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RESEARCH PAPER

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Effect of anti-caking agents on moisture sorption isotherms of palmyra-palm jaggery granules

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SUMMARY :

Jaggery granules, prepared from palmyra-palm syrup, were mixed with five levels (0.5 to 2 %w/w) of anti-caking agents [tri calcium phosphate, (TCP) or corn starch (CS)] and their moisture sorption isotherms were determined without or with addition of anticaking agents by the static equilibrium method using saturated salt solutions at four temperatures of 25, 35 and 45̊C. The moisture sorption isotherms for this granular jaggery samples are Type-III isotherms and the effect of temperature on equilibrium moisture content (EMC) values upto a water activity values of 0.3 to 0.5 show no significant effect. Among two moisture sorption isotherms (MSI) models tested with the experimental data for this high sugar food, GAB model was found to be the best fit followed by Iglesias and Chirife model. The monolayer moisture content (M_0) of the granular jaggery samples varied from a minimum of 4.195% (d.b.) for the granulated jaggery without anticaking agent at 45°C to a maximum of 7.303% (d.b.) for granulated jaggery with TCP and 9.178% (d.b.) for granulated jaggery with corn starch @ 2.0% at a temperature of 25°C. A decreasing trend for both Mo and C values but increasing trend for K was obtained with the increase in temperature. The monolayer moisture content of jaggery granules with addition of TCP or CS has been found to posses good correlation with temperature. The net isosteric heat of sorption (q_{st}) of jaggery granules without addition of anti-caking agents, decreased exponentially from 29.132 to 4.833 kJ mol^{-1} with the increase in moisture content from 2.5 to 15% (d.b.). It was also observed that, net isosteric heat of sorption was found to be higher for the jaggery granules without addition of anti-caking agents as compared to samples with addition of anti-caking agents.

KEY WORDS : Jaggery, Palmyra-palm, Palm juice, Anti-caking agents, Moisture sorption isotherm, Water activity, Net isosteric heat of sorption

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Jaggery, a sugar rich food product is produced all over the world under different names, such as *Gur* (India), *Desi* (Pakistan), *Panela* (Mexico and South America), *Jaggery* (Burma and African countries), *Hakuru* (Sri Lanka), *Htanyet* (Myanmar), *Panocha* (Philippines), *Rapadura* (Brazil) and *Naam Taan Oi* (Thailand) (Thakur, 1999). It is consumed directly or used for preparation of sweet confectionery items and ayurvedic / traditional medicines (Pattnayak and Misra, 2004), and it may have a role to reduce the chance of lung cancer (Sahu and Paul, 1998). Jaggery is prepared traditionally by concentrating sugarcane juice (*Saccharum officinarum*) in open atmosphere boiling. In addition, sap collected from palm trees such as palmyra-palm (*Borassus flabellifer* L.), coconut palm (*Cocos nucifera* L.), wild date-palm (*Phoenix sylvestris* L.) and sago palm (*Caryota urens* L.) are also used for preparation of jaggery (Pattnayak and Misra, 2004). The sap or juice collected from these trees contains around 10-12 per cent total sugars; mainly comprised of sucrose, less amount of reducing sugars and other minerals and vitamins (Dalibard,1999). All these jaggery products have their own characteristic taste and aroma and their production is seasonal. India produces about 6 million tonnes of jaggery annually, which accounts 70 per cent of the total production in the world; 65-70 per cent of the total jaggery is from sugarcane, the remaining 30 per cent is from palms (Kamble, 2003).

In India, jaggery is mainly produced in the month of November to April and stored (Uppal and Sharma, 1999). Jaggery deteriorates fast and become watery within 1 or 2 weeks due to its hygroscopic nature and thus deteriorates its quality through microbial fermentation. Also production of invert sugar through microbial degradation further increases the hygroscopicity of the jaggery (Rao and Rao, 1959).

For the ease of handling, packaging and storage, jaggery in granular form is becoming popular which could be made either from concentrated juice or solid jaggery (Rao *et al*., 2007). However, hygroscopic nature of jaggery granulated product initiate caking and follows deterioration by mould and yeast. The strict control of moisture content and storage at low temperatures are key factors in minimizing the effects of caking in powders. However, anti-caking agents are added to hygroscopic food powders to improve their flowability and to inhibit caking (Peleg and Hollenbech, 1984). Addition of any anti-caking agents e.g., corn starch (CS) and tri calcium phosphate (TCP) in sugar minimizes the caking problem by absorbing moisture. It acts as a physical barrier to keep the crystals separated and then prevents formation of lumps (Junk and Pancoast, 1973).

A knowledge of moisture sorption isotherms of granulated jaggery products at different storage temperature could be a useful tool for its handling, storage and packaging system design and drying (Van den Berg, 1984). The effect of moisture absorption on storage quality of solid sugarcane jaggery under different agro-climatic regions was investigated by Sastry *et al.* (1965). The moisture absorption isotherms of solid sugarcane, palmyra-palm and date-paalm jaggery (Verma and Narain, 1990 and Rao *et al*., 2006) have been reported. They observed that, increase in both temperature and relative humidity increase the equilibrium moisture content of the jaggery. The information on moisture sorption isotherms of palmyra-palm jaggery granules with addition of anti-caking agents is not available.

