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SORPTION ISOTHERM STUDY OF GLUTEN FREE NOODLES PREPARED FROM BUCK WHEAT FLOUR, MAIZE FLOUR AND POTATO STARCH

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ABSTRACT

Moisture sorption isotherms of gluten free noodles at temperature range 25°C-50°C were determined using the standard gravimetric static method. The experimental sorption curves were fitted by five equations: modified Henderson, modified smith, modified exponential, modified Oswin and GAB monolayer. From the present study it was concluded the equilibrium moisture content (EMC) of noodles decreased with increase in temperature, at constant equilibrium relative humidity (%ERH). All isotherms had a shape characteristic i.e. type II, with low equilibrium moisture contents at water activity below 0.7 afterwards sharply increased equilibrium moisture contents at higher water activity. Among the applied models, the GAB monolayer model was found best to describe the moisture sorption isotherms of noodles. The study has provided information and data which will be useful in large-scale commercial production of gluten free noodles.

Keywords: Gluten free noodles; buckwheat flour; corn flour; potato starch; moisture sorption isotherms; GAB monolayer.

Introduction:

Noodles are thin, long strip of pasta or a similar flour paste, eaten with a sauce or in a soup. Noodles are prepared from unleavened dough which is rolled flat and cut into desired shapes. With increase in availability of myriad of convenient foods, noodles have gained importance and are consumed globally due to their characteristics such as easy to mass produce, widely acceptable taste, preferred texture and affordable price. Noodle texture is a critical characteristic and ingredients like flour, starch, water and protein and various additives dictate the textural properties of the product. Water absorption level has a major impact on textural properties of noodles (Hatcher et al, 1999). Owing to high gluten content (12-14%) hard wheat flour is generally used for the preparation of noodles; additionally, it has elastic toughness which holds its shape well once baked (Chu, 2004). Presence of high contents of gluten in wheat flours causes problems in gluten sensitive people leading to celiac diseases. Celiac disease is caused by the intake of gluten proteins from wheat, rye, barley, and possibly oat (Bilgicli 2008). Indigestion of dietary gluten, also affects absorption of important nutrients such as iron, folic acid, calcium and fat soluble vitamins (Lai 2001). Gluten free noodles can be an alternative to overcome problems in celiac patients.

Buckwheat (*Fagopyrum esculentum*), traditional crop cultivated in Asia, Central, and Eastern Europe, is rich in dietary fiber which has a positive physiological effect in the gastrointestinal tract and also significantly influences the metabolism of other nutrients (Halbrecq, Romedenne, & Ledent, 2005). Buckwheat groats contain appreciable amount of resistant starch which is helpful in preventing colon cancer (Kreft & Skrabanja, 2002; Kreft, Srabanja, Ikeda, Ikeda & Bonafaccia, 1996). Buckwheat groats also contain rutin, a secondary plant metabolite that antagonizes the increase of capillary fragility associated with haemorrhagic disease or hypertension in humans (Wantanbe 1998; Kreft, Knapp & Kreft, 1999; and Park, Kim, Choi, Heo, Kim & Lii, 2000). Use of buckwheat flour in preparation of noodles has certain concerns; it adversely affects the color value of noodles (Bilgicli 2008) and exhibits low cohesion quality (Ogasawara, and Obara, 1968). Appearance and eating quality are two distinct characteristics of noodles; hence, it is importance to overcome this shortcoming associated with usage of buckwheat flour. Addition of corn flour and potato starch can overcome this problem. Corn flour, due to its higher carotene content is receiving increased attention as an attractive ingredient in the extrusion industry imparting attractive yellow color and great expansion characteristic as expansion is an important parameter in the production of a cereal-based extruded snack food (Tahnoven, Hietanen, Sankelo, Kortaniemi, Laakso & Kallio, 1998). Maize is also recommended as a safe food for celiac patients since it possesses no gluten (Mestres, Colonna, Alexandre & Matencio, 1993). Maize is also rich in Xantohophllys which have a significant antioxidant activity (Plate and Gallaher 2005). The mixture of buckwheat flour and corn flour has very poor binding properties. Various binders can be used in buckwheat noodles such as root meal from lotus (*Nelumbo nucifera*), ground meal from potato (*Solanum tuberosum*), ground meal from hen's egg (*Gallus domesticus*), and dried ground meal from green tea (*Camellia sinensis*) (Ikeda, Asami, Linj, Honda, Suzuki, Arap, & Yasumoto, 2005). Starch, regarded as most important constituent of cereals, greatly influences the quality of the product they are added to (Wani, Singh, Shah, Schweiggert-Weisz, Gul & Wani, 2012). Potato starch and its derivatives are used in many recipes, for example, in noodles, wine gums, cocktail nuts, potato chips, hot dog sausages, bakery cream and instant soups and sauces, in gluten-free recipes since potato starch has no gluten.

