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Moisture Sorption Characteristics of Selected Commercial Flours (Wheat, Rice and Corn) of Bangladesh

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Abstract Moisture sorption isotherms of commercial wheat flour, rice flour and corn flour were determined within the water activity range of 0.11-0.93 at different temperatures (5°C, 30°C and 55°C) using the static gravimetric method. The moisture sorption isotherm of all flours exhibited type II characteristics according to BET classification. It was found that corn flour had a higher sorption capacity than wheat and rice flour. Temperature influence on sorption behavior was found that, for wheat and corn flour, the sorption capacity decreased with the increase of temperature, while for the rice flour an opposite behavior was observed at water activity value higher than 0.75. The Clausius–Clapeyron equation was used to calculate the net isosteric heat of sorptions. For all flours, the heat of sorption decreased with the increase of EMC.

Keywords: *sorption isotherms, wheat flour, rice flour, corn flour, water activity*

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1. Introduction

Bangladesh is a land of agriculture. Rice, wheat and corn are the most producing as well as the most consuming crops in the country [1,2]. With the change in lifestyle and food habits, the consumption of different commercial flours are increasing day by day all over the world [3]. Quality of baked products mainly depends on flour quality [4] where rheological and analytical properties of commercial flour greatly influenced by milling process [5].

Rice flour (*Oryza sativa*) is a form of flour made from finely milled rice. It is a particularly good substitute for wheat flour, which causes irritation in the digestive systems of those who are gluten-intolerant [6]. Rice flour is also used as a thickening agent in different formulated food. It is a regular ingredient in Bangladeshi cuisine which is used in rotis and different desserts such as shondesh and bhapa phitha or other steamed rice cakes [1,7].

In Bangladesh, the consumption of wheat (*Triticum aestivum*) flour has risen dramatically over the last decade due to the increasing population, changing food habit and health consciousness [4]. Wheat is the second most consuming cereals in Bangladesh where Atta (a mixture of endosperm and bran) and Moyda (only starchy white part) are the two major forms [1]. Due to its higher protein content (11.4±1.1%), gluten and fiber content, the demand for wheat flour increasing day by day in all over the world [8].

Corn (*Zea mays*) has emerged as another important cereal crop after rice and wheat in Bangladesh as the country's annual maize output reached the new high of 3.27 million tonnes in 2017-18 [2]. Several extensive research on the gluten-free product has done and concluded that corn flour is one of the best options as it improves the structure, mouthfeel, acceptability and shelf life of bakery items [9].

In Food, moisture sorption is a process where the water molecule is progressively and reversibly combine with the food solids via chemical sorption, physical adsorption, and multi-layer condensation [10]. This thermodynamic process uses to describe the relationship between equilibrium moisture content of a food and its water activity at constant temperature and pressure [11]. Equilibrium moisture content (EMC) is the limiting moisture content approached by a food when it exposed to a specific humid environment for a long time. Water activity is the ratio of the vapor pressure of water in the food to the vapor pressure of pure water at the same temperature and pressure [8]. Basically, sorption isotherm indicates the “quality” of water in food which determines the participation of water in physical, chemical and microbiological reactions based on availability [12]. The knowledge of sorption characteristics of food is highly important to food technologists in regards to storage stability, design and modeling of drying system, moisture maintenance, food package design, and prediction of quality, shelf life and moisture change during storage [8,11,13]. Although research on sorption characteristics of starchy products is very few [11,12,14,15], we found some recent sorption study on rice [14,16], on wheat [3,8,17] and also on corn [18]. No information was found about the sorption behavior of commercial wheat, corn and rice flour of Bangladesh.