Various workers have reported sorption behaviour of sugar rich foods and adopted various sorption models to explain the experimental data (Iglesias *et al.*, 1975; Saravacos *et al*., 1986; Verma and Narain, 1990; Tsami *et al.*, 1990; Ayranci *et al.*, 1990 and Alhamdan and Hassan, 1999). Chirife and Iglesias (1978) applied their model for sorption data of nine high sugar fresh fruits, predominantly containing reducing sugars (glucose and fructose). For dried apricot, fig and raisin, Ayranci *et al*. (1990) found Halsey equation was a better fit than the Iglesias and Chirife equation.

The objective of this study was to determine the sorption isotherms of granular form of palmyra palm jaggery at three temperatures namely, 25, 35 and 45°C and correlate the experimental sorption data to three sorption models namely, Iglesias and Chirife and Guggenheim-Anderson-de Boer (GAB). Further, the net isosteric heats of sorption at different moisture levels have been evaluated.

EXPERIMENTAL METHODS

Preparation of samples:

About fifty five (55) litres of juice (sap) was collected from several palmyra-palm trees at Kharar village (87° 19' E, 22° 25' N), East Midnapur district, West Bengal, India with initial total soluble solid content of 16 (%w/w). It was first filtered through a fine muslin cloth and boiling was carried out in an open shallow aluminum pan. A mild bleaching agent at the rate of 5g/50 litre juice was added intermittently during boiling for clarification of juice. Boiling of juice continued in a regulated manner for more than 2 hours till the syrup attained total soluble solids around 81 (%w/w).

Granular jaggery has been prepared from concentrated juice of palmyra-palm as per the procedure described elsewhere (Rao *et al*., 2008). The particle size distribution of the granular jaggery samples has been determined by sieve analysis technique (Linden, 1996). Mass mean diameter of the palmyra palm jaggery granules have been found to be 163 µm. The sucrose and total reducing sugars (%) in the jaggery samples have been determined according to the methods described elsewhere (AOAC, 1984). The sucrose (non– reducing) and reducing sugars of palmyra palm jaggery was estimated to be 70.5 per cent and 10.9 per cent.

Anti-caking agents :

Two anti-caking agents (tri calcium phosphate and corn starch, both are food grade) representing different chemical groups, were selected. Before mixing the anti-caking agents, the granulated jaggery was passed through a 500 µm sieve. Based on the preliminary experiments, this study was conducted at five concentration levels of both TCP and CS (0.5, 0.88, 1.25, 1.63 and 2.0 %w/w) as per the experimental design (response surface single factor quadratic design). The anti-caking agent was thoroughly mixed manually to the granulated jaggery sample and moisture sorption isotherms were determined as described in the following paragraph.

Moisture sorption isotherms :

Moisture sorption of granulated jaggery samples were determined at 25, 35 and 45 °C by static gravimetric technique based on isopiestic vapour transfer technique (Swami *et al*., 2005). Saturated salt solutions of various inorganic salts (NaOH, CH_3COOK, $MgCl_2$, K_2CO_3, $MgNO_3$, $NaNO_3$, NaCl, KCl and KNO_3, all reagent grades) were employed to generate controlled humidity environment in a desiccator ranging between 10 and 90 per cent (Greenspan, 1977 and Labuza *et al*., 1985) and maintained at different temperatures of 25, 35 and 45°C. Pre-weighed samples of palmyra- palm jaggery (in triplicate) were taken in respective weighing bottles and placed them in the desiccators maintaining constant relative humidity with the saturated salt solutions as described above. Partial vacuum was created inside each desiccator to accelerate the absorption process (Swami *et al*., 2005). The desiccators were kept in an incubator maintained at constant temperature with variation ±1°C over the set value. Samples were weighed periodically with an interval of 2 days till constant weights were obtained. It took about 10 days.

The moisture contents of each sample (in triplicate) was determined by vacuum oven drying method (AOAC, 1984) and averaged.

Fitting to sorption models:

The sorption data so obtained were fitted into two MSI models namely, GAB and Iglesias and Chirife (Table A).

where, M is the equilibrium moisture content; M_o is the monolayer moisture content; a_w is the water activity; $M_{0.5}$ is equilibrium moisture content at a_w=0.5; C, K, b and p are the constants for respective Eq. (1 and 2).