Knowledge of sorption isotherms is important for predicting stability and quality changes in packaging and storage of dried foods and sorption isotherms are essential for designing, modelling, and optimization of many processes such as drying, aeration, and storage (Labuza, Kaneene, & Chen, 1985).

Hence, present work was carried to develop noodles based on combination of buckwheat flour, maize flour, and potato starch powder. Subsequently their techno functional properties and moisture sorption isotherms were studied.

2. Material & Methods:

2.1 Preparation of buckwheat flour and corn flour

Buckwheat grains were thoroughly cleaned, followed by grinding and sieving through 52 mesh size sieve. Corn flour was prepared after nixtamailization process of Arnold (2011). Grinded flour was sieved through 52 mesh size sieve.

2.2 Preparation of noodles

Noodles were prepared by a laboratory scale single screw extruder (La Monferrina, Italy). Buckwheat flour and corn flour were mixed into different proportions, and desired amount of potato starch was added to the mixed flour Water was added to the mixed flour to a level so that the mix extrudes properly through cold extruder. Conditioning of mixed flour was done for 25-30 min for moisture equalization. Conditioned dough was fed to hopper of the extruder and extruded through noodle die of size 1.2 mm. Extruded noodle strands were cut into small size (25-30 cm) by a sharp stainless steel knife and dried to a final moisture content of less than 14% in a cabinet drier at 40-50˚C (Owens, 2001 and Hatcher, 2011).

2.3 Sorption isotherms

The static equilibrium method was used for determining sorption characteristics of optimized noodles sample. The optimised samples were place in desiccators with appropriate humidity and then placed in an incubator to achieved equilibrium for a period of 21 days.

Table1. Six levels of water activity (a_w) at three temperatures (25, 40 and 50^{o}C) were performed for samples which correspond to the storage conditions of noodles. The prepared concentrations of H_2SO_4 (10, 20, 30, 40, 50 and 60%) were transferred into the desiccators and the desiccators were covered with lids and kept as such for moisture equilibration at room temperature for 2 days (Peng, Chen, Wu & Jiang, 2007; Ait Mohamed, Kouhila, Jamali, Lahsasni & Mahrouz, 2005).The vapours observed at the inner side of the desiccators were wiped off with a clean dry cloth. Then, about 5g (±0.001) of dried samples were taken in each of the Petri plates and covered with lids. The samples were weighed after an interval of 2 days. The EMC was acknowledged when three consecutive weight measurements showed a difference of less than 0.001g. The EMC of each sample was determined by using a drying oven whose temperature was fixed at 105^{0}C (Ait Mohamed, Kouhila, Jamali, Lahsasni & Mahrouz, 2005).

2.3.1 Analysis of sorption data

Various models have been proposed for sorption isotherms. In the present study, the description of the relationship between EMC, equilibrium relative humidity (ERH) and temperature for the noodles were verified according to models given in **Table 2** (Henderson, 1952; Basunia and Abe 2001; Ait Mohamed, Kouhila, Jamali, Lahsasni & Mahrouz, 2005, Singh, Singh & Sodhi, 2002; Ghodke, Goswami, Chakraverty, 2007).

2.3.2 Adequacy of fit for various empirical models

To fit the experimental data to the various empirical models, nonlinear regression analysis was carried out with statistical software STASTICA 7.0 for windows 7 OS. The fitness of models were evaluated by calculating the 'Mean Relative percent Deviation modulus' (E%) and the Root Mean Square Error (RMSE).

The mean relative deviation (E%) is an absolute value that was used because it gives a clear understanding of the mean divergence of the estimated data from the measured data.

$$E\,(\%) = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{\text{Experimental Value} - \text{predicted value}}{\text{Experimental value}}\right| \qquad (1)$$

The values of less than 5.0 indicates an Excellent fit while the values greater than 10 are indicative of poor fit. The RMSE gives the deviation between predicted and experimental value. Smaller the value of RMSE better will be the model and it indicates the fitting ability of the model. RMSE is defined by the following equation:

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i=1}^{N}(\text{Experimental value}-\text{Predictedvalue})^2}{N}} \qquad (2)$$

2.3.3 Determination of net isosteric heat of sorption

The net isosteric heat of sorption was calculated as follows:

Step I: Calusis-Clapeyron equation was used to calculate net isosteric heat of sorption (Ghodke, Goswami, Chakraverty, 2007) as follows.

$$\frac{\partial \ln(a_w)}{\partial T}=\frac{Q_{st}^{net}}{RT^2} \qquad \text{———} \quad (3)$$

Where 'ERH' is Equilibrium Relative Humidity, 'T' is absolute temperature; 'Q_{st}' is isosteric heat of sorption in kJ kg^{-1} and 'R' is the Universal Gas constant.

Step II: Assuming that the net isosteric heat of sorption (Q_{st}) is temperature independent, integrating above equation gives:

$$\ln(a_w)=-\left(\frac{Q_{st}^{net}}{R}\right)\frac{1}{T}+K \qquad \text{———} \quad (4)$$

Step III: Microsoft Excel (Office 2007) for windows 7 OS was used to carry nonlinear optimization which was used to find the best equation for sorption isotherms and the net isosteric heat of sorption.

