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Moisture Desorption and Adsorption Chareteristics of Gum Arabic from *Acacia senegal* and *A. seyal*

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Abstract: The objective of this paper was to study the moisture isotherms characteristics of gum Arabic produced by *Acacia senegal* and *A. seyal*. The equilibrium moisture content of the gum was determined by the standard static gravimetric methods using various saturated salts solutions in closed desiccators to provide a range of RH of 0 to 96%. Gum samples were placed in these desiccators, and kept inside the oven at specified temperature (30, 40, 50 and 60°C) until equilibrium moisture content was obtained. Desorption and adsorption isotherms of gum Arabic exhibited sigmoid curves and indicated clear hysteresis effect. The statistical analysis indicated that the relationship between equilibrium moisture content and RH could be well explained by third-order polynomial functions. Equilibrium moisture content increased with increase in RH but decreased with increase in temperature.

Key words: Sorption isotherms; equilibrium moisture content; gum Arabic; polynomial functions; drying

INTRODUCTION

Water is a natural constituent of all biological products. It is found in all parts of a living tree and it is an important component of leaves, fruits and tree exudates including gum (Siau 1971; Skaar 1972; Desh and Dinwodi 1991). Traditionally, discussions on controlling the water in products have focused on moisture content (MC) which provides valuable information about product quality. Another important moisture measurement is water activity which is the ratio of water vapor pressure in a product to the vapor pressure of pure water. It provides essential information about the energy or availability of water in a product

(Tencl 1999; Simpson 1998). A material that desorbs and adsorbs moisture until it is in equilibrium with the surrounding is called a hygroscopic material. Equilibrium moisture content (EMC) is the MC of a hygroscopic material in equilibrium with a particular environment in terms of relative humidity (RH) and temperature (Skaar 1972; Brooker *et al.* 1999). It is the final result of moisture exchange between the product and the surrounding air (Arabhosseini *et al.* 2006).

EMC values of biological products vary among species and/ or variety, the physiological maturity and the history of the product. EMC is also affected by the way equilibrium was obtained, i.e. whether by losing or gaining water (Correa *et al.* 1999; Brooker *et al.* 1999). The process of increasing MC (water gain) is termed adsorption, and, that of decreasing moisture content (water loss), desorption. The relationship between equilibrium RH and EMC is usually expressed by means of sorption isotherms at certain temperature. Previous research showed that in lignocellulosic and various agricultural materials adsorption isotherms exhibit lower EMC than desorption isotherms at a given RH (Skaar 1972; Correa *et al.* 1999; Brooker *et al.* 1999; Arabhosseini *et al.* 2006; Hamdan *et al.* 2007; Ahmed *et al.* 2010).

This information is required for drying, mixing, packaging and storage of biological materials to maintain the quality during the storage period. It is also required to stop the drying process at aimed MC to avoid quality losses and to save energy (Pahlevanzdeh and Yazdani 2004; Arabhosseini *et al.* 2005; Menkov and Durakova 2006; Ariahu *et al*. 2006)

When gum is exposed to atmospheric conditions it loses moisture to the atmosphere until it comes to a low enough MC that is at equilibrium with surrounding environment. This EMC is expected to vary mainly with RH and with the temperature. No information was found on the hygroscopic EMC of gum Arabic or the effects of air RH and temperature combinations.

The objectives of this research work were to study the sorption isotherms characteristics of gum Arabic from *Acacia senegal* and *A.seyal* for RH values ranging between 0 and 96% and in temperature range of 30 to 60°C.

MATERIALS AND METHODS

Gum Arabic samples were collected in the form of nodules from healthy trees of *Acacia senegal* and *A. seyal* growing in Kordofan and Gadarif, respectively. Fresh gums were directly collected from their trees and brought to laboratory in plastic bags and stored in a refrigerator at 4 °C to keep the MC at initial green condition until needed.