Analysis of data :

Analysis was made with Origin 6.1 package (Origin Lab Corporation, Northampton, MA 01060, USA, 2000) to fit Eq. (1 and 2) by non-linear curve fitting. Microsoft Excel (Microsoft Corporation, USA, 2003) was used to fit Eq. (2) by linear regression. Statistical validity of the fit to the model was evaluated using modeling efficiency (EF) according to the following equation (Hasan and Nurhan, 2004).

$$\mathbf{EF} = \frac{\sum_{i=1}^{N}\left(\mathbf{M}_{\exp,i}-\mathbf{M}_{\exp,ave}\right)^2 - \sum_{i=1}^{N}\left(\mathbf{M}_{pre,i}-\mathbf{M}_{\exp,i}\right)^2}{\sum_{i=1}^{N}\left(\mathbf{M}_{\exp,i}-\mathbf{M}_{\exp,ave}\right)^2} \quad ....(3)$$

where M_{exp} is the experimental equilibrium moisture

Table A : Moisture sorption isotherm models used to analyze EMC - a_w data for jaggery samples

Model	Mathematical expression	Equation No.	Reference
GAB	$\frac{M}{M_0} = \frac{CKa_w}{(1-Ka_w)(1-Ka_w+CKa_w)}$	(1)	Van den Berg (1984)
Iglesias and Chirife	$\ln\left[M + \left(M^2 + M_{0.5}\right)^{1/2}\right] = ba_w + p$	(2)	Chirife and Iglesias (1978)

content, M_{pre} is the predicted equilibrium moisture content, $M_{exp,ave}$ is the average value of experimental equilibrium moisture content and N is the number of data points.

Isosteric heat of sorption:

Net isosteric heat of sorption, q_{st} has been estimated at constant moisture contents from the plot of a_w versus 1/T using Clausius Clapeyron Eq. (4) applicable to sorption process (Rizvi, 1986).

$$\ln a_w = \frac{q_{st}}{RT} + Z \quad .... (4)$$

where, q_{st} is net isosteric heat of sorption, kJ mol^{-1}; R is universal gas constant (8.314 x 10^{-3} kJ mol^{-1} K^{-1}); T is the absolute temperature in K and Z is integral constant.

EXPERIMENTAL FINDINGS AND ANALYSIS

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Nature of isotherms:

Fig 1 shows typical MSI of the granulated jaggery sample without addition of anti-caking agents for 25, 35 and 45°C. Each data point on this curve represent the mean value of three replications. This trend demonstrates Type III isotherm characteristics (according to BET classification, Brunauer *et al.*, 1940 and Rizvi, 1986); increase in EMC with the increasing water activity (a_w), all of them almost similar to other high sugar foods (Maroulis *et al.*, 1988 and Chinachoti and Steinberg, 1984). At lower a_w values, water might have been adsorbed only to the surface – OH sites of the crystalline sugar, thus, showing very low moisture content. At higher aw values, dissolution of sugar occurs and a crystalline sugar gets converted to amorphous state, resulting higher absorption of moisture to the newly opened up active adsorption sites (Ayranci *et al.*, 1990).

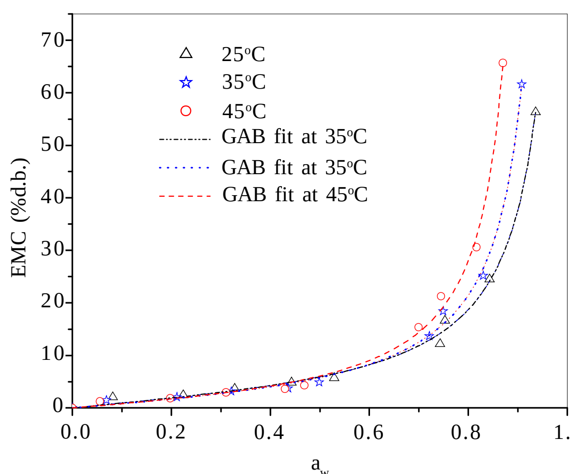

Fig. 1. Sorption isotherms of granulated jaggery samples without addition of anticaking agent at 25, 35 and 45°C, fitted to GAB model

Effect of concentration of anti-caking agent:

Fig. 2 and 3 shows MSI of the granulated jaggery sample with addition of TCP and CS @0.5 % at 25°C (similar for other concentrations of 0.88, 1.25, 1.63 and 2.0 %w/w, not shown). No apparent difference among the EMC values of the granulated jaggery samples with

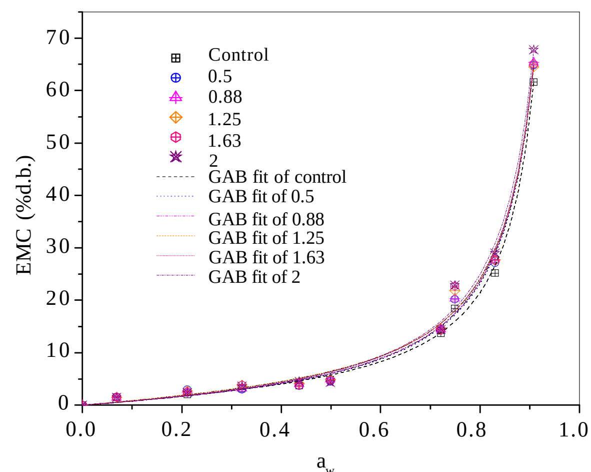

Fig. 2: Sorption isotherms of granulated jaggery samples with addition of TCP at 25°C, fitted to GAB model