2.3.4 Determination of net isosteric heat of vaporization

Step I: The heat of vaporization $\left(h'_{fg}\right)$ of noodles at different moisture contents and temperature can be determined using the EMC data and Clausius- Clapeyron equation as follows (Ghodke, Goswami, Chakraverty, 2007).

$$\frac{h'_{fg}}{h_{fg}}=\frac{\ln(RH_1P_{vs1})-\ln(RH_2P_{vs2})}{\ln P_{vs1}-\ln P_{vs2}} \qquad \text{———} \quad (5)$$

Where, t is the temperature in °C. RH_1 and RH_2 are extreme equilibrium relative humidities and P_{vs1} and P_{vs2} are saturated vapor pressure.

Equation (5) expresses the ratio of the heat of vaporization of the moisture in a biological material at particular moisture content to that of the heat of vaporization of pure water at the same temperature. When the ratio was established, the heat of vaporization of the moisture in the biological material at the desired moisture content was determined for any temperature T_3 as long as $T_1 < T_3 < T_2$ where T_1, T_2 and T_3 are temperature of biological material in °C.

Step II: The saturation vapour pressures at different temperatures in equation 5 were calculated using Teten's equation (Weiss, 1977; Ciro, Osorio, & Cortes, 2008).

$$\mathbf{s}\, P_{vs} = 0.61078*10^{\left[\frac{7.5\times T}{237.3+T}\right]} \qquad \text{———————} \qquad (\mathbf{6})$$

Step III: $\left(h_{fg}\right)$ values were found from steam tables and $\left(h'_{fg}\right)$ values were determined from the equation 5.

3. Results & Discussions

3.1 Sorption isotherms of noodles

Sorption isotherms of the noodles were obtained at 25, 40 and 50°C and the data were analysed by Henderson, Smith, Exponential, Oswin and GAB Monolayer (Guggenheim, Anderson and De Boer) equations.

3.1.1 Sorption curves

Figure 1 shows relationship between equilibrium moisture content (ERH) and water activity of noodles. It indicates that with increase in water activity, there was an increase in ERH. This is because at high water activity, there is an increase in water vapor pressure in the environs. The increase in water vapor pressure gradient between sample and environment results in migration of water molecules to the sample, thus increasing the EMC of product. The increase in equilibrium moisture content was low up to a_w of 0.3 and beyond a_w of 0.7 there was a sharp increase.

On extrapolation of the curve to pass through the origin (i.e. zero water activity value), the sorption isotherm **Figure 1** may be represented as sigmoid curve of Type II isotherm according to Bruneauer's classification (Andrade, Lemus & Perez, 2011). This pattern is frequently found for biological and food materials (Blahovec, 2004). In type II pattern, the food material absorbs small amounts of water at low values of water activity, followed by a gradual higher moisture uptake with increase of water activity. Sigmoid type II curve has also been observed by Van Den Berg, (1981) and Muhtaseb et al. (2004) in wheat starch and starch powder, respectively.

For noodle samples, a decrease in equilibrium moisture content had been observed with increase in storage temperature at a given water activity. With increase of temperature the water molecules get excited and move to a higher energy level. Due to the excitation, the reduction in intermolecular (between water molecules) and intramolecular (between water molecule and food surface) forces of attraction result in the separation of water molecule from their sorption sites (i.e. active sites). The release of water molecules from active sites result in lowering of EMC with increase in temperature at a given water activity. Labuza, Kaanene & Chen, (1985) also reported that sorbed molecules gain kinetic energy with increase in temperature, which promotes escape of water from the sorbent surface. Muhtaseb et al., (2004) and Ghodke, Goswami, Chakraverty, 2007 also reported that temperature affects the mobility of water and dynamic equilibrium between vapour and adsorbed phases. The change in EMC with temperature may be attributed to a critical change in the moisture adsorption capacity due to temperature difference (Lima and cal -Vidal, 1983).

3.1.2 Fitting of sorption models to experimental sorption data

Two criteria were used to evaluate the goodness-of-fit of each isotherm model; mean relative deviation modulus (E %) and root mean square error (RMSE) (**Table 3**). The E (%) value of less than 10% is indicative of the correlation providing a good representation of the data (Lomauro, Bakshi & Chen, 1985). RMSE value accounts for the number of constants in the model, with the magnitude of this parameter giving a measure of the reliability of the model to describe the experimental data, irrespective of the number of parameters. The lower the calculated values of E % and RMSE, better is the ability of the models to represent the experimental data (Chen and Morey, 1989).

Oswin model, an empirical model consisting of series expansion of sigmoid curve is used to relate the water activity of up to 0.5 (Oswin,1946). Smith model, an empirical model describes final curved portion water sorption isotherm for high molecular weight biopolymers and it considered that there are two fractions of water that are sorbed on dry surface, first fraction exhibited a higher condensation of heat than normal and second fraction was of multi layer of condensed molecules. Moisture content in the second fraction was proportional to the logarithm of difference between water activity and pure sample (Sahin & Gulum, 2006; Da Silva, Gouveia & Almedia, 2002).