Preparation of saturated salt solutions

For the determination of desorption and adsorption isotherms, it was necessary to provide a number of RHs at each temperature to which samples were exposed until they reached their EMC. Nine salts were used to prepare saturated solutions to maintain a range of RHs (0 to about 95%) at each of four temperatures (30, 40, 50 and 60°C). This method is based on the fact that equilibrium RHs of specific salts solutions are of well known physical property (Greenspan 1976). Saturated salt solutions were provided by dissolving a salt in distilled water at the required temperature inside desiccators. While adding the salt, the solution was stirred using a glass rod and the addition of the salt was continued until there was only a small excess amount remaining undissolved for a period of 24 hours inside the oven to make sure that the prepared solution was saturated. RHs were measured by connecting two thermocouples to a Delta T-logger (DL2e type) and assigned to record the wet (inside the desiccators) and dry (outside the desiccators) bulb temperatures of the air. The saturated salt solutions used and corresponding RHs at different temperatures are given in Table 1.

Determination of the sorption isotherms

The test samples were placed on Petri dishes in the closed desiccators containing the various salts at each oven temperature. The samples were weighed every day until the constant weight was obtained or the difference was at least±0.001g between two successive weights, indicating that EMC was reached. Finally, the samples were dried to a constant weight in the oven at a fixed temperature of 105°C to obtain the dry mass of each sample and determine the desorption EMC at a given RH and temperature. It equals the difference in mass before and after oven-drying divided by the oven-dry weight.

After desorption isotherms were obtained the oven-dried samples were used to determine adsorption isotherms. The samples were placed inside the desiccators containing the various salts with RHs ranging from 11 to 96% at each of the four temperatures. Also, the weight of samples was taken daily until adsorption isotherms were obtained. The data collected from the two experiments were used to draw the full cycles of desorption and adsorption isotherms (the hysteresis). The relationship between gum EMC and RH was investigated using polynomial regression analysis (Neter *et al*. 1983).

Table 1. Saturated salt solutions and equilibrium relative humidity at different temperatures

No	Salt formula	Equilibrium relative humidity % at			
		30 °C	40°C	50°C	60°C
1	K_2SO_4	96.00	95.82	95.82	95.82
2	KCl	84.3	82	81.2	80.25
3	NaCl	75.6	75.3	74.4	74.5
4	KI	68.86	66.09	64.49	63.11
5	$Mg(NO_3)_2$	51.4	48.4	45.4	47.3
6	K_2CO_3	43.16	40	38.5	37.7
7	$MgCl_2$	32.8	31.6	30.54	29.26
8	$KC_2H_3O_2$	22	20.8	20.4	20
9	LiCl	11.3	11.2	11.1	11