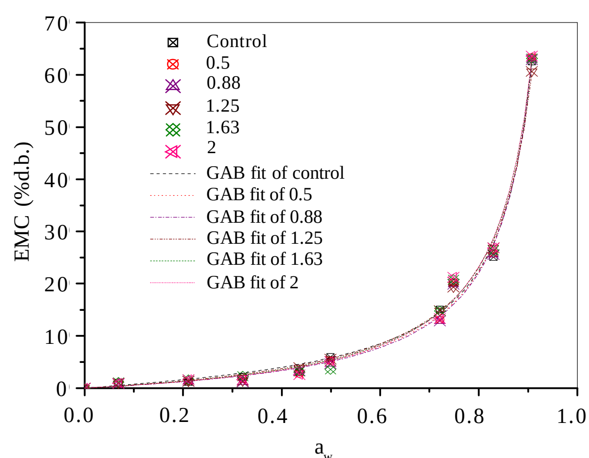

Fig. 3: Sorption isotherms of granulated jaggery samples with addition of corn starch at 25°C, fitted to GAB model

addition of TCP and corn starch over the entire range of water activity at 25°C. However, at higher temperature, EMC of granulated jaggery with 2.0% level of TCP and CS showed slightly higher value (a_w between 0.3 and 0.8) than that of lower levels of TCP and CS. This might be attributable to higher hygroscopicity at higher a_w values.

Effect of temperature on moisture sorption of granulated jaggery samples :

All the MSI of granulated jaggery samples without addition of anticaking agent (Fig.1), with addition of anticaking agents (Fig. 4 to 5) show no significant effect of temperature on the respective EMC values upto a water activity values of 0.3 - 0.5. However, beyond this value, at any particular value of a_w, EMC increased as the temperature increased. This kind of temperature effect on isotherms at higher level of water activity has been reported by many workers for high sugar foods like, fresh and dried fruits (Saravacos *et al.*, 1986; Tsami *et al.*, 1990; Verma and Narain, 1990; Ayranci *et al.*, 1990; Hasan, 1991; Leiras and Iglesias, 1991; Manuel and Sereno, 1993; Alhamdan and Hassan, 1999 and Rao *et al.*,2006) which has been termed as crossing over behaviour for this group of foods. This phenomenon is attributable to dissolution of more crystalline sugar at higher temperature and higher humidity (water activity) environment resulting more water is held by the sugar in those foods giving high EMC values.

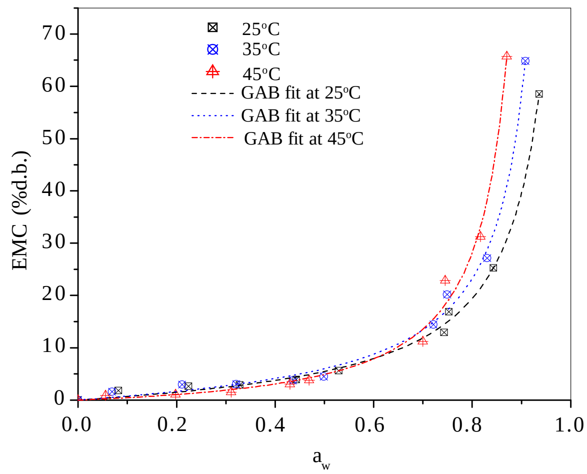

Fig. 4: Moisture sorption isotherms of granulated palm jaggery at 0.5% level of TCP and temperature of 25, 35 and 45°C, fitted to GAB model

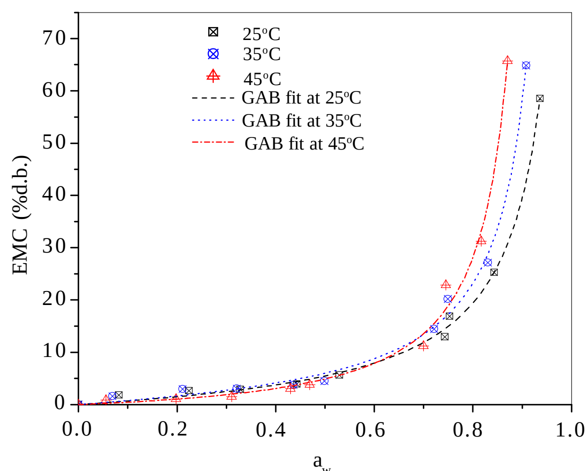

Fig. 5: Moisture sorption isotherms of granulated palm jaggery at 0.5% level of corn starch and temperature of 25, 35 and 45°C, fitted to GAB model

Fitting sorption data to various models :

The sorption data so obtained were fitted to various models such as GAB and Iglesias and Chirife, equations and the model parameter so obtained are shown in Tables 1 and 2. Tables shows the estimated parameters of GAB and Iglesias and Chirife models for all the granulated jaggery samples without (or) with addition of anticaking agents at three temperatures along with statistical estimates. Comparing these two models on the basis of modeling efficiency, GAB model appears to be best with higher values of EF compared to other model. Although Iglesias and Chirife model was well applied to nine high sugar fresh fruits with sugars mostly in dissolved form, but it gave lowest model efficiency for jaggery samples; possibly due to presence of high amount of crystalline non-reducing sugars in the jaggery samples.