3.1.3 Discussion of best fitted model (GAB Monolayer model)

Model coefficients of the equations fitted to the sorption isotherms of noodles are shown in (**Table 4)**. GAB monolayer model covers much wider range of water activity ($0.05 < a_w < 0.9$) of isotherm. In this equation, C and K are sorption constants and X_0 is monolayer moisture content.

For noodles, with increase in temperature the values of C and K decreased; and that of X_0 increased (**Table 5**). The reduction of C value with increase in temperature may be the indication of more enthalpy and gain in kinetic energy resulting in loss of more moisture at higher temperature (Diosady, Rizvi, Cai & Jagdeo, 1996)**.** Such a decrease of C indicates an increase in shorter residence time for the adsorbed molecule, with the adsorption process become strongly localised (Calzetta-Resio et al., 1999). Lower value of k indicates structured state of sorbate (water molecule) in the layer following the monolayer. A clear correlation of the constant K with temperature was not observed (Al-Muhtaseb et al., 2004).

The monolayer moisture content (X_o) increased from 2.74 to 2.94 when the temperature increased from 25°C at 40°C; and decreased from 2.94 to 2.84 when the temperature increased from 40°C to 50°C. The random pattern of sorption of water might be due to the reason that the adsorption of water can be attributed to the basic components of foods such as polymeric materials viz., proteins, starch, etc., and soluble solids e.g. sugars (Saravacos, Tsiourvas & Tasmi, 1986) and the temperature does not necessarily have similar effects on their interactions with water (Jayendra, Singh, Patil & Patel, 2005). Decrease in X_0 with increase in temperature due to reduction in number of sorption sites because of chemical and physical changes has been also reported (McMinn and Magee, 2003; Kim, et. al., 1998).

3.1.4 Net isosteric heat of sorption

The net isosteric heat of sorption is a measurement of the energy or intermolecular bonding between water molecules and absorbing surfaces (Faladeet, Adetunji & Aworth 2003). It gives an understanding of the mechanism of sorption hence, measure of physical, chemical and microbiological stability of food material under different storage conditions.

3.1.4.1 Determination of ERH values

From the following GAB monolayer model a_w and (ERH %) was calculated (Oluwamukomi 2009; Sawhney et al., 2011).

$$M_e = \frac{X_o C.k.a_w}{\left[(1-k.a_w)(1-k.a_w+C.k.a_w)\right]} \qquad \text{———}(12)$$

GAB equation can be rearranged into a second degree polynomial equation, as we have C, k and X_0values

$$\frac{a_w}{M_e} = \alpha a_w^2 + \beta a_w + \gamma \qquad \text{————}(13)$$

Where,

$$\alpha = \frac{K}{X_0}\left(\frac{1}{C}-1\right), \beta = \frac{1}{X_0}\left(1-\frac{2}{C}\right) \& \gamma = \frac{1}{X_0 CK}$$

Solving equation 13, we get two values of a_w at particular moisture content. Out of these two values, the negative value of water activity was rejected and only the positive value was considered for further analysis. % ERH was determined from a_w values at moisture contents of 10, 11 and 12%. The value of % ERH evaluated from best fitted GAB monolayer model at different temperatures and moisture contents is given in **Table 6.**

3.1.4.2 Determination of net isosteric heat of sorption $\left(Q_{st}^{net}\right)$

The isosteric heat of sorption values were calculated from equation (4) by plotting the sorption isotherm as the natural logarithm of equilibrium relative humidity ($\log_e$ ERH) against $1/T_{abs}$, for specific moisture content **Table 6**. A typical $\log_e$ ERH vs. 1/T plot for noodles at constant moisture content is illustrated in **Figure 2**. $\left(Q_{st}^{net}\right)$ Values were determined from the slope of the line which is equal to $\left(Q_{st}^{net}\right)/R$. **Figure 2** shows a progressive decrease in the net isosteric heat of sorption with increasing moisture content. Maximum net isosteric heat of sorption was observed at 10% moisture content as compared to 11 and 12% moisture content of the product. The maximum net isosteric heat of sorption values were 7.89 kJ/mol at 10% moisture content and decreased to 6.86 kJ/mol at 12 % moisture content **Table 7**.