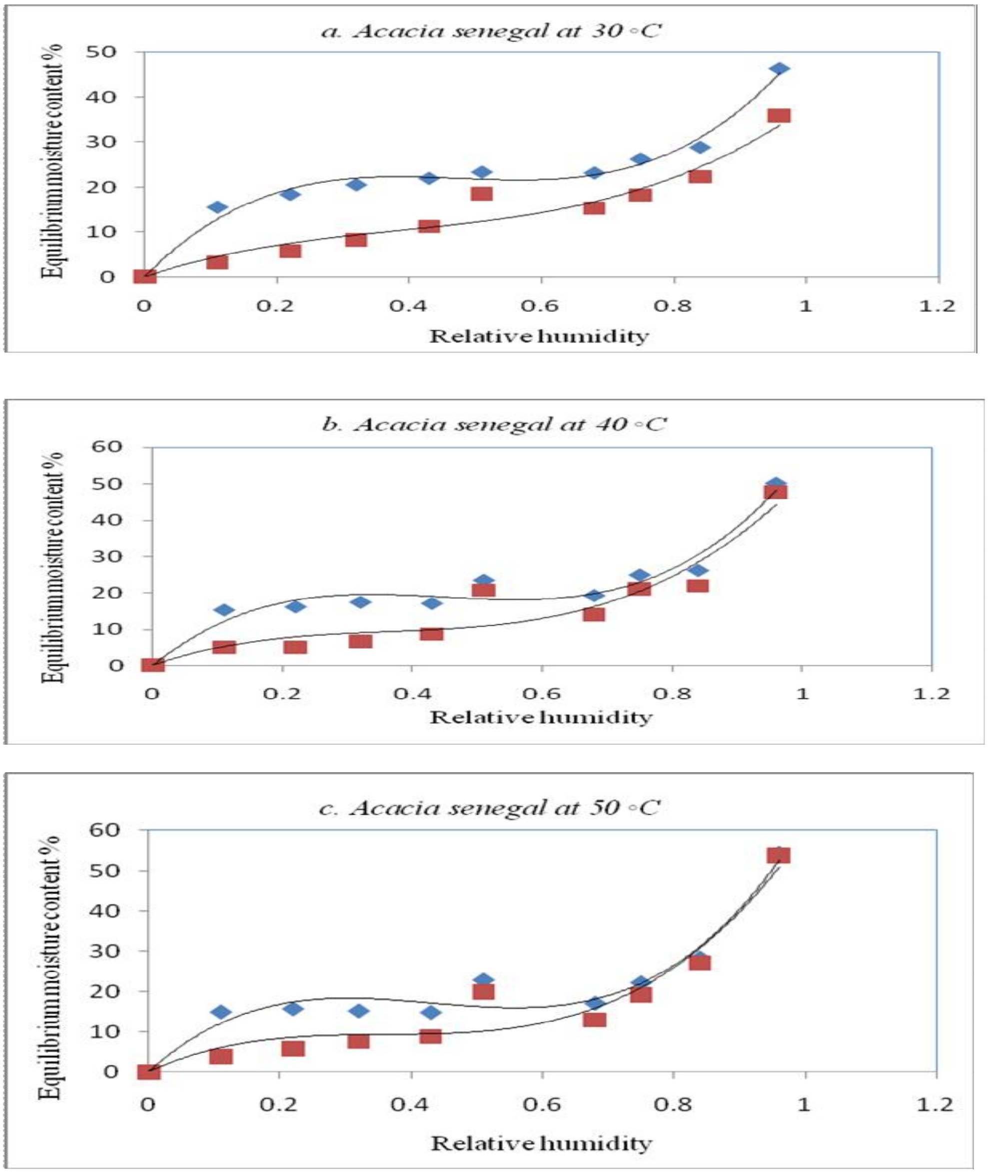
RESULTS AND DISCUSSION

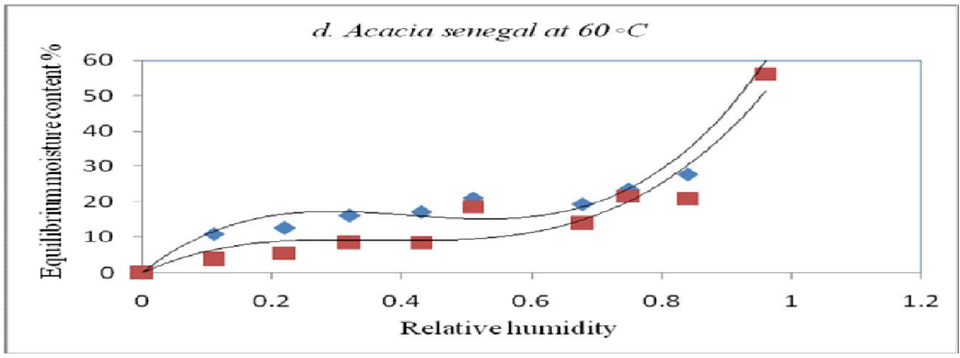
Drying of gum Arabic started with average initial MC around 53.65 and 45.5 (dry basis) for *A. senegal* and *A. seyal*, respectively. Sorption characteristics of gum from *A. senegal* and *A. seyal* are given in Fig. 1 (a-h) to illustrate desorption and adsorption phenomena. It can be seen that equilibrium moisture content (EMC) increases with increasing RH at a given temperature. At each RH desorption isotherms had higher water content than do adsorption isotherms. This phenomenon has been explained in terms of the loss and gain of hydroxyl groups. In the original green condition, the available polar hydroxyl groups in cell wall polymers are almost entirely satisfied by bound water. In dry gum, which has lost its bound water, however, shrinkage brings the polar hydroxyl groups close enough together to satisfy each other, this results in diminished adsorption when re-wetted (Koch 1985; Haygreen and Bowyer 1989). The term describing the differences between adsorption and desorption moisture content is called hysteresis. The value of hystersis was smaller at the low and high RHs than at the intermediate RHs forming a loop, which is evident in Figure 1(a-h). For both gum species the hysteresis loop is slightly open at the upper end of the curves.