According to literature [12] moisture sorption behavior of most food is nonlinear and sigmoid shape (Type II).The moisture sorption isotherm can be divided into three small regions from lower to higher water activity zone [11,18]. In the first region, at the lower humid condition, represents strongly bound water (where enthalpy of vaporization is higher than pure water). In the second region, water molecule binds loosely than in the first region and in the third region, available water, call free water (most loosely binds), that held in the voids, crevices and large capillaries. Moisture sorption capacity of different food products is different due to their different proximate compositions especially the presence of some hygroscopic components such as sugar, salt and alcoholic substances [15]. The amount of starch and structure of its two major components (Amylose and Amylopectin) mostly responsible for moisture sorption of cereal products [14]. As well as composition, the temperature has a great influence on the sorption characteristics of food products. Generally, the amount of adsorbed water by food is decreases as the increase of temperature [12,19]. Temperature effect on sorption capacity was reported that hydrophobic hydration of biopolymers (e.g. dextran) rapidly decreases with increasing temperature that's why lower water sorption happens at the higher temperature [20].

The main objective of this research was to determine the sorption isotherm of three different commercial flour of Bangladesh (wheat, rice and corn). The specific objectives include proximate composition analysis and to observe the temperature effect on sorption behavior.

2. Materials and Methods

Commercial wheat flour (Bosundhora atta), corn flour (Noor-Nobi) and milled rice flour (BRRI-28 variety) collected from local market of Bangladesh Agricultural University, were used in this study. The Initial moisture content of the samples was determined by triplicate, taking 10-gram flour and dried in hot air oven as per ASAE recommendation [21]. Following this method, we dried samples at 105°C until constant weight was obtained. The initial moisture content of rice, wheat and corn flour was found 13.80%, 13.83% and 12.86% respectively on the dry weight basis (d.b).

The collected rice, wheat and corn flours were analyzed for protein, fat and ash content as per AOAC [22]. All experiments repeated three times.

The static gravimetric method was used to determine the sorption characteristics of the flours over a water activity range of 0.11 to 0.93 at temperature 5, 30, and 55°C. Though the method takes a long time, it was reported as one of the most precise methods of moisture sorption analysis [17]. The triplicate of rice, wheat and corn flour sample each weighing about 10 gram were put into the ceramic crucible and placed inside the glass desiccator. The saturated salt solution of LiCl, $KC_2H_3O_3$, $MgCl_2 6H_2O$, K_2CO_3, $Mg(NO_3)2.6\,H_2O$, $CaCl_2$, NaCl, KCl and KNO_3 were used to maintain a specific water activity (a_w) inside the desiccator. In this way, the a_w value was maintained 0.11, 0.2, 0.33, 0.44, 0.52, 0.68, 0.75, 0.85 and 0.93 respectively. An open flat container having uniform holes was used to hold crucibles, which was arranged in a way, so that crucible will not be in contact with the saturated salt solution. The marked desiccators were placed in a Genlab (England) Incubator (Model M75CPD) for maintaining the constant temperature. The incubator temperature was monitored to keep it within ±1°C. Samples were weighed periodically until weight variation was less than 0.001 g. It was found that equilibrium was attained within a maximum of 4 weeks. After equilibrium was reached, the equilibrium moisture content (EMC) of the samples was determined in triplicate according to the ASAE method.

The net isosteric heat of sorptions or water binding energy of wheat flour, rice flour and corn flour were calculated by Clausius-Clapeyron equation suggested by several authors [16,23,24,25,26], as follows

$$\ln a_w = \frac{E_b}{RT} + Constant \tag{1}$$

Where, E_b is the water binding energy or net isosteric heat of sorptions (kJ/mol), a_w is the water activity, T is the absolute temperature (°K) and R is the universal gas constant (0.008314 kJ/mol. °K). The value of E_b gives useful information for industrial energy consumption and for drying equipment design [27]. The E_b value was calculated from the slope of the plot between $\ln a_w$ and 1/T at constant moisture content. The a_w values were taken for 10, 12, 15, 18, 20 and 25% of EMC (d.b) at three different temperature. Finally, a plot of the net isosteric heat of water sorption can be obtained against moisture content.

3. Result and Discussion

3.1. Proximate Compositions of Wheat Flour, Rice Flour and Corn Flour

The proximate compositions of wheat, rice and corn flour are shown in Table 1.