The $\left(Q_{st}^{net}\right)$ values were large at low moisture content and then decreased with an increase in material moisture content. The isosteric heat of sorption has a strong dependence on moisture content. The high value of net isosteric heat at low moisture may be due to the fact that during initial stages (at lower moisture content) of sorption, there are more active (sorbent) sites available on the food surface covered with water molecules to form a monolayer. As moisture content increased these sites become occupied, sorption occurs on the less active site on monolayer, resulting in a lower heat of sorption. This indicates that energy of interaction between sorbate and sorption site is greater than the energy that holds the sorbate molecule together (Iglesias and Chirife, 1982; McMinn and Magee, 2003). Such a trend is also reported in crackers, cookies, rice and many cereal grains (Benado and Rizvi, 1985; Kim et al., 1998; Tolaba et al., 1997). This is in agreement with the work of Mazza and LeMaguer (1978) for yellow globe onion, Saravacos et al. (1986) for sultana raisins. Giraldo et al. (2011) reported that increased in net isosteric heats of sorption at low moisture content is an indication of strong water-food interactions in the fruit.

3.1.4.3 Determination of heat of vaporization $\left(h_{fg}^{/}\right)$

The heat of vaporization $\left(h_{fg}^{/}\right)$ of noodles at different temperature (25, 30, 35, 40, 45 and 50°C) and moisture content (10, 11 and12% d.b.) calculated by EMC data and Clausius-Clapeyron equation and those of pure water $\left(h_{fg}\right)$ are shown in **Table 8**.

The values of $\left(h_{fg}\right)$ of pure water have been seen from the steam tables. The data shows that heat of vaporization of noodles increased with decrease in the moisture content and temperature. This behaviour appears to indicates that an interaction between water and food matrix components. As moisture content decreases active sites loses water, which results in a higher energy requirement for moving these water molecules. The similar results have also been given by Ghodake, Goswamy & Chakraverty (2007) for different types of leaves of tea.

The sorption isotherm curves of noodles were type II, provides valuable information about the hygroscopic equilibrium of noodles. Out of the applied models GAB monolayer model seems to be most suitable for describing the sorption isotherm of the noodles in the temperature range 25 to 50^{o} C. The net sorption heat decreased with an increase in equilibrium moisture content. Monolayer moisture content of gluten free noodles decreased with an increase in temperature at constant water activity.

4. Conclusion:

The main aim of this work was to develop gluten free noodles from Buckwheat flour, maize flour and food grade potato starch powder. From the present study it was concluded the equilibrium moisture content (EMC) of noodles decreased with increase in temperature, at constant equilibrium relative humidity (%ERH). All isotherms had a shape characteristic i.e. type II, with low equilibrium moisture contents at water activity below 0.7 afterwards sharply increased equilibrium moisture contents at higher water activity. Among the applied models, the GAB monolayer model was found to describe the moisture sorption isotherms of noodles. The net isosteric heat of sorption for noodles varied between 6.86 to 7.89 kJ/mol at moisture levels of 10 to 12% (d.b.). Heat of vaporization of noodles increased as the moisture

References:

Ait Mohamed, L., Kouhila, M., Jamali, A., Lahsasni, S., and Mahrouz, M. (2005). Moisture sorption isotherms and heat of sorption of bitter orange leaves (Citrus aurantium). *Journal of Food Engineering*, 67(4): 491–498.

Andrade, P. R. D., Lemus, M. R. and Perez, C. C. E. (2011). Models of sorption isotherm for food: used and limitations. *Vitae, Revista De La Facultad De Quimica Farmaceutica,* 18(3): 325-334

Arnold, D. (2011). Mesoamerican Miracle Megapost: Tortillas and Nixtamalization. http://www.cookingissues.com/2011/03/09/mesoamerican-miracle-megapost-tortillas-and nixtamalization/. Retrieved on 26-02-13.

Benado, A.L. and Rizvi, S.S.H. 1985. Thermodynamic properties of water on rice as calculated from reversible and irreversible isotherms. J. Food Sci. *50,* 101-105.

Bilgiçli, N. (2008). Utilization of buckwheat flour in gluten-free egg noodle production. *Journal of Food, Agriculture and Environment,* 6(2): 113-115.

Blahovec, J. (2004). Sorption isotherms in materials of biological origin mathematical and physical approach. *Journal of Food Engineering,* 65: 489–495.

Calzetta Resio,A., Aguerre, R.J., & Suarez,C. (1999). Analysis of thesorptional characteristics of amaranth starch. *Journal of Food Engineering,* 42, 51–57.

Chen, C. C. and Morey, R. V. (1989). Comparison of four EMC/ERH equations. *Transactions of American Society of Agricultural Engineers,* 32:983–989.

Chu, M. (2004). "Wheat Flour". Cooking for Engineers. Retrieved 2009-08-14

Ciro, H., Osorio, J. A. and Cortis, E. A. (2008). Determination of isosteric heat to plantin pulp (*Musa paradisiaca*) by sorption isotherms. *Dyna, Ano 75, Nro,* 156. Pp. 127-134.

Da Silva, M., Gouveia, J., Almeida, F. (2002). Desorption and isosteric heat of mango pulp. *Rev Bras Eng Agríc Ambient,* 6 (1): 123-127.

Diosady, L. L, Rizvi S. S. H, Cai, W. and Jagdeo, D. J. (1996) Moisture sorption Isotherms of Canola meals, and application to packaging. *Journal of Food Science,* 61(1): 204-208.

