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ABSTRACT

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ABSTRACT

In the semi arid conditions of Sudan, the determination of moisture sorption isotherms at different temperatures and water activities to establish the correctly storage conditions for crops grains is highly needed. The objective of this study was to determine the moisture sorption isotherms of two local varieties of sorghum (Sorghum bicolor L Moench.) namely; Tabat and Wad Ahmed at various temperatures and water activities. The study was conducted at the Department of Agricultural Engineering, University of Khartoum and the Department of Grains Technology, Food Research and Processing Center, Shambat, Sudan during the period from December 2006 to December 2008. Water sorption isotherms were determined using standard static gravimetric method at temperatures 25°C; 35°C and 45°C over a range of water activities from 0.112 to 0.865. The water activities were maintained using saturated salt solutions inside air-tight glass desiccators, while incubators were used to maintain a constant temperature. The results showed that, there is a highly significant (P ≤ 0.01) effect of water activity nested within temperature and also for the interaction between water activity nested within temperature and cultivars. Wad Ahmed cultivar gave the highest values of adsorption (13.633%db) and desorption (15.665%db) equilibrium as compared to Tabat cultivar (13.615%db and 15.410%db, respectively) at the same temperature and water activities. Increasing temperature from 25°C to 45°C decreased the sorption isotherms at a constant water activity, while increasing water activities from 0.112 to 0.865 increased the sorption isotherms for both adsorption and desorption equilibrium at a constant temperature. It is concluded that, moisture sorption isotherms of sorghum grains play important roles in such technological processes as drying, handling, packaging, storage, mixing and other processes that requires the prediction of food stability, glass transition and estimation of drying time and texture and prevention of deteriorative reactions.

Keywords: water activity, water sorption isotherms; sorghum.

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I. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a major cereal cultivated as food and feed in the semi arid regions of the world. It plays a crucial role in the world food economy as it contributes to rural household food security. It feeds millions of people on a daily basis in the developing countries, providing dietary starch and proteins, some vitamins and minerals phytochemicals with substantiated health benefits (Taylor and Duodu, 2017; Adebo *et al*., 2018). In Sudan, sorghum grain is the most important staple cereal food crop for human nutrition as they are the major sources of nutrients, proteins and calories for populations. Sorghum grain storage including above ground and underground facilities. Both types include traditional and modern storage facilities. However, large amounts of grain are lost during post harvest operations such as threshing, cleaning, storing and transportation. Evidently, this is due to the poor traditional harvesting and storage methods as well as the inadequate threshing tools. Grain losses in the traditional stores can reach 50%, they range between 5% and 13% for modern storage facilities; 6%in the underground pits and only 1% in silos (Abdalla *et al.*, 2002). Therefore, the knowledge of moisture sorption isotherms of cereal and oilseed grains are so essential in order to establish storage condition since they give information about the humidity-water activity (a_w) relation at given temperature, to prevent deterioration during storage (Bianco *et al.*, 2007). The sorption of moisture by the product from the atmosphere and the atmosphere from the product will occur during storage and packaging. The moisture sorption isotherm of food graphically relates its equilibrium moisture content in either desorption or adsorption, to the water activity (aw) at a definite temperature. These isotherms are extremely important quantitative measures in food preservation, storage, packaging and drying (Chen, 2000, Arslan Togrul, 2005 and Medeiros *et al.*, 2006). Equilibrium moisture content for the adsorption and desorption processes does not have the same values. Grain that is losing moisture to the air i.e. desorption or drying, has a higher equilibrium moisture content than if the same grain being initially at lower moisture content began adsorbing moisture from air at the same relative humidity. The equilibrium moisture content for desorption is higher than for adsorption at a particular water activity. Raji and Ojediran (2011) determined moisture sorption isotherms of millets at temperature range of 30–70°C and water activity range of 0.07–0.98 using the static gravimetric method. His result revealed that, sorption isotherms of millet decreased with increasing temperature. Water activity revealed the material's interaction with environmental conditions to determine the amount of moisture that can be lost or gained, or the relative closeness of any given moisture content to one that represents product stability in storage. The relationship between the water activity (aw) and moisture content of a material at a given temperature is called the moisture sorption isotherm which divided into three zones; Zone I (aw < 0.25) represents the monolayer water, which is strongly associated with the food material, unable to freeze and not easily removed by drying. Zone II (0.25 < aw < 0.75) represents the water that is adsorbed or absorbed in multi layers within foods and solutions of soluble components. Zone III (aw > 0.75) represents the "free" water, which is available for microbial growth and enzymatic activity and freezable and easily removed by drying (Fennma, 1996). Arabhosseini *et al.* (2010) and Chico-Santamarta *et al.* (2011) stated that, water activity between 0.6 and 0.7 represents the maximum allowable level to limit microbial degradation in aerobic storage. Bonner and Kenney (2013) reported that, water activity decreased with increasing temperatures. In Sudan, no effort has been reported on determining the moisture sorption isotherms properties of Sorghum (Sorghum. *bicolor* L. Moench) at various temperatures to establish the storage conditions. Therefore the objective of this study was to evaluate the moisture sorption isotherms of Sorghum (Sorghum. *bicolor* L. Moench) at various temperatures and water activities

