components (wheat flour and Himaize™260). Also, food components like protein have hydrophilic groups that bind water molecules[28]. At higher a_w, the sugar component of the product renders the most significant influence on the sorption behaviour, resulting in an increased equilibrium water uptake at all temperatures.

It can be observed from Fig.1 that the moisture sorption behaviour of the product was temperature dependent. There was a decrease in EMC, at a given a_w and increasing temperature, which shifted the isotherm of higher temperatures to the right. Similar results have been reported by Sharma[27], *et al*. for basundi mix, Rakshit[19], *et al*. for a legume based wadi product and by McMinn[18], *et al*. for their oat based products. This was indicative of a reduction in the hygroscopic nature of chicken wheat crisps. This tendency is generally credited to a reduction in the number of active water binding sites due to various chemical and physical changes induced by temperature; For instance, gelatinisation of starch and denaturation of protein[29]. The increase in temperature may also cause activation of the water molecules to higher energy levels, which leads them to become less stable and break away from the water-binding sites of the product, thus decreasing the EMC[30].

This phenomenon has many consequences, for example, at a given moisture content, the increase in water activity with increasing temperature can result in an increased chemical and microbiological reaction rate, thus, boosting the degradation of product[31]. Similar results of the sorption capacity to decrease with increasing temperature have been reported for cookies and crackers[18,32,33]. Cadden[34] reported that oat bran became less hygroscopic with an increase in temperature from 25 °C to 37 °C.

3.2 Sorption Models and Surface Area of Adsorption

The moisture sorption data of chicken wheat crisps was fitted to a two-parameter model (BET), a three-parameter model (GAB) and a four-parameter model (Peleg) as shown in Table 2.

As it is indicative from the R^2 values for sorption models, good fits for the data were obtained. It is desirable to have an R^2 value of close to 1 and a per cent RMS value of <12 per cent[19]. According to this criteria the best fits were obtained in the order of Peleg model> GAB model> BET model.

The GAB equation has been successfully used to describe the sorption behaviour of foods[35,36]. GAB equation has been recommended by the European Project Group COST 90 on physical properties of Foods[19] as the fundamental equation for the characterisation of water sorption of food materials[37]. The GAB equation has been found to represent adequately the experimental data in the entire range of a_w 0.1 - 0.9, and the parameters of GAB model have a physical meaning. Monolayer moisture content (X_m) refers to the water strongly bound to the sample at specific sorption sites, and any deteriorative change

Table 2. Model parameters, coefficient of determination (R2) and %RMS for sorption isotherms of chicken wheat crisps at varying temperatures

Sorption model	Temp (°C)	Model parameters				R^2	%RMS
BET		X_m	C				
	5	5.8535	2.0529			0.9788	22.5043
	25	5.1234	2.2408			0.9755	22.0292
	40	3.3988	4.5844			0.97345	12.7202
GAB		X_m	C	k			
	5	84.3687	0.245	0.4788		0.9973	9.6141
	25	30.382	0.5473	0.5484		0.99656	10.172
	40	6.4021	1.6698	0.8206		0.9968	9.7278
Peleg		A	b	c	D		
	5	26.9563	1.7899	0.02219	-1.9464	0.9997	1.462
	25	0.01187	-2.1959	24.0624	1.7692	0.999	2.0979
	40	21.9247	2.5997	2.1188	0.0865	0.9991	3.2128

in the food occurs beyond this X_m value[19]. The X_m value obtained from GAB model ranged between 6.4021 %db to 84.3687 %db, and decreased with an increase in temperature from 5 °C - 40 °C. However, the values for k and C increased with increasing temperature. The decrease in X_m with increase in temperature could be attributed to loss of certain active sorption sites, resulting from the physical and chemical changes that occur with an increase in temperature[19]. Similar results have been reported by other researchers[18-20, 27]. Monolayer moisture content in BET model has similar meaning to X_m of GAB model and ranged from 3.3988 %db - 5.8535 %db. These values were however less than the X_m values obtained from GAB model.

GAB model has been reported to give good fits by McMinn[18], *et al.* for oat biscuits, Palou[32], *et al.* for their cookies, Kim and Okos[33] for crackers and Cadden[34] for oat bran.