Falade, K. O., Adetunji, A. I. and Aworth, O. C. (2003). Adsorption isotherm and heat of sorption of fresh- and osmo oven dried plantain slices. *European Food Research and Technology,* 217: 230–234.

Ghodake, H. M., Goswami, T. K., and Chakraverty, A. (2007). Moisture sorption isotherms, heat of sorption and vaporization of withered leaves, black and green tea. *Journal of Food Engineering,* 78: 827–835.

Giraldo, G.I., C.E. Orrego-Alzate, L.M.Grajales, V. Telis, A.L. Gabas and J. Telis-Romero. 2011. Effect of drying methods on the thermodynamic properties of blackberry pulp powder. Dyna 78(168): 139-148.

Halbrecq, B., Romedenne, P. and Ledent, J. F. (2005). Evolution of flowering ripening and seed set in buckwheat (Fagopyrum esculentum Moench): quantitative analysis, *European Journal of Agronomy*, 23: 209-224

Hatcher, D. H. (2011). Asian noodle processing, cereals processing technology, Wood Head Publishing Ld (CRC Press LLC), pp143-144.

Henderson, S. M. (1952). A basic concept of equilibrium moisture. *Agricultural Engineering,* 33: 29–32

Iglesias HA, Chirife J. (1976).Prediction of the effect of temperature on water sorption isotherm of food materials. *Journal of Food Technology* Mar-Apr; 11 (2): 109-116.

Ikeda, K., Asami, Y, Linj, R, Honda, Y., Suzuki, T., Arap, R. and Yasumoto, K. (2005). Characterization of buckwheat noodles with various dough-binders with respect to mechanical characteristics. *Fagopyrum* 22: 63-69.

Kim.S.S, Kim.Y.S.,Kim D.W., Shin. S.G., and Chang K.S.(1998). Moisture sorption characteristics of composite foods filled with strawberry jam. *Lebensmittel wissenscraft und- technologie.* 31:397-401

Kreft, I. Srabanja, V., Ikeda, S. and Bonafaccia, G. (1996). Dietary value of buck wheat. *Research reports biotechnical faculty of the University of Lubuljana,* 67: 73-78.

Kreft, S. Knapp, M. and Kreft, I. (1999). Extraction of rutin from buckwheat (Fagopyrum esculentum Moench) seeds and determination by capillary electrophoresis. *Journal of Agricultural and Food Chemistry*, 46:2020–2023.

Labuza, T. P., Kaanene, A. and Chen J. Y. (1985). Effect of temperature on the moisture sorption isotherms and water activity shift of two dehydrated foods. *Journal of Food Science,* 50: 382-391

Lai, H.M. (2001). Effects of rice properties and emulsifiers on the quality of rice pasta. *Journal of Science and Food Agriculture,* 83:203-221.

Lima, A. W. O. and Cal Vidal, J. L., (1983). Hygroscopic behavior of freeze dried bananas. *Journal of Food Technology*, 18(6):687-696.

McMinn WAM, Magee TRA. Thermodynamic properties of moisture sorption of potato. J Food Eng. 2003;60(2):157–165. doi: 10.1016/S0260-8774(03)00036-0

Mestres, C. Colonna, P. Alexandre, M.C.and Matencio, F. (1993) Comparison of various processes for making maize pasta. *Journal of Cereal Science*, 17:277-290.

Ogasawara. Y. and Obara, T. (1968) Eiyo to Shokuryo 22: 87- 90.

Oswin CR(1946). The kinetics of package life. III. The Isotherm. *J Soc Chem Ind* (12): 419-421.

Owens, G. (2001).Cereals processing technology. Woodhead Publishing Limited ISBN 143.

Park, C.H. Kim, Y.B. Choi, Y.S. Heo, K. Kim, S.L. and Lee, K.C. (2000). Rutin content in food products processed from groats, leaves and flowers of buckwheat. *Fagopyrum,* 17: 63-66.

Peng, G., Chen, X., Wu, W. and Jiang, X. (2007). Modelling of water sorption isotherm for corn starch. *Journal of Food Engineering*, 80:562-567.

Plate, Y. A. and Gallaher, D. D. (2005).The potential health benefits of corn components and products. *Journal of Cereal Foods World*, 50:305-314.

.

Sahin, S. and Gulum, S. (2006). Physical Properties of Foods. New York, United States: Springer press. pp 205-218

Saravacos, G. D., Tsiourvas, D. A. and Tasmi, E. (1986). Effect of temperature on water adsorption isotherms of sultana raisins. *J. of Food Sci*., 51(2): 381-383

Singh, N., Singh, J. and Sodhi N. (2002). Morphological, thermal, rheological and noodle-making properties of potato and corn starch. *Journal of the Science of Food and Agriculture.* 82(12):1376 - 1383.