The monolayer moisture content (M_0) of the jaggery samples were increased with increase in concentration of TCP and corn starch. M_0 values varied from a minimum of 4.195% (db) for the granulated jaggery without anticaking agent at 45°C to a maximum of 7.303% (db) for granulated jaggery with TCP and 9.178% (db) for granulated jaggery with corn starch @ 2.0% at 25°C. A decreasing trend of M_o values was obtained with the increase in temperature. The same trend was observed in the case of C values. However, increasing trend was observed in the case of K values.

Monolayer moisture content variation with temperature :

Monolayer moisture content of granulated jaggery samples at various levels of TCP and corn starch and temperatures are shown in Fig. 6 and 7. It was observed that, the monolayer moisture content increases with the increase in level of TCP and corn starch from 0.5 to 2.0 per cent.

The monolayer moisture content has been found to posses good correlation with temperature for TCP as given in Eqs. (5-7).

$$M_{25°C} = 4.278 + 1.3582T \quad \textbf{(r = 0.976)} \qquad ....(5)$$

$$M_{35°C} = 4.454 + 0.476T \quad \textbf{(r = 0.935)} \qquad ....(6)$$

$$M_{45°C} = 4.239 + 1.177T \quad \textbf{(r = 0.964)} \qquad ....(7)$$

The monolayer moisture content has been found to posses good correlation with temperature for CS as given in Eqs. (8-10).

$$M_{25°C} = 4.238 + 1.451T \quad \textbf{(r = 0.982)} \qquad .....(8)$$

$$M_{35°C} = 4.488 + 0.478T \quad \textbf{(r = 0.966)} \qquad ......(9)$$

$$M_{45°C} = 4.211 + 1.251T \quad \textbf{(r = 0.982)} \qquad .....(10)$$

Net isosteric heat of sorption

Net isosteric heat of sorption (q_{st}) for granulated

Table 1: Estimated parameters of GAB and Iglesias and Chirife models at various levels of anti-caking agent (TCP) at 25, 35 and 45°C

Model	Anti-caking levels (%)					
	Control	0.5	0.88	1.25	1.63	2.0
			25°C			
GAB						
M_o(%db)	4.4011	5.0578	5.132	5.987	6.628	7.303
C	2.1837	1.2646	1.105	1.053	0.788	0.676
K	0.9879	0.982	0.980	0.972	0.968	0.966
EF	0.996	0.997	0.997	0.996	0.997	0.999
Iglesias and Chirife						
b	1.604	1.698	1.771	1.774	1.836	1.804
p	0.366	0.299	0.247	0.268	0.222	0.262
EF	0.992	0.992	0.992	0.993	0.992	0.994
			35°C			
GAB						
M_o(%db)	4.377	4.864	4.977	5.05	5.191	5.468
C	1.8	1.442	1.418	1.639	1.448	1.278
K	1.027	1.022	1.022	1.019	1.018	1.017
EF	0.996	0.995	0.996	0.993	0.991	0.992
Iglesias and Chirife						
b	1.789	1.800	1.787	1.757	1.790	1.813
p	0.272	0.293	0.305	0.337	0.314	0.306
EF	0.992	0.990	0.992	0.991	0.990	0.992
			45°C			
GAB						
M_o(%db)	4.195	4.984	5.337	5.439	6.349	6.794
C	1.72	0.726	0.671	0.595	0.483	0.387
K	1.078	1.07	1.065	1.065	1.055	1.053
EF	0.996	0.992	0.992	0.994	0.994	0.995
Iglesias and Chirife						
b	1.957	2.155	2.118	2.156	2.133	2.195
p	0.222	0.053	0.084	0.052	0.074	0.021
EF	0.992	0.991	0.991	0.990	0.992	0.992

Table 2: Estimated parameters of GAB and Iglesias and Chirife models at various levels of anti-caking agent (Corn starch) at 25, 35 and 45°C

Model	Anti-caking levels (%)					
	Control	0.5	0.88	1.25	1.63	2.0
			25°C			
GAB						
M_o(%db)	4.4011	5.806	6.684	7.692	8.339	9.178
C	2.1837	0.675	0.672	0.562	0.562	0.475
K	0.9879	0.941	0.952	0.940	0.948	0.936
EF	0.996	0.995	0.995	0.994	0.994	0.994
Iglesias and Chirife						
b	-0.047	-0.040	-0.104	-0.040	-0.048	-0.040
p	2.216	2.116	2.326	2.118	2.116	2.201
EF	0.990	0.993	0.990	0.986	0.993	0.990
			35°C			
GAB						
M_o(%db)	4.377	4.987	5.020	5.484	5.539	5.638
C	1.8	1.027	0.950	1.009	0.904	0.844
K	1.027	1.021	1.020	1.010	1.013	1.013
EF	0.996	0.993	0.993	0.994	0.994	0.994
Iglesias and Chirife						
b	-0.058	-0.038	-0.114	-0.048	0.005	0.058
p	2.217	2.179	2.273	2.209	2.132	2.217
EF	0.990	0.990	0.990	0.993	0.993	0.990
			45°C			
GAB						
M_o(%db)	4.195	4.556	4.593	4.768	5.177	5.268
C	1.72	1.034	1.796	1.859	1.092	0.877
K	1.078	1.107	1.107	1.104	1.098	1.098
EF	0.996	0.998	0.998	0.998	0.998	0.998
Iglesias and Chirife						
b	-0.159	-0.190	-0.180	-0.109	-0.141	-0.181
p	2.352	2.377	2.266	2.286	2.332	2.379
EF	0.986	0.986	0.984	0.983	0.986	0.986