Table 1. Proximate compositions of flours

	Wheat flour	Rice flour	Corn flour
Moisture (%d.b)	13.83± 0.15^a	13.80± 0.25^b	12.86± 0.12^c
Protein (%d.b)	11.66± 0.13^a	7.4± 0.09^b	9.60± 0.10^c
Fat (%d.b)	1.36± 0.05^a	2.1± 0.01^b	4.28± 0.02^c
Ash (%d.b)	1.13± 0.01^a	1.02± 0.01^b	1.35± 0.02^c
***Carbohydrate (%d.b)**	85.85	89.48	84.77
***Energy (cal/100 g)**	353.4	357.13	368.6

d.b, dry basis. The values are mean ± S.D of three independent determinations. Superscript letters in a row differ significantly ($p \leq 0.05$).
* Calculated Value.

The mean moisture content of the wheat flour, rice flour and corn flour was found to be 13.83%, 13.80% and 12.86% on dry weight basis (d.b) respectively. In past study, moisture content of jet-milled wheat flour was reported as 14.17%d.b [28] where 12.98% d.b for refined wheat flours [7]. The moisture content of brown rice flour and corn flour was reported as 12.04 and 9.86 % respectively on the basis of dry matter content [4]. Variations in moisture content may be due to the variation in drying conditions and packaging system of the company. The protein content of wheat, rice and corn flour were found to be 11.66%, 7.4% and 9.60%d.b respectively. The Protein content of the refined wheat flour and brown rice flour reported as 12.58% and 8.5% [7] where 8.98% and 9.88% found for rice flour and corn flour respectively [4]. The variation in protein content varies with the type of grain, variety and the processing conditions etc. Loss of protein may be due to non- enzymatic browning [29]. The fat content of the wheat flour, rice flour and corn flour was found to be 1.36%, 2.1% and 4.28% d.b respectively. These values are in good agreement with previous research [4,7,15,30]. It was found that corn flour has maximum ash content (1.35%) where wheat and rice flour has the ash content of 1.13 and 1.02% respectively. Total carbohydrate content was determined by difference i.e., by subtracting the measured protein, fat and ash from 100 and it was found to be 85.85% for wheat flour, 89.48% for rice flour and 84.77% for corn flour. Variation of total carbohydrate content is a result of variation in moisture, protein, fat and ash content, causes of which were discussed earlier.

3.2. Sorption Behavior of Wheat Flour, Rice Flour and Corn Flour

Experimental adsorption isotherms obtained for wheat flour, rice flour and corn flour at room temperature (30°C) over the water activity range 0.11 to 0.93 are presented in Figure 1. The equilibrium moisture content (EMC) at each water activity (a_w) point shows the mean value of three replications.

According to BET classification [31], all the obtained sorption isotherms had the sigmoidal shape. It was found that sorption characteristics of all fours significantly influenced by water activity and EMC increases, with the increase of water activity.

From Figure 1, it is seen that, at the higher water activity (above 0.75), considerable absorption take place and the product absorb little water at the lower water activity (below 0.52). A crossover of corn sorption isotherm was noticed over isotherm of rice flour at 0.44 water activity level where wheat flour followed a similar adsorption trend like rice flour over the whole range of water activity. From Figure 1, it is clear that sorption behavior of corn flour is more uniform compared to wheat and rice flour, in that the knee is more distinct at around a_w 0.70. Corn flour absorbs little water, particularly at lower a_w (<0.52) where at a_w of above 0.75 it absorbs considerably higher moisture as noted for wheat and rice flour. The EMC values at 0.52 a_w are 10.67, 12.90 and 14.03 % d.b for the flour from wheat, rice and corn respectively where EMC at 0.75 a_w are given 15.78, 17.6 and 21.76% d.b respectively. The higher EMC was given by corn flour, particularly at higher a_w, due to higher sugar content, as sugar has high solubility character at higher humid condition [32]. At water activity higher than 0.85, sucrose is mainly responsible for the sharp increase of sorption behavior of foods [33].