II. MATERIALS AND METHODS

2.1 Experimental work

The experimental work was carried out at the Department of Agricultural Engineering, University of Khartoum and the Department of Grains Technology, Food Research and Processing Center, Shambat, Sudan during the period from December 2006 to December 2008. For the study purpose, two local sorghum grains varieties namely, Tabat and Wad Ahmed (Plate 1 and 2) were obtained from Sorghum Research Programme, Agricultural Research Corporation, Wad Medani, Gezira State, Sudan.

2.2 Equipments

The following equipment was used in the experiments.

1. A sensitive balance: model AB54-S, Mettlre Toledo make and made in Switzerland, with

an accuracy of ±0.001 g was used for weighing the samples in the different experiments.

2. An air-oven: model KAT-NR 28452 Elektro-Helios makes and made in Sweden was used for the determination of the moisture content (m.c.).
3. Two incubators: model Gallenkamp make and made in England both with temperature range of -10°C to 50°C (Plate 3.3) were used for determination of sorption isotherms of samples.
4. A hardness tester: model No.174886make and made by Seiskusho LTD – Japan was used to measure grain hardness.
5. A shaker apparatus: model KL. 2 No. 490 Edumund Bühler make and made in Germany was used for preparation of sorghum samples for desorption test. .
6. A venire caliper: was used for measuring the size of grains.
7. A refrigerator: model Sanyo-Freezer makes and made in Germany was used for storing sorghum samples.
8. A hectoliter: was used for determination of test weight of grain sample.
9. Crucible containers: were used to determine ash contents of grain sample.
10. A thermometer: was used to measure the temperatures.
11. Aluminum dishes or containers: were used for determination of moisture contents of grain sample.
12. Graduated measuring cylinders: with a volume of 100 ml were used for measuring the volume of distilled water.
13. A small micro-Kjeldhl flask with volume of 100 ml was used for determination of protein contents of grains sample.
14. A glass rod: was used to stir the saturated salt solutions.
15. A hair hygrometer: was used to check the attained air relative humidities of the saturated solutions.
16. Glass desiccators: in which samples of sorghum were tested for equilibrium moisture content (EMC.) determination
17. Conical flasks: each with volume of 250 ml for the preparation of the saturated salt solutions.

III. ADSORPTION AND DESORPTION ISOTHERMS AND EQUILIBRIUM MOISTURE CONTENT (EMC) DETERMINATION

For adsorption and desorption isotherms of the samples the standard static gravimetric method as stated by Wolf *et al.*, (1985) was used. For adsorption isotherms the samples were dried to (3.03%) dry basis, of moisture content, by using an air oven (KAT-NR 28452 Elektro-Helios, Sweden) with air circulation and the air temperature was adjusted at 40°C to achieve the final moisture content for adsorption. The final weight that gave the dried samples was determined by using the equation (1) as described by Gough (1983). A saturated salt solution of potassium chromate (K_2CrO_4) maintaining water activity of 0.865 was prepared at a temperature of 25°C ± 1.0°C and was used to determine the range of the expected values for desorption equilibrium moisture content of grain samples. Three samples each of 500 g in weight were taken from the dried grains of each cultivar and placed in Kilner air tight jars. The amount of distilled water added to each jar to condition the grains so as to obtain the intended moisture content range was determined using the equation (2) as reported by Gough (1983). The jars were placed onto a shaker device (Edumund Bühler, KL. 2 No. 490, Germany) for preparation of the samples for desorption test of moisture content of 32.02% dry basis. The shaking was done over a period of three days, four times a day, for 45 minutes following the procedure reported by Ismail (1994). All the jars were emptied and the samples wrapped in aluminum foil and put inside polyethylene bags and stored in the refrigerator until they were used for EMC determination. The wetted sorghum samples were allowed to equilibrate for 6 h in the room condition before being used.

$$B = \frac{A\,(100-a)}{(100-b)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$Q = \frac{A\,(b-a)}{(100-b)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

B = Final weight of sample after drying kg.