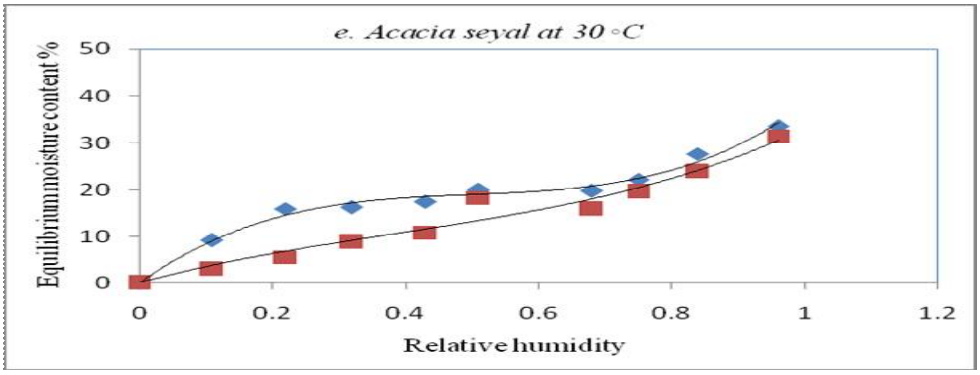
The isotherms exhibited sigmoid shaped curves at all temperatures, which is characteristic for materials rich in carbohydrates (Wolf *et al.* 1972). Similar results were reported for many biological materials in the literature (Lahsasni *et al.* 2003; Arabhosseini *et al.* 2005; Menkov and Durakova 2005; Kumar and Mishra 2005; Ariahu *et al*. 2006). The isotherms were satisfactorily explained by third order polynomial functions. The regression functions for desorption and adsorption phenomena at temperatures 30, 40, 50 and 60°C are given in Table 2 for *A. senegal* and *A. seyal*. There were no considerable differences between *A. senegal* and *A. seyal*. The coefficient of determination, R^2, revealed that the proportion of the variation in EMC that was explained by RH indicating high goodness of fit to the regression lines in both gum species. Simpson (1979) and Iglesias and Bueno (1999) classified five types of sorption isotherms depending on the thickness of layers, forces of attraction between the vapor and solid and capillary condensation in rigid capillaries. Sorption isotherms measured for acacia gum showed the type II BET classification shape, which is characterized by having more than one layer of vapor on the solid and where the forces of attraction between the vapor and solid are large.

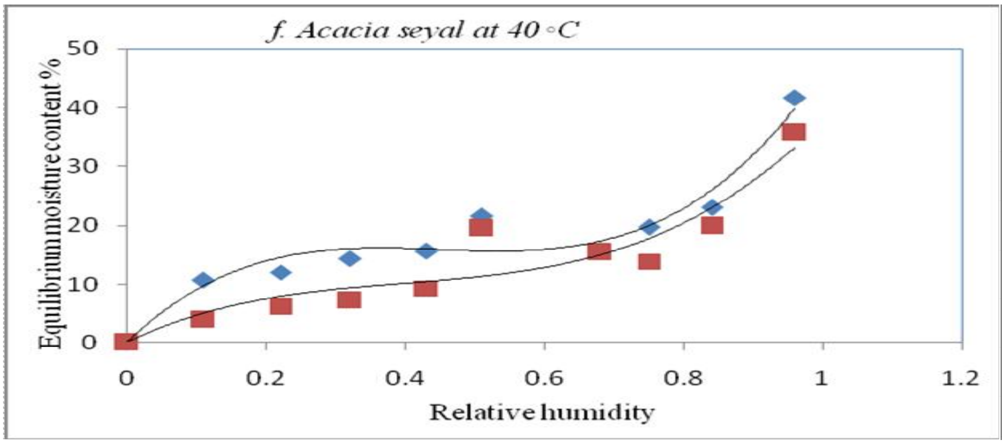
Table 2. Regression functions for desorption and adsorption EMC at temperatures 30, 40, 50 and 60° C