3.3. Effect of Temperature on Sorption Behavior

The effect of temperature on the adsorption behavior of commercial wheat, rice and corn flour is shown in Figure 2, Figure 3 and Figure 4 respectively. For all flours, it was observed that adsorption capacity (or EMC) decreases with increasing temperature at a fixed water activity point.

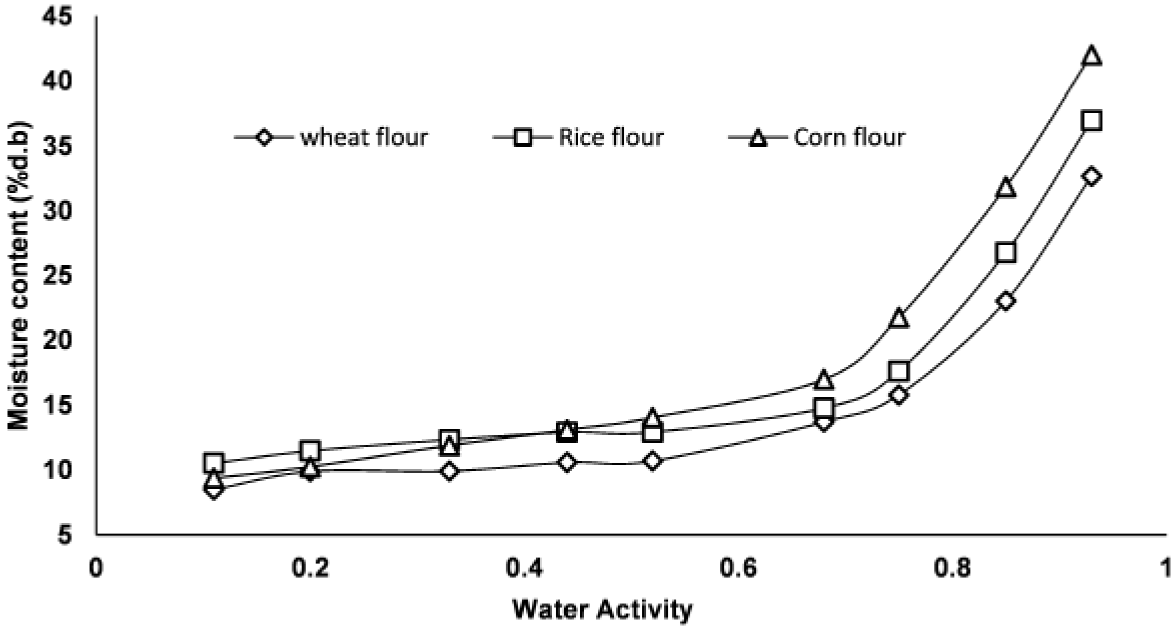

Figure 1. Sorption isotherm of commercial wheat flour, rice flour and corn flour at room temperature (30°C)