Q = Weight of water to be added kg.

A = Initial weight of sample before drying kg.

a = Initial moisture content of sample (percent wet basis).

b = Desired final moisture content of sample (percent wet basis).

The standard static gravimetric method as stated by Wolf *et al.*, (1985) was used for determining the equilibrium moisture content data for both adsorption and desorption isotherms. Triplicates of pre-conditioned samples (10g ±0.001g each for desorption and 5g ±0.001g each for adsorption) were placed on circular plastic Petri dishes placed on a plastic platform inside the glass desiccators. Six saturated salt solutions, which were used to maintain the constant water activities, are shown in Table 1. The salt solutions and the samples were put in the desiccators which were placed inside incubators (Gallenkamp, temperature range of -10°C to 50°C, England) with, adjusted at 25°C; 35°C and 45°C±1.0°C. The samples were weighed daily using an electronic sensitive balance until a constant weight with obtained from three successive readings was a difference of ± 0.001g. The final moisture content of the samples, after attaining equilibrium was determined according to the standard method of the Association of Official Analytical Chemists (AOAC, 1990). In this method, well-mixed triplicate of grain samples each of an initial weight of about 2 ± 0.001 g were dried in an air-oven set at 105±1.0°C for 24 hours. The moisture content of the samples determined on percent dry basis at this stage was EMC. All the experiments were carried in triplicates and the average value at each temperature and water activity was determined.

3.1 Water activity (a_w) determination

Water activity (a_w) can be given by the following equation mentioned by McLaughin and Magee (1998):

$$a_w = \frac{P_f}{P_o} = \frac{ERH}{100} \qquad (3)$$

Where:

aw = Water activity decimal
Pf = Vapour pressure of water in the food Nm-2.
Po = Vapour pressure of pure water at the same temperature Nm-2
ERH = Equilibrium relative humidity %

Table 1: Water activity ($a_{w.}$) values of the saturated salt solutions at three temperatures, 25°C, 35°C and 45°C.

Salt chemical formula	Water activity (a_w)		
	25°C	35°C	45°C
LiCL	0.112	0.112	0.113
$KC_2H_3O_2$	0.227	0.184	0.195
K_2CO_3	0.438	0.435	0.432
$Na\ NO_2$	0.643	0.633	0.605
NaCl	0.748	0.756	0.745
K_2CrO_4	0.865	0.863	0.846

Source: Kalemullah and Kaillappan (2004)

IV. EXPERIMENTAL DESIGN

A factorial experimental design of three factors namely; two varieties, three temperature levels and six levels of water activity being nested within temperature. Data were analyzed following the method described for a completely randomized design. Statistical tools such as ANOVA and DMRT were used to analyze the experimental data.

