ABSTRACT

The quality of preserved food is largely dependent on its moisture content, moisture migration and/or moisture uptake of the food during storage. Therefore, the water activity level, which corresponds to a range of equilibrium moisture contents, must be determined by, for example, the use of moisture isotherms. The shape of the isotherm curve is dependent on the interactions between the vapour molecules and the solid material which can aid understanding of the mechanism taking place during water sorption. The moisture sorption isotherms of heat treated flour, culinary flour and convective oven baked Madeira (high ratio) cake were experimentally determined using a standard gravimetric method. Experimental data was compared with traditional mathematical models and their goodness of fit evaluated. The isotherms showed that heat treated and culinary flours exhibited Type II characteristics with cake showing Type III, due to its higher sugar content. Ferro-Fontan, GAB and Peleg models all adequately represented the results.

Keywords: Flour; cake; moisture; isotherm; model

INTRODUCTION

One of the main preservation methods for food is the control of water activity: this is achieved by either removing or binding water such that the food becomes stable to both microbial and chemical deterioration, [1]. A greater understanding of moisture sorption isotherms has led to better design and operation methods and also in the prediction of product shelf life behaviour [2].

The shape of the isotherm is determined by the relationship between water activity and moisture content. For most food materials it is nonlinear and usually sigmoidal in shape, differing as a result of the chemical composition and physical condition of the food constituents. Sorption isotherms are classified into five general types [3] which were based on van der Waals adsorption of non polar gases adsorbing on various nonporous solid substrates. Type II and Type III can be applied to foodstuffs. Type II, which has a sigmoid shape, is represented by most process foods, whereas Type III can be applied to foods with a high concentration of crystalline components, such as sugar and salt.

Isotherm models have been developed which can be divided into a number of categories: kinetic models based on a mono-layer formation, empirical and semi-empirical models. Each model has a reasonable success in representing experimental sorption data, depending on the water activity range and type of foodstuff. There is no general isotherm equation to fit all because water activity depends on the food structure.

The GAB equation is an improved version of the BET equation for multilayer adsorption and was adopted by a group of Western food researchers [4]. The equation satisfactorily represents experimental data within the water activity range of 0 to 0.95 for most foods.

The Ferro-Fontan equation [5], which is a semi-empirical isotherm, accurately represents food products such as proteins, starches, cereals, meats and vegetables, with a water activity range of 0.04 to 0.96.

The Peleg equation [6], an empirical model, is used for moisture isotherms of both sigmoid and non-sigmoid shapes.

The Smith equation [7] was developed as a two parameter empirical model, describing the moisture sorption behaviour of high molecular weight biopolymers.

The Lewicki I equation [8] was developed based on Raoults law, assuming that water in food occurs as free water with bulk molecular properties.
There are a number of moisture sorption isotherm studies on flour and starchy products, e.g. maize flour at temperatures of 27°C to 40°C and water activity of 0.01 to 0.82 [9]. The experimental data were compared with a number of models which showed that the GAB model was acceptable.

Two other teams of researchers [10], [11] studied the adsorption and desorption of chickpea flour using storage temperatures of 10°C to 40°C and water activity range of 0.11 to 0.85. The Type II isotherm was fitted to four models which proved to be suitable for describing the water activity, temperature and equilibrium moisture content.

Water sorption of hard and soft wheat flours as well as flour components have been studied [12]. Starch, damaged starch, gluten, soluble and insoluble pentosans were determined at 25°C and at different levels of humidity, from 10 to 95%. The GAB model was effectively applied to the experimental data which showed that the two flours had similar isotherms.

Sorption isotherms were determined for sponge cakes at 20°C and high water activities as a function of their internal porosity [13]. The equilibrium moisture content values increased suddenly with water activity greater than 0.9, but it decreased with increasing fat content. The moisture uptake followed a Type III isotherm and was successfully modelled using the Ferro-Fontan equation.

Desorption isotherm at 25°C was reported on sponge cake [14] with a sigmoidal shape giving a sudden decrease in equilibrium moisture content below a water activity of 0.8. The experimental data was successfully modelled using the GAB equation.

Adsorption isotherms were reported [15] for microwave baked Madeira cake and flour at a temperature range 5-60°C and relative humidity range of 0.40-0.96. They displayed Type III isotherm behaviour for the cake and Type II behaviour for the flour with sorption capacity decreasing with increasing temperature for both cake and flour. Experimental data were fitted to several isotherm models with the Ferro-Fontan proving to be the best fit.