The surface area of adsorption for chicken wheat crisps at 5 °C, 25 °C and 40 °C were estimated to be 20487.25 m^2/g, 17931.9 m^2/g, and 11895.8 m^2/g respectively. The surface area of adsorption decreased with increase in temperature, and can be explained by the fact that the surface area of proteins show a direct relation to the X_m. A large surface area relates to a higher number of polar groups visible, resulting in increase in adsorption[24]. Food components such as protein have polar hydrophilic groups and hence have a higher water binding capacity. This makes such components a preferred sorption sites for the water molecules. Water molecules also result in a hydrogen bond formation with certain specific groups leading to hydrophobic hydration[28]. With increase in temperature the surface area for adsorption decreases mainly due to decrease in number of these hydrophilic groups and hydrophobic hydrations. Similar results have been observed by other researchers as well[19].

3.3 Isosteric Heat of Sorption

The net isosteric heat of sorption is defined as the amount of energy above the heat of vapourisation of water associated with the sorption process, and gives a measure of the water-solid binding strength.

EMC in the temperature range of 5 °C - 40 °C were obtained by interpolating the experimental data using GAB equation as shown in Table 3. It was observed that the a_w at a particular moisture content increased with increase in temperature. The q_{st} decreased with an increase in moisture content, being 8202.6 KJ mol^{-1} at 2 per cent moisture content to 3545.5 KJ mol^{-1} at 10 per cent moisture content. This decrease in q_{st} with an increase in moisture content depicts a strong interdependence on the moisture content. (Table 3, Fig. 2)

Kim and Okos[33] also reported a decrease in the net isosteric heat of sorption for cookies and crackers with increasing moisture content.

Palou[32], *et al.* observed comparable maximum net isosteric heats of adsorption for cookies and corn snacks in the moisture content range of 5 per cent – 7 per cent. The comparable values were attributed to damage to the active sorption sites during processing. McMinn[18], *et al.* also reported similar results in oats biscuits.

Table 3. Equilibrium water activity (a_w) and net isosteric heat of sorption (q_{st}) of chicken wheat crisp at diffrent moisture contents

Moisture content (%)	a_w at different temperature (°C)			q_{st} (KJ mol^{-1}
	5	25	40	
2	0.142	0.187	0.21	8202.6
4	0.307	0.33	0.379	4211
6	0.414	0.44	0.55	5578.7
8	0.502	0.54	0.609	3880.1
10	0.578	0.62	0.686	3454.5

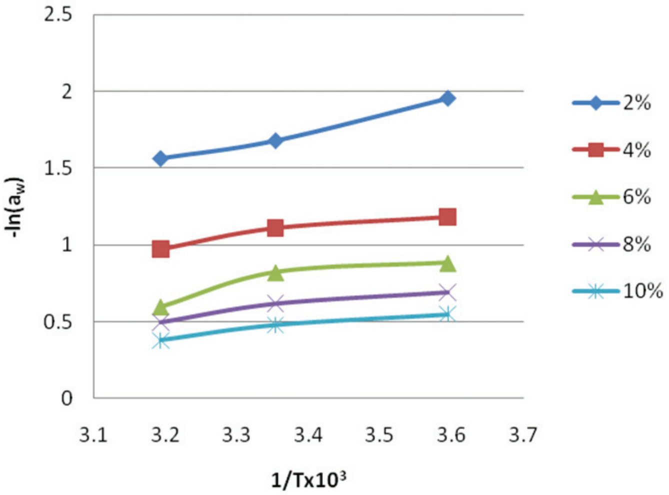

Figure 2. Sorption isosters of chicken wheat crisps at different moisture contents.

4. CONCLUSION

The present study was conducted in order to understand the sorption characteristics of chicken-wheat crisps at a temperature range of 5 °C - 40 °C at a a_w range of 0.1-0.9 and describe the surface area of adsorption. Peleg and GAB models fitted the sorption data best. GAB model was used to make predictions of a_w values at different moisture contents. X_m and surface area for adsorption was seen to have decreased with an increase in temperature being indicative of reduction in active sorption sites. It is concluded that the optimum storage temperature for chicken-wheat crisps lies at 5 °C – 25 °C. This study can serve as the explanation for the onset of various physico-chemical and microbiological events in chicken-wheat crisps that may lead to its spoilage. For example, the present study reveals that the surface area for adsorption was more at lower temperatures and it decreased with an increase in temperature, so the shelf-life of chicken-wheat crisps at lower temperatures will be more than at higher temperatures. Besides, the Isosteric heat of sorption estimated using the GAB model, decreased with increase in moisture content.

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CONTRIBUTORS

Ms S. Bhardwaj is a PhD research scholar at DFRL, Mysuru. Her broad are of research is 'functional food product development' and the products developed by her during her tenure at DFRL are under consideration for patent application through DRDO.
She has participated in design of the research plan, organised the study, participated in experiments, coordinated the data analysis, and contributed to the writing of the manuscript..

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