Sisawad, S., and Chatket, I. (1989). Transparent noodles from other bean starches. A. H. Ghee, N. B. Hen, and L. K. Kong, eds. *Trends in Food Biotechnology*, Singapore,309

Tahnoven, R., Hietanen, A., Sankelo,T., Kortaniemi,V.M., Laakso, P., and Kallio, H. (1998). *Snack Foods: Labensmittel Untersuchung Forschung,* 206: 360-363.

Tolaba M.P., Suarez C., and Viollaz P. (1997). Heats and entropies of sorption of cereal grains: a comparison between internal and differential quantities. *Drying technology* 15(1):137-150

Van Den Berg, C. (1981). Vapor sorption equilibria and other water-starch interactions; a physicochemical approach. (PhD Thesis). Agricultural University, Wageningen, the Netherlands

Wani, A. A., Singh, P., Shah, M. A., Schweiggert-Weisz, U., Gul, K. & Wani, I. (2012). Rice starch diversity: effects on structural, morphological, thermal, and, physicochemical properties- A review. *Comprehensive Reviews in Food Science & Food Safety,* 11:417-435.

Watanabe, M. (1998). Catechins as antioxidants from buckwheat (Fagopyrum esculentum Moench)roats. *Journal of Agricultural and Food Chemistry*, 46:839–845.

Weiss, A. (1997). Algorithms for the calculations of moist air properties on a hand calculator. *Transactions of the ASAE,* 6:1133:1136.

Figure 1: Relationship of Equilibrium moisture content (EMC) versus water activity (ERH) at 25, 40 & 50˚C for optimized sample.

Figure 2: Graphs for calculation of isosteric heat of sorption of noodles with different moisture contents.