Plate 1: Tabat sorghum cultivar

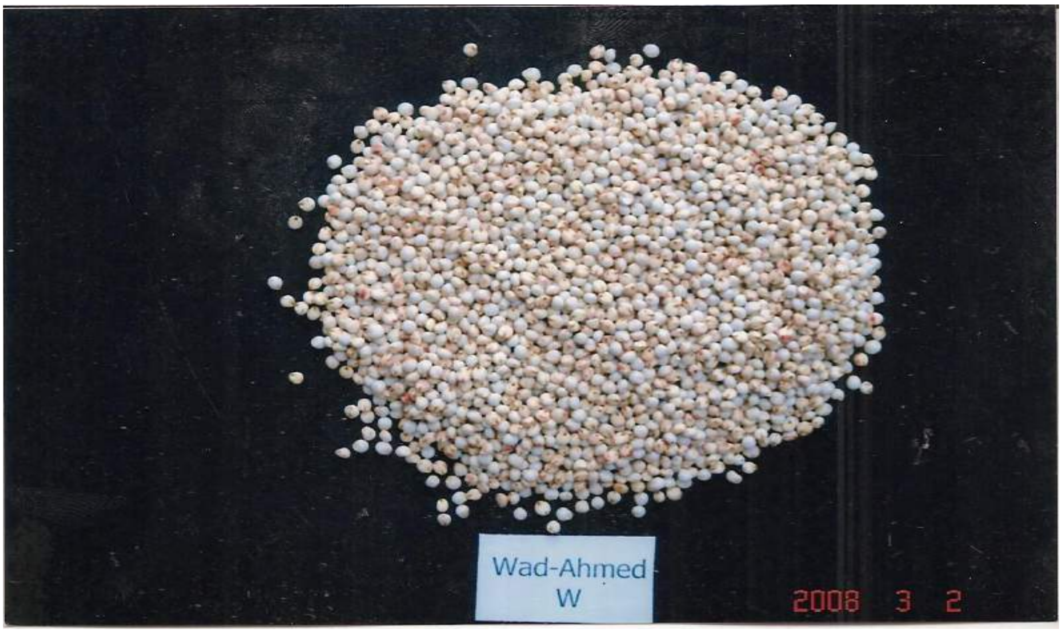

Plate 2: Wad Ahmed sorghum cultivar

V. RESULTS AND DISCUSSION

Moisture sorption characteristics of agricultural and food products play important roles in such technological processes as drying, handling, packaging, storage, mixing, freeze-drying and other processes that requires the prediction of food stability, shelf life, glass transition and estimation of drying time and texture and prevention of deteriorative reactions.

The relationship between the adsorption moisture sorption isotherms and the two local sorghum cultivars, temperature and water activity was presented in Table 1 and Fig. 1 and 2. Equilibrium moisture content for the adsorption and desorption processes does not have the same values. Statistical analysis showed that, there were a highly significant effect ($P \leq 0.05$) between moisture sorption isotherms and two local varieties and also for the interaction between water activity nested within temperature and cultivars. It is clear that, the adsorption means values for Wad Ahmed cultivar is greater than Tabat cultivar. On the other hand, increasing temperature from 25°C to 45°C decreased the equilibrium moisture content for a constant water activity. So the change in adsorption value among the temperature differs with the change in sorghum cultivars, the highest values are obtained for both cultivars at 25°C. The adsorption value for each cultivar was increasing with the increases in water activity nested within temperature. The highest values were obtained under the highest water activity at 25°C for Wad Ahmed cultivar compared to Tabat cultivar. The results were in conformity with the results obtained by Raji and Ojediran (2011) who determined moisture sorption isotherms of millets at temperature range of 30–70°C and water activity range of 0.07–0.98 using the static gravimetric method. His result revealed that, sorption isotherms of millet decreased with increasing temperature.

The water activity of foods at higher temperatures plays a major role during drying and storage of dry products. The changing in water activity of food ingredients and effective diffusivity to control moisture migration in multi domain foods, when temperature changes occur is highly difference. Increasing water activity from 0.112 to 0.865 increased the equilibrium moisture content for both the adsorption and desorption isotherms at a constant temperature. The relationship between equilibrium moisture content and water activity at various temperatures was found to decrease with increasing temperatures. The results confirmed that, water activity decreased with increasing temperatures as mentioned by Bonner and Kenney (2013). Therefore, the results were in agreement with the results obtained by Arabhosseini *et al.* (2010) and Chico-Santamarta *et al.* (2011) who mentioned that, water activity between 0.6 and 0.7 represents the maximum allowable level to limit microbial degradation in aerobic storage.

Table 2 and Fig. 3 and 4 showed that, the equilibrium moisture content for desorption is higher than for adsorption at a particular water activity. The desorption value for each cultivar increased with the increase in water activity nested within temperature. The highest desorption values was obtained for the highest water activity at 25°C. The change in desorption value among the temperature differs with the change in sorghum cultivars, the highest value of desorption was recorded under Wad Ahmed cultivar as compared to Tabat cultivar at 25°C. These results were in agreement with result obtained by Togrul and Togrul and Arslan (2006) who reported that, many food deterioration reactions and the growth of important microorganisms such as fungi depend on the water activity of the food, and water activity is thus an important variable to produce food stability.