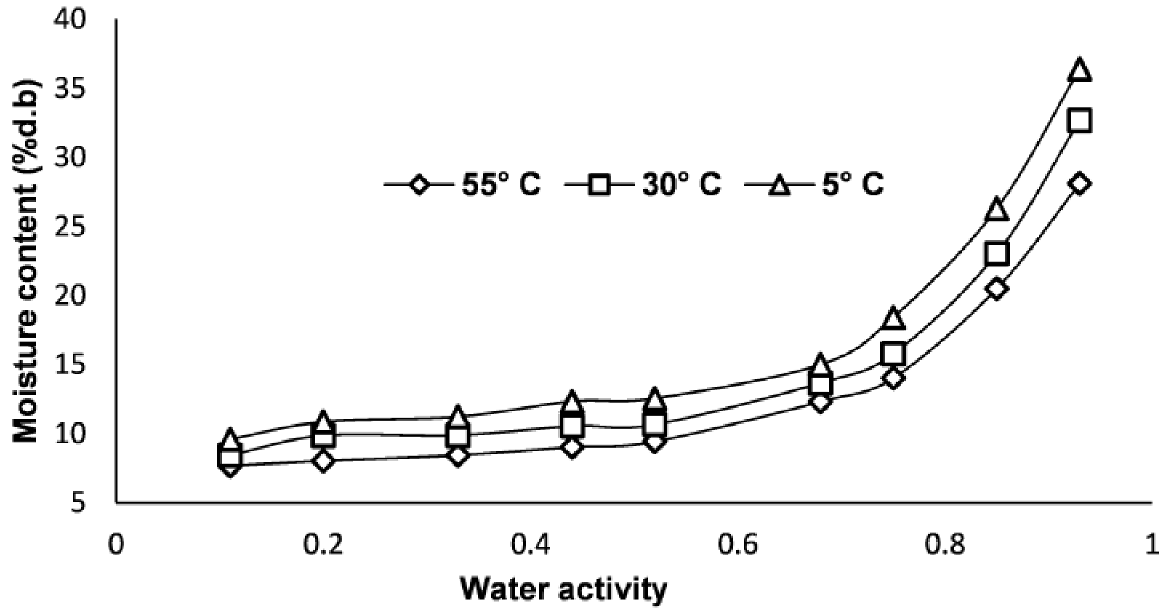

Figure 2. Influence of temperature on sorption behavior of wheat flour

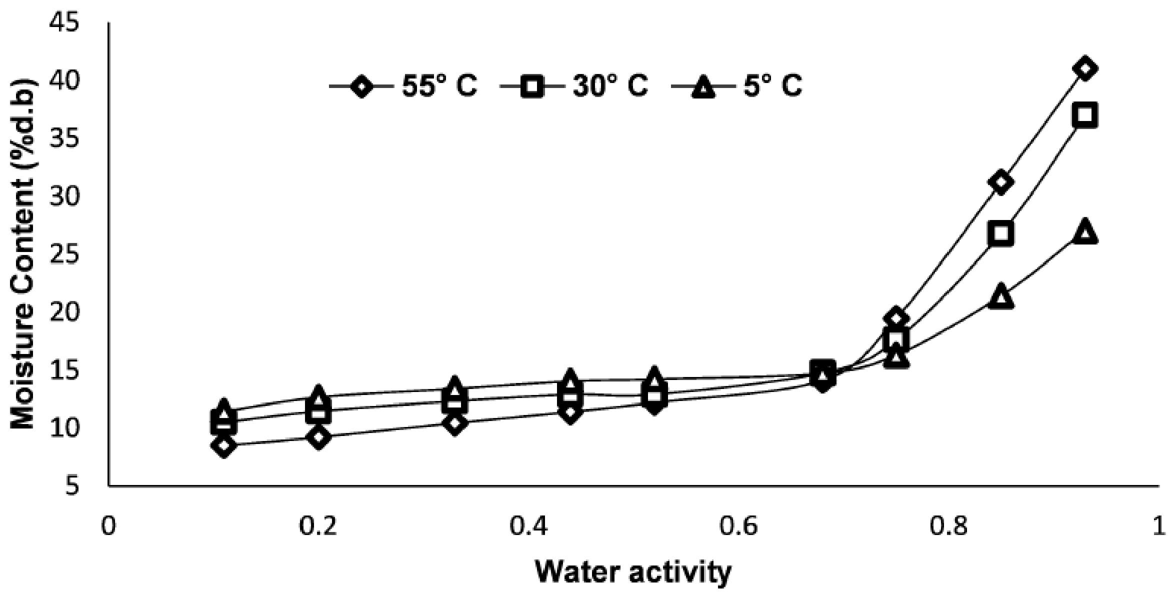

Figure 3. Influence of temperature on sorption behavior of rice flour

From Figure 2, it can be seen that, EMC at each a_w point is higher for every higher temperature. The clear difference in sorption curve at a_w over 0.75 indicates that sorption characteristics of wheat flour greatly influenced by the temperature at higher humid conditions. Similar trend was also found similar sorption characteristics of wheat flour at 20 °C and 65 °C [8].