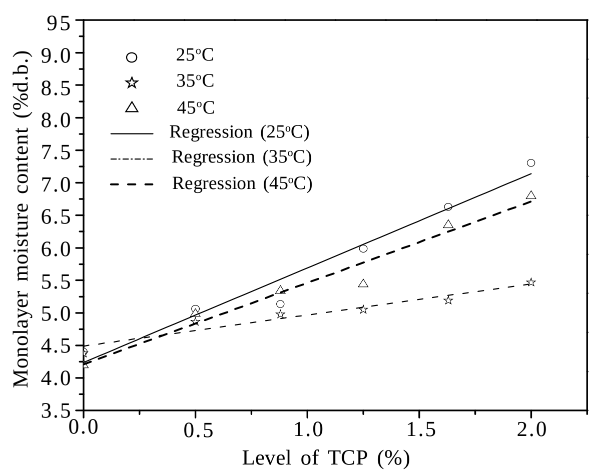

Fig. 6: Variation of monolayer moisture content of granulated jaggery samples with various levels of TCP at temperature of 25, 35 and 45°C

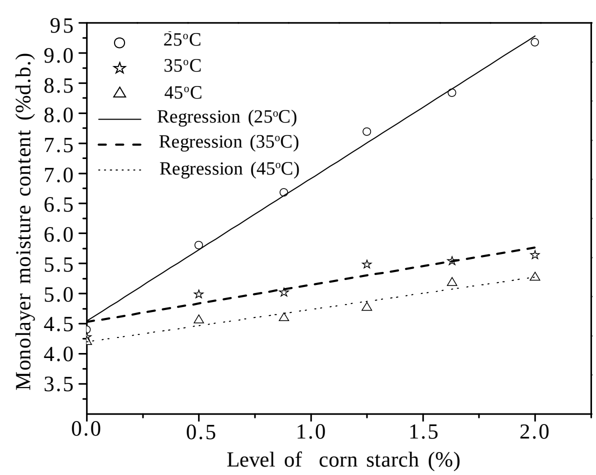

Fig. 7: Variation of monolayer moisture content of granulated jaggery samples with various levels of corn starch at temperature of 25, 35 and 45°C

jaggery with different level of anticaking agent *i.e.* TCP and CS at different moisture levels obtained from respective isotherms are shown below for the adsorption processes in Tables 3 and 4. All these samples follow similar trend as those of other food materials. Value of q_{st} found to decrease from 29.132 kJ/mol to 4.833 kJ/mol for the jaggery granules with the increase in moisture content from 2.5 to 15% (d.b.) without addition of anti-caking agent. It was observed that, with the addition of CS @ 0.5, 0.8, 1.25, 1.88 and 2, q_{st} values were found to decrease from 12.835 to 2.059; 6.516 to 1.846; 6.593 to 0.597; 6.229 to 1.205 and 7.003 to 1.019 kJ/mol with the increase in moisture content from 2.5 to 15% (d.b.), respectively; for TCP are 6.476 to 0.087, 7.324 to 1.329, 8.627 to 0.917, 5.922 to 0.760 and 7.503 to 0.550 kJ/mol, respectively. It was observed that the heat of sorption decreases with the addition of either one of the anti-caking agents TCP and CS. At different level of anti-caking agent, heat of sorption of the jagger granules remains more or less equal. The values of q_{st} for the granular jaggery samples without addition of anti-caking agents are found to be higher as compared to samples with

Table 3 : Isosteric heat of sorption for the jaggery granules with addition of TCP

M.C. (%/db)	Control	0.55	0.8	1.25	1.88	2
	q_{st}	q_{st}	q_{st}	q_{st}	q_{st}	q_{st}
2.5	29.132	6.476	7.324	8.627	5.922	7.503
5	25.098	4.265	5.838	4.083	4.703	3.739
7.5	19.688	2.199	3.678	2.834	2.551	1.871
10	10.534	1.378	2.504	1.520	1.885	1.744
12.5	6.848	1.136	1.999	1.314	1.107	0.792
15	4.833	0.087	1.329	0.917	0.760	0.550

Table 4 : Isosteric heat of sorption for the jaggery granules with addition of CS