Temperatures C°	Equations	R^2
	Acacia senegal	
30	EMC= $225.1x^3 – 329.1x^2 + 150.4$ x (Desorption)	0.983
	EMC= $88.41x^3 – 90.90x^2 + 50.34x$..(Adsorption)	0.943
40	EMC= $252.3x^3 – 346.6x^2 + 145.7x$ (Desorption)	0.948
	EMC= $153.5x^3 – 156.1x^2 + 63.60x$ (Adsorption)	0.899
50	EMC= $286.3x^3 – 376.1x^2 + 147.8x$ (Desorption)	0.952
	EMC= $204.6x^3 – 204.5x^2 + 74.91x$ (Adsorption)	0.935
60	EMC= $320.3x^3 – 380.4x^2 + 143.3x$. (Desorption)	0.952
	EMC= $224.0x^3 – 244.8x^2 + 79.71x$ (Adsorption)	0.904
	Acacia seyal	
30	EMC= $127.0x^3 – 194.0x^2 + 102.5x$ (Desorption)	0.987
	EMC= $45.19x^3 – 45.12x^2 + 39.19x$ (Adsorption)	0.961
40	EMC= $199.4x^3 – 265.2x^2 + 114.9x$ (Desorption)	0.943
	EMC= $110.7x^3 – 120.1x^2 + 57.27x$ (Adsorption)	0.886
50	EMC= $244.1x^3 – 284.3x^2 + 112.0x$ (Desorption)	0.956
	EMC= $174.1x^3 – 174.8x^2 + 67.74x$ (Adsorption)	0.925
60	EMC= $241.2x^3 – 270.0x^2 + 103.0x$ (Desorption)	0.926
	EMC= $204.2x^3 – 205.8x^2 + 73.49x$ (Adsorption)	0.899


a. Acacia senegal at 30 ◦C
Equilibrium moisture content %
Relative humidity
b. Acacia senegal at 40 ◦C
Equilibrium moisture content %
Relative humidity
c. Acacia senegal at 50 ◦C
Equilibrium moisture content %
Relative humidity


d. Acacia senegal at 60 ◦C
Equilibrium moisture content %
Relative humidity
0
10
20
30
40
50
60
0.2
0.4
0.6
0.8
1
1.2


e. Acacia seyal at 30 ◦C
Equilibrium moisture content %
Relative humidity
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1
1.2


f. Acacia seyal at 40 ◦C
Equilibrium moisture content %
Relative humidity
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1
1.2