Experimental adsorption isotherm of rice flour at 5°C, 30°C and 55°C is presented in Figure 3. It was observed that the effect of temperature below a_w value of around 0.75, was expected, as like as wheat flour (decrease of EMC with the increase of temperature). A great change in the hygroscopic behavior of rice flour was observed at higher a_w (at around 0.75) where crossover of isotherms happened between 55°C and 5°C curves. This finding is a very good agreement with previous research [14] where similar sorption characteristics of rice flour was also observed. This author also explained such behavior of rice flour as- with the increase of temperature, greater exposer of the hydrophilic group or active site happens. Generally, at higher water activity, carbohydrate-rich foods show a crossover behavior with temperature variation [34]

Sorption behavior of corn flour at the different temperatures is shown in Figure 4. It was found that, at all experimental temperatures (5°C, 30°C and 55°C), corn flour shows a sigmoidal shaped sorption isotherm. The decrease of EMC with increasing temperature mostly followed a similar trend over the whole range of water activity (0.11 to 0.93). Similar temperature effect on the hygroscopic behavior of maize flour was reported several researchers [18,35]

The net isosteric heat of sorption or water binding energy (E_b) of different flour was obtained as per Clausius-Clapeyron equation (Equation 1). Influence of moisture content on the isosteric heat of sorption is shown in Figure 5.