M.C. (%/db)	Control	0.55	0.8	1.25	1.88	2
	q_{st}	q_{st}	q_{st}	q_{st}	q_{st}	q_{st}
2.5	29.132	12.835	6.516	6.593	6.229	7.003
5	25.098	8.756	6.177	4.796	4.935	4.994
7.5	19.688	6.188	4.887	3.339	3.695	3.583
10	10.534	4.403	4.098	2.209	2.689	2.653
12.5	6.848	3.081	2.676	1.314	1.874	1.696
15	4.833	2.059	1.846	0.597	1.205	1.019

Table 5 : Exponential relationship between Isosteric heat of sorption and moisture content for adsorption process

TCP		Exponential equation	Correlation co-efficient, R
	Control	q_{st}=50.491(-0.1543M)	0.984
	0.5	q_{st}=19.143 (-0.2972M)	0.914
	0.88	q_{st}=10.722 (-0.1387M)	0.996
	1.25	q_{st} =10.929 (-0.1741M)	0.981
	1.63	q_{st} =9.7586 (-0.1704M)	0.995
	2	q_{st} =10.949 (-0.2033M)	0.986
Corn starch		q_{st} =28.836 (-0.2043M)	0.892
	0.5	q_{st} =18.321 (-0.1443M)	1.000
	0.88	q_{st} =9.7842 (-0.1028M)	0.970
	1.25	q_{st} =12.169 (-0.1864M)	0.985
	1.63	q_{st} =9.3279 (-0.1307M)	0.994
	2	q_{st} =10.77 (-0.1506M)	0.995

addition of the anti-caking agents.

An attempt to evaluate the relationship between the net isosteric heat of sorption (q_{st}) and equilibrium moisture content (M), Tsami *et al.* (1990) proposed an empirical exponential correlation (Eq. 11) as:

$$q_{st}=q_0e^{-\alpha M} \quad .....(11)$$

where, q_0 and α are the characteristics parameters.

The exponential relationship between M (%d.b.) and q_{st} for the jaggery granules with or without addition of anti-caking agents at different levels is given in Table 5.

Conclusion:

The moisture sorption isotherms for palmra-palm jaggery granules are Type-III isotherms. All the MSI of jaggery granules without (or) with addition of anti-caking agents show no significant effect of temperature on the respective EMC values upto a water activity values of 0.3 - 0.5. However, beyond this value, at any particular value of a_w, EMC increased as the temperature increased. GAB model appears to be best with high modeling efficiency for the prediction of EMC values of palmya-palm jagger granules. A decreasing trend of monolayer moisture content (M_o) values was obtained with the increase in temperature. The monolayer moisture content increases with the addition of either one of TCP and CS from 0.5 to 2.0 per cent. Net isosteric heat of sorption followed an exponential relationship with the moisture content and decreases with the addition of either one of the anti-caking agents TCP and CS.

LITERATURE CITED

AOAC (1984). Sugars and sugar products. In: *Official methods of analysis of the association of official analytical chemists*. (Sidney Williams,ed.) Vol.**III**. pp: 573-575. Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA.

Alhamdan, A.M. and Hassan, B.H. (1999). Water sorption isotherms of date pastes as influenced by date cultivor and storage temperature. *J. Food Engg.,* **39**: 301-306.

Ayranci, E., Ayranci, G. and Dogantan, Z. (1990). Moisture sorption isotherms of dried apricot, figs and raisin at 20°C and 30°C. *J. Food Sci.,* **55** (6): 1591-1593.

Brunauer, S., Deming, L.S., Deming, N.E. and Troller, E. (1940). On the theory of van der waals adsorption of gases. *J. American Chemical Society,* **62**: 1723-1732.

Chinachoti,P. and Steinberg, M.P. (1984). Interaction of sucrose with starch during dehydration as shown by water sorption. *J. Food Sci.,* **49**(6) : 1604-1608.

Chirife, J. and H.A. Iglesias. (1978). Equation for fitting water sorption isotherms of foods Part-I. A review. *J.Food Technol.,* **13**: 159-174.

Dalibard, C. (1999). Overall view on the tradition of tapping palm trees and prospects for animal production. *Livestock Res. Rural Develop.,* **11**(1) : 1-37.

Greenspan, L. (1977). Humidity fixed points of binary saturated aqueous solutions. *J. Res. National Bureau of Standard Phy. & Chem.,* **81** (A): 89-96.

Hassan, B.H. (1991). Water sorption isotherm of dried dates, *Bulletin of Faculty of Agriculture, Univ. Cairo,* **42** (4) : 1213.

Hasan, T. and Nurhan, A. (2004). Mathematical model for prediction of apparent viscosity of molasses. *J. Food Engg.,* **62** : 281-289.

Iglesias, H.A., Chirife, J. and Lombardi, J.L. (1975). Water sorption isotherms in sugar beet root. *J. Food Technol.,* **10** : 299-308.

Iglesias, H.A. and Chirife, J. (1978). An empirical equation for fitting water sorption isotherms of fruits and related products. *Canadian Institute of Food Sci Technol.,* **11** : 12-15.