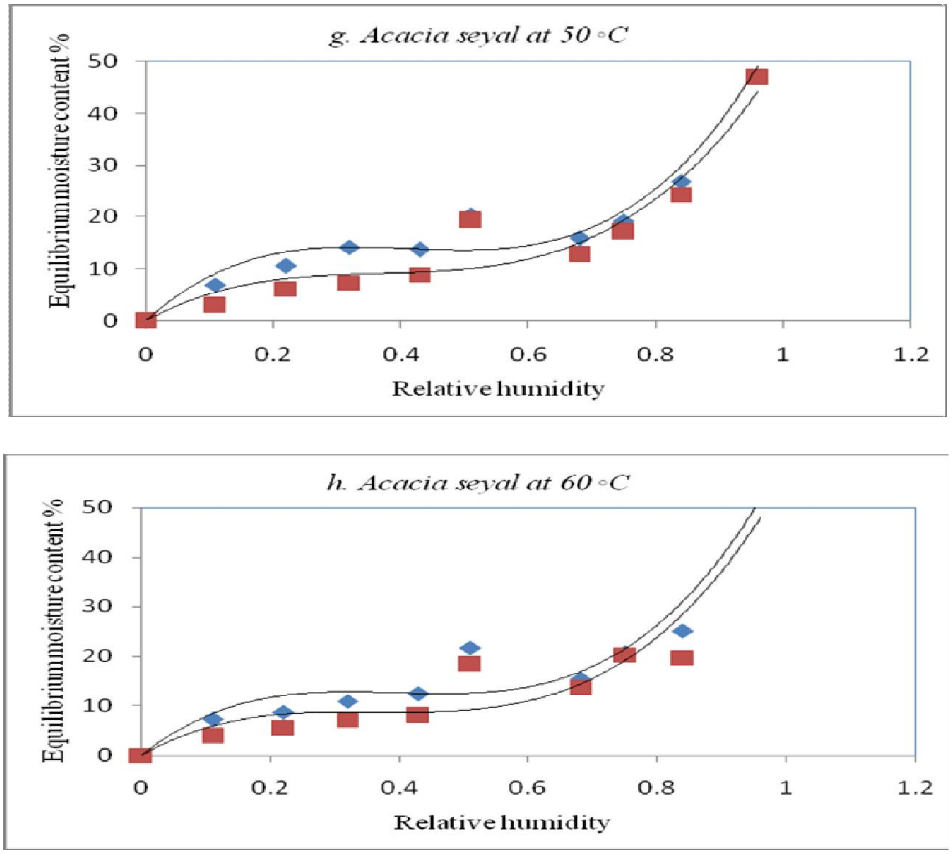


Fig. 1. (a-h). Desorption and adsorption isotherms of gum of *A. senegal* and *A. seyal*

Increasing temperature caused decrease in EMC at all levels of RH (Fig 2). It can be noted that the effect of temperature at the lower RH is very slight than the higher RH. Labuza (1984) explained that if RH is kept constant, an increase in temperature causes a decrease in the amount of absorbed water. This indicates that the material becomes less hygroscopic at higher temperatures. When increasing temperature, water molecules get activated due to their energy level and become less stable and break away from water-binding sites of hygroscopic materials, thus decreasing the monolayer-moisture content. This is the reason why the degree of water sorption decreased with increasing temperature at a given RH.

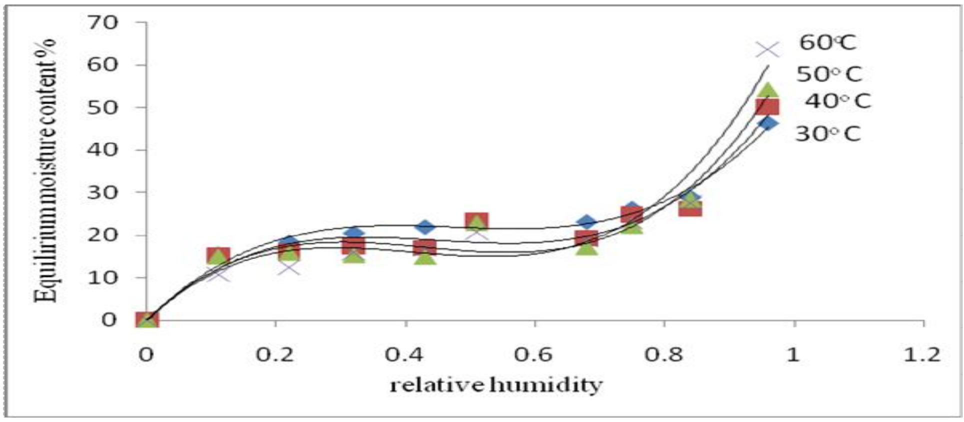


Fig. 2. Desorption isotherms of *Acacia senegal* at all levels of temperatures

CONCLUSIONS

According to the data and results of this study the following can be concluded:
The relationship between desorption and adsorption EMC on one hand and RH on the other exhibited sigmoid shaped curves. The EMC of *A. senegal* and *A. seyal* gums increases with RH and decreases with increasing the temperature. The hysteresis between desorption and adsorption isotherms was evident

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