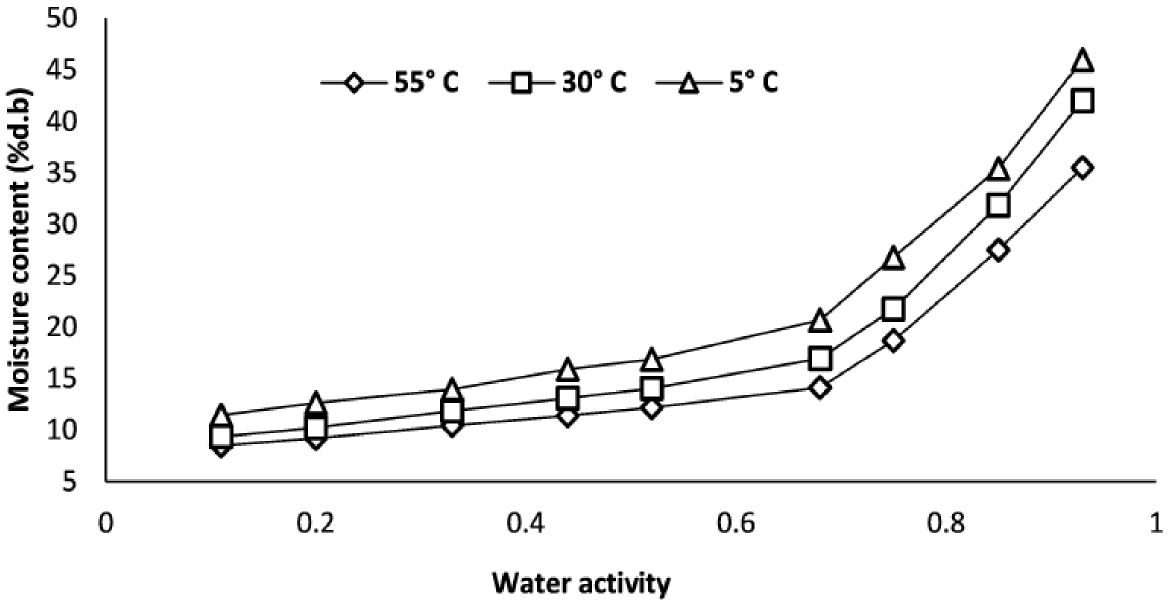

Figure 4. Influence of temperature on sorption behavior of corn flour

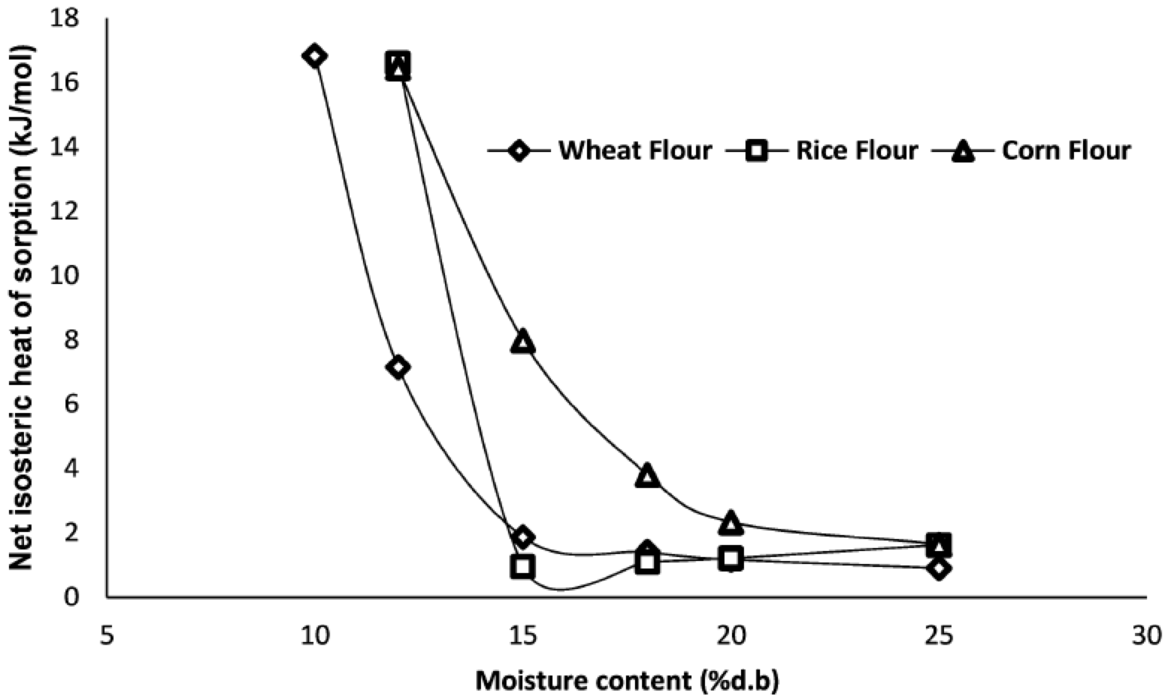

Figure 5. Influence of moisture content on the net isosteric heat of sorption of wheat, rice and corn flours

It was observed that, the net isosteric heat of sorption decrease with increasing EMC. It was also observed that, over EMC range of 10 to 25%d.b wheat, rice and corn flour has similar range of net isosteric heat of sorption, 17-1.5 kJ/mol. A Small deviation in the trend of isosteric heat of sorption of corn flour may be due to the crossover charactaristics of isotherm at 0.75 a_w. The higher value of E_b at lower moisture content is an indication of 'tightness' of water molecules thus high energy required to remove this water. The range of net isosteric heat of sorption has been reported as 19.4-1.4 kJ/mol for rice flour [14]. Net isosteric heat of sorption of wheat flour tends to zero at above EMC of 20%d.b [8]. Similar result was also reported for commercial maize flour of Nigeria [35]

4. Conclusion

The proximate analysis of commercial wheat, rice and corn flour of Bangladesh was done. Moisture sorption isotherms were analyzed over a water activity range of 0.11 to 0.93 at three at temperature 30°C, 5°C and 55°C. In all cases, a sigmoidal shape, characteristic of type II isotherms according to BET classification, was found. Corn flour found as the most hygroscopic flour at the higher water activity. The sorption capacity of all commercial flours decreased with the increase of temperature where a crossover of isotherms happens at around 0.75 water activity in rice flour. Net isosteric heats of sorption were calculated which was found to decrease with an increase of EMC.

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