Junk, W. R. and Pancoast, H. M. (1973). Boiling point elevations of sugar solutions. In H.M.Pancoast, (Ed.), *Handbook of sugars: For processors, chemists & technologists* (1st Ed.), (pp. 42-66), The AVI Publishing Company Inc., West Port, Connecticut.

Kamble, K. D. (2003). Palm gur industry in India. *Indian J. Tradit. Knowl.,* **2** (2) : 137-147.

Labuza,T.P., Kaanane, A. and Chen, J.Y. (1985). Effect of temperature on the moisture sorption isotherm and water activity shift of two dehydrated foods. *J. Food Sci.,* **50**: 385 - 392.

Leiras, M.C. and Iglesias, H.A. (1991). Water vapour sorption isotherms of two cake mixes and their components. *Internat. J. Food Sci. & Technol.,* **26**: 91.

Linden, G. (1996). Methods of particle size analysis. In: *Analytical techniques for foods and agricultural products*; Melcion J.P., Monredon F.De., Eds.; VCH Publishers: New York, pp. 229-248.

Manuel, M. and Sereno, A. (1993). Effect of temperature on sorption isotherms and heats of sorption of quince jam. *Internat. J. Food Sci. & Technol.,* **28**: 241.

Maroulis, Z.B., Tsami, E., Marinos-Kouris, D. and Saravacos,

G.D. (1988). Application of the GAB model to the moisture sorption isotherms for dried fruits, *J. Food Engg.,* **28** : 63-78.

Microsoft Office Professional Edition (2003). *Microsoft office excel*. One Microsoft Way, Redmond, WA 98052-6399, USA: Microsoft, Inc.

Origin (2000). *Non-linear curve fit.* Ver.6.1. Northampton, MA 01060, USA: Origin Lab, Inc.

Pattnayak, P.K. and Misra, M.K.(2004). Energetic and economics of traditional gur preparation: A case study in Ganjam district of Orissa, India. *Bio-mass & Bio-energy,* **26**: 79-88.

Peleg, M. and Hollenbach (1984). Flow conditioners and anti-caking agents. *Food Technol.,* **38** : 93-102.

Rao, P.V.K. Jagannadha, Das, S.K. and Das, M. (2006). Moisture sorption isotherms of sugarcane, palmyra and date-palm jaggery. Paper presented, American Society of Agricultural and Biological Engineers Annual International Meeting (paper no. 063007), July 9- 12, Portland, USA.

Rao, P.V.K. Jagannadha, Das, Madhusweta and Das, S.K. (2007). Jaggery – A traditional Indian Sweetener. *Indian J. Tradit. Knowl.,* **6** (1) : 95-102.

Rao, P.V.K. Janannadha, Das, Madhusweta and Das, S.K. (2008). Thermophysical properties of sugarcane, palmyra-palm and date-palm granular jaggery. *Internat. J. Food Propert.,* **11** : 876-886.

Rao V.P. Surya Prakash and Rao, N.V. Mohan (1959). Some fundamentals considerations in the storage and transport of jaggery. *Indian J. Sugarcane Res. & Develop.,* **3** (2) : 84 - 89.

Rizvi, S.S.H. (1986). Thermodynamic properties of foods in dehydration. In *Engineering Properties of Foods* (M.A. Rao and S.S.H. Rizvi -Ed.), 133-214. New York: Marcel Dekker Publications.

Sahu, A.P. and Paul, B.N. (1998). The role of dietary whole sugar- jaggery in prevention of respiratory toxicity of air toxics and in lung cancer. *Toxicology Letters,* **95**(1) : 154.

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

Sastry, A.S., Ghosh, A.K. and Bajpai, J.P. (1965). Effect of different temperatures and humidities on the keeping quality of gur (Jaggery). *Indian J. Sugarcane Res. Develop.,* **3**: 325-331.

Swami, S.B., Das, S.K. and Maiti, B. (2005). Moisture sorption isotherms of black gram nuggets (Bori) at varied temperatures. *J. Food Engg.,* **67** : 477-482.

Thakur, A.K. (1999). Potential of jaggery (Gur) manufacturing in Punjab state. In: *Proceedings of the National Seminar on Status, Problems and Prospects of Jaggery and Khandsari Industry in India* (edited by Jaswant Singh). pp.70–76. Indian Institute of Sugarcane Research, Lucknow, 2 - 3 December.

Tsami,E., Marinos-Kouris, D. and Maroulis, Z.B. (1990). Water sorption isotherms of raisins, currants, figs, prunes and apricots. *J. Food Sci.,* **55**(6): 1594-1597.

Uppal, S.K. and Sharma, S. (1999). Evaluation of different methods of jaggery (gur) storage in subtropical region. *Indian J. Sugarcane Technol.,* **14** (1) : 17-21.

Van Den Berg, C.(1984). Description of water activity of foods for engineering purposes by means of the GAB model of sorption. In: *Engineering and food* Vol.**1** (B.M.McKenna-Ed.), 311. London: Elsevier Applied Science Publications.

Verma, V.K. and Narain, M. (1990). Moisture absorption isotherms of jaggery. *J. Stored Prod. Res.,* **26**(2): 61-66.

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