Figure 1

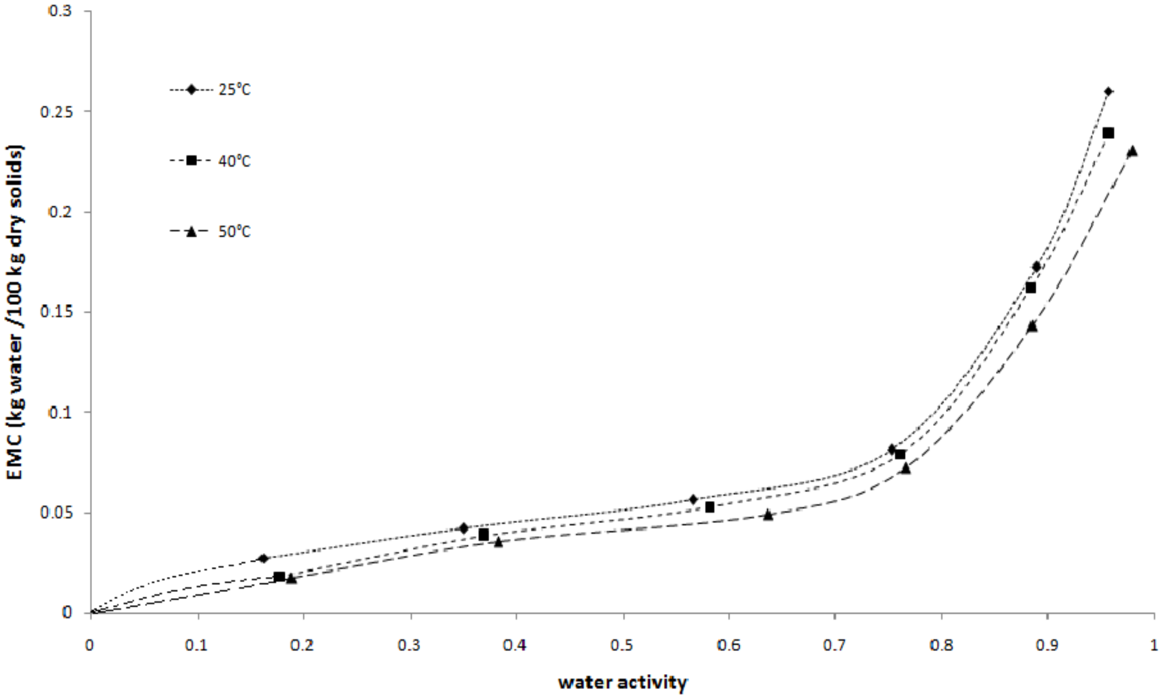

Figure 2

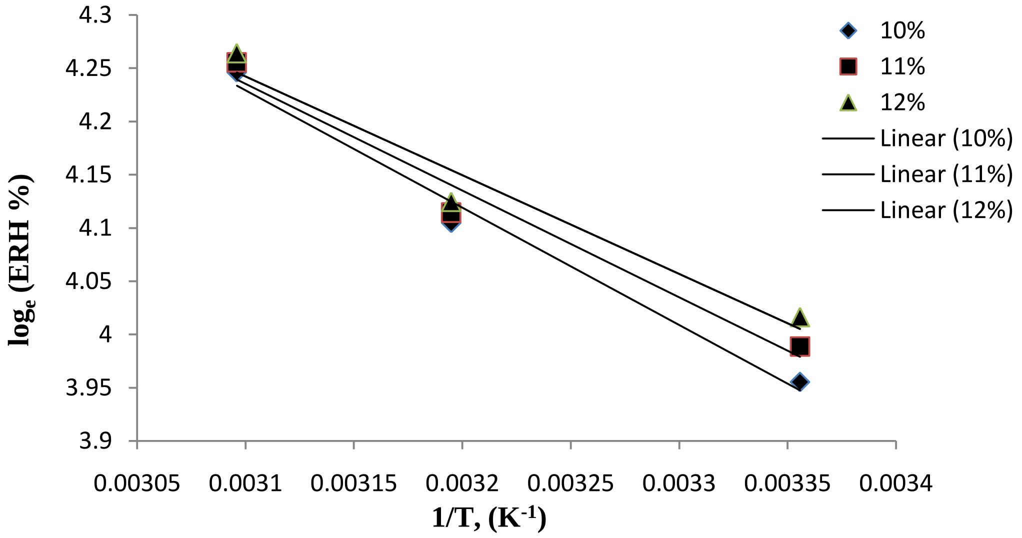

Table 1: Relative humidity (decimal) in sulphuric acid solution at various temperatures

Table 2: Statistical results obtained with different models for optimized sample

Table 3: Model coefficients of the equations fitted to the sorption isotherms of noodles.

Table 4: Model coefficients of GAB model

Table 5: Equilibrium relative humidities (ERH) at different temperatures and moisture contents

Table 6: Net isosteric heat of sorption of noodles with different moisture content

Table 7: Heat of vaporization (Q_{st}) of noodles at different temperatures and moisture contents

Table 1

Sulphuric acid conc. (%)	**Temperature**		
	25^0 C	**40^0 C**	**50^0 C**
10	0.956	0.956	0.979
20	0.889	0.882	0.884
30	0.752	0.760	0.765
40	0.565	0.581	0.636
50	0.350	0.370	0.382
60	0.162	0.178	0.188

Table 2

Model name	**Model**	**Parameters**
Modified Henderson	$M_e = \left[-\frac{\ln(1-a_w)}{A(t+C)} \right]^{\frac{1}{B}}$	Me = Equilibrium moisture content (db) t = temp. in ^{o}C
Modified Smith	$M_e = (A + B.t) - [(C + D.t)\ln(1-a_w)]$	a_w= water activity
Modified Exponential	$M_e = (A + B.t)\exp(Ca_w)$	A,B,C and D products constants
Modified Oswin	$M_e = (A + B.t)\left(\frac{a_w}{1-a_w} \right)^C$	C, K = temperature dependent products constants

GAB Monolayer	$M_e = \frac{C.K.X_0.a_w}{[(1-K.a_w)(1-K.a_w+C.K.a_w)]}$	X_o = monolayer moisture content

Table 3

Parameter	Temperature °C	Modified Henderson	Modified Smith	Modified Exponential	Modified Oswin	GAB Monolayer
E%	25	2.47	3.22	8.92	0.47	0.07
	40	3.62	2.64	7.46	0.82	0.45
	50	1.57	1.98	10.77	1.78	0.70
RSME	25	0.95	0.97	1.14	0.58	0.38
	40	0.80	0.76	0.85	0.69	0.46
	50	0.65	0.65	0.72	0.95	0.48

Table 4

Temp.	Model coefficient	Modified Henderson	Modified Smith	Modified Exponential	Modified Oswin
25^0C	A	42.57	383.00	-2.45	0.009
	B	-5726.74	-15.32	0.11	0.21
	C	-17.02	-426.21	4.34	0.52
	D		17.28		
40^0C	A	-14.87	200.48	– 1.89	19.36
	B	-2850.13	-8.04	0.08	-0.57
	C	26.05	-240.04	4.38	0.51
	D		9.90		
50^0C	A	-24.078	383.00	0.46	9.66
	B	2902.01	-15.323	-0.008	-0.19
	C	-20.39	-426.21	4.61	0.41
	D		17.28		

Table 5

Temp.	C	K	X_0
25°C	31.73	0.93	2.74
40°C	5.44	0.92	2.94
50°C	3.80	0.90	2.84

Table 6

	Moisture content (% d.b.)		
Temp (^{0}C)	**10**	**11**	**12**
25	52.20	53.98	55.49
40	60.62	61.21	61.83
50	69.83	70.48	71.10

Table 7

Moisture content (% d.b.)		
10	**11**	**12**
7.89	7.49	6.86

Table 8

	Moisture content % (d.b)			
Temp ^{0}C	**10**	**11**	**12**	**Pure water**
25	2837.865	2801.413	2773.363	2442.5
30	2764.83	2734.023	2710.317	2430.7
35	2709.126	2682.358	2661.76	2418.8
40	2664.327	2640.592	2622.328	2406.9
45	2626.688	2605.318	2588.873	2394.9
50	2594.141	2574.664	2559.677	2382.9