The objectives of this work were to determine the moisture sorption isotherms for heat treated flour, culinary flour, convective oven baked Madeira cake and crust from the cake, using a standard gravimetric method with a range of temperatures and relative humidities. The resulting experimental data were compared with traditional isotherm models.

MATERIALS & METHODS

Heat treated flour was prepared from base flour in a fluidised bed dryer (Sherwood Scientific, model MK11), using a range of temperatures (80-130°C) and times (5-30 minutes) when the moisture content reduced from 13% to <4% (wet basis). The moisture content of the heat treated flour was increased to its original value by spraying a known volume of water onto the flour during mixing in a Kenwood mixer (model KM199).

Madeira cake batter was prepared based on published ingredients and procedures [16], and baked in a convective oven (Glenlab, model OV125) at 175°C for 45 minutes. Sorption isotherms were determined using the standard gravimetric technique in which the weight of the sample was measured discontinuously within sealed desiccators at constant temperature. Bone dry samples were placed in Petri-dishes inside the desiccators in which sulphuric acid solutions were used to control the specific relative humidity within the system. The prepared desiccators were then placed in a controlled oven at 40°C and 60°C and at room temperature of 20°C. The samples were allowed to equilibrate until there was no discernable weight change.

RESULTS & DISCUSSION

Equilibrium moisture content data are shown in Figures 1-5. Moisture content for both heat treated and culinary flour (Figures 1 and 2) approximates a Type II sigmoidal shape isotherm as described by the BET classification. The figures also show a significant increase approaching a water activity of 1.0. This is typical sorption behaviour for products with high starch composition [17], [10].
Generally, the equilibrium moisture contents tend to decrease with increasing temperature at constant water activity. Both flours exhibit a similar trend.

The moisture isotherms for Madeira cakes produced from heat treated and culinary flour (Figures 3 and 4) followed the form of a Type III isotherm according to the BET classification, where the equilibrium moisture content increased exponentially with increasing water activity. This may be due to the ingredients of the cake which contained a high level of sugar (115%), because the moisture sorption of crystalline materials occurs by different mechanisms than many other materials.
Details of research work on sponge cake have been reported [18], [12] showing a Type III sorption curve. The isotherms were not significantly affected by temperature over the range 4 to 20°C. Madeira cake from heat treated and culinary flour have a similar trend – there was no significant difference in the isotherms between 20°C and 40°C. However, the Madeira cake produced from culinary flour adsorbed
moisture at a much higher rate at 60°C than cake made from heat treated flour, suggesting a structural
difference between the two flours.
Unlike the isotherms for flour, which show that the equilibrium moisture content decreases with increasing
temperature at constant water activity, the cake isotherms show an opposite trend, i.e. equilibrium moisture
content increases with increasing temperature at constant water activity. This observed behaviour can be due
to a different adsorption mechanism or an increase in sugar solubility with increasing temperature because of
the high sugar content.
The moisture isotherm for Madeira cake crust also followed a Type III form, (Figure 5) but there is a
dramatic increase in the equilibrium moisture content when the water activity is greater than 0.8. This is
likely due to the high levels of caramelised sugar in the crust adsorbing more moisture at a higher
temperature.

![Figure 5](image_url)

**Figure 5.** Experimental adsorption isotherm of Madeira cake crust produced from heat treated flour at 40°C.

Several mathematical models were applied to the experimental results.
Both heat treated and culinary flour had good agreement between the experimental data and the Ferro-Fontan
and GAB models for all temperatures giving an average $R^2$ value of 0.997, which agreed with literature
results on wheat flour [12].
For Madeira cake samples using heat treated and culinary flour, Ferro-Fontan, GAB, and Peleg models
adequately represented the adsorption data with average $R^2$ values of 0.999. It has been reported [13] that the
Ferro-Fontan model gave an accurate representation of the moisture sorption isotherms of sponge cake at
20°C. The GAB model was successfully used [14] to predict the shelf life of sponge cake.
Models were also applied to the experimental data of crust from Madeira cake where again there was good
agreement with the Ferro-Fontan, GAB and Peleg models.

**CONCLUSIONS**

On the basis of this work, the following conclusions can be drawn.
- The equilibrium moisture content of flour decreases with increasing temperature at constant water
  activity.
- The equilibrium moisture content of Madeira cake increases with increasing temperature at constant
  water activity.
- Both heat treated and culinary flour exhibited Type II characteristics, whereas Madeira cake exhibited Type III behaviour.
- Ferro-Fontan, GAB and Peleg models proved to be an adequate representation of the sorption behaviour of heat treated and culinary flour as well as Madeira cake and crust.

REFERENCES