Table 1: Mean values of adsorption equilibrium moisture content (% d.b) for sorghum grain cultivars at different temperatures and water activities

Temperature (°C)	Water activity (decimal)	Variety (% d.b)		Mean
		Tabat	Wad Ahmed	
25	0.112	6.799^{h}	7.198^{g}	6.999^{p}
	0.227	10.921^{f}	11.024^{f}	10.977^{k}
	0.438	11.728^{d}	11.310^{e}	11.747^{j}
	0.643	15.559^{c}	15.655^{c}	15.607^{g}
	0.748	16.783^{b}	16.874^{b}	16.829^{d}

	0.865	19.785^{a}	19.735^{a}	19.747^{a}
	Mean	13.592^{a}	13.633^{a}	13.615^{a}
35	0.112	6.288^{m}	6.458^{k}	6.373^{q}
	0.184	8.636^{k}	8.889^{i}	8.763^{n}
	0.435	9.841^{hi}	9.945^{g}	9.893^{l}
	0.633	13.429^{g}	14.859^{e}	14.144^{h}
	0.756	16.198^{e}	16.328^{c}	16.264^{e}
	0.863	18.861^{b}	18.977^{b}	18.919^{b}
	Mean	12.209^{b}	12.577^{b}	12.396^{b}
45	0.113	5.208^{j}	5.317^{j}	5.263^{r}
	0.195	7.890^{i}	8.566^{h}	8.228^{o}
	0.432	9.032^{g}	9.268^{f}	9.150^{m}
	0.605	12.732^{c}	13.355^{c}	13.044^{i}
	0.745	15.650^{c}	15.932^{d}	15.791^{f}
	0.846	18.847^{a}	18.742^{a}	18.794^{c}
	Mean	11.560^{d}	11.863^{c}	11.712^{c}
Means of variety		12.453^{a}	12.699^{a}	

Means with the same letter are not significantly different from each other, according to Duncan's Multiple Range Test (DMRT).

Table 2: Mean values of desorption equilibrium moisture content (% d.b) for sorghum grain cultivar at different temperatures and water activities

Temperature (°C)	Water activity (decimal)	Variety (% d.b)		Mean
		Tabat	Wad Ahmed	
25	0.112	6.799^{h}	7.198^{g}	6.999^{p}
	0.227	10.921^{f}	11.024^{f}	10.977^{k}
	0.438	11.728^{d}	11.310^{e}	11.747^{j}
	0.643	15.559^{c}	15.655^{c}	15.607^{g}
	0.748	16.783^{b}	16.874^{b}	16.829^{d}
	0.865	19.785^{a}	19.735^{a}	19.747^{a}
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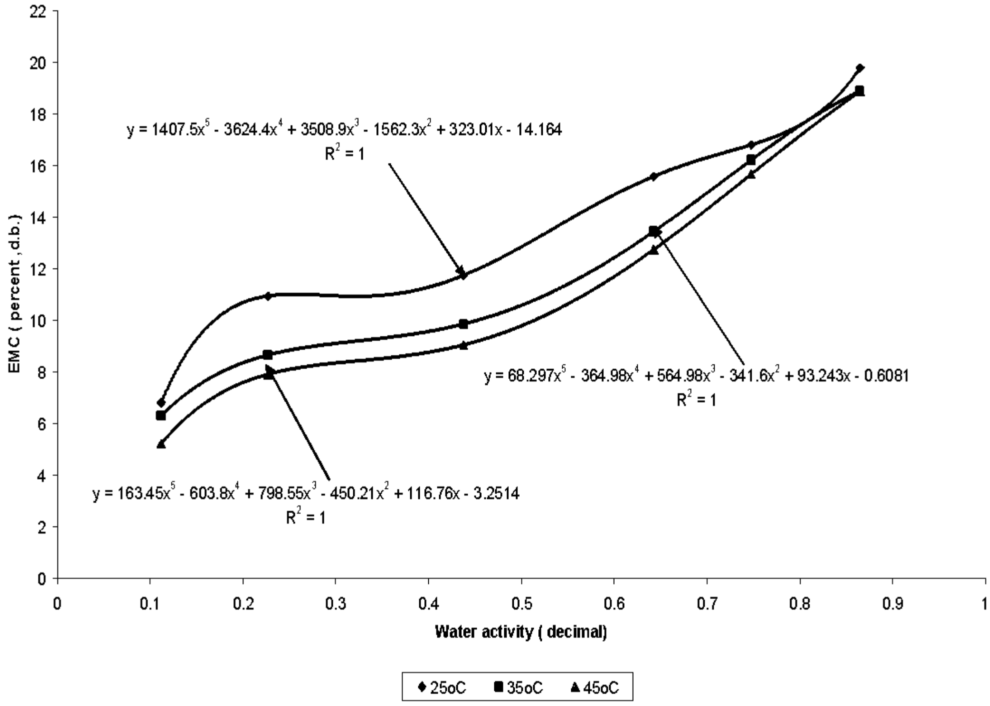

Fig 4.1 Adsorption isotherms of Tabat cultivar at three temperatures (25oC,35 oCand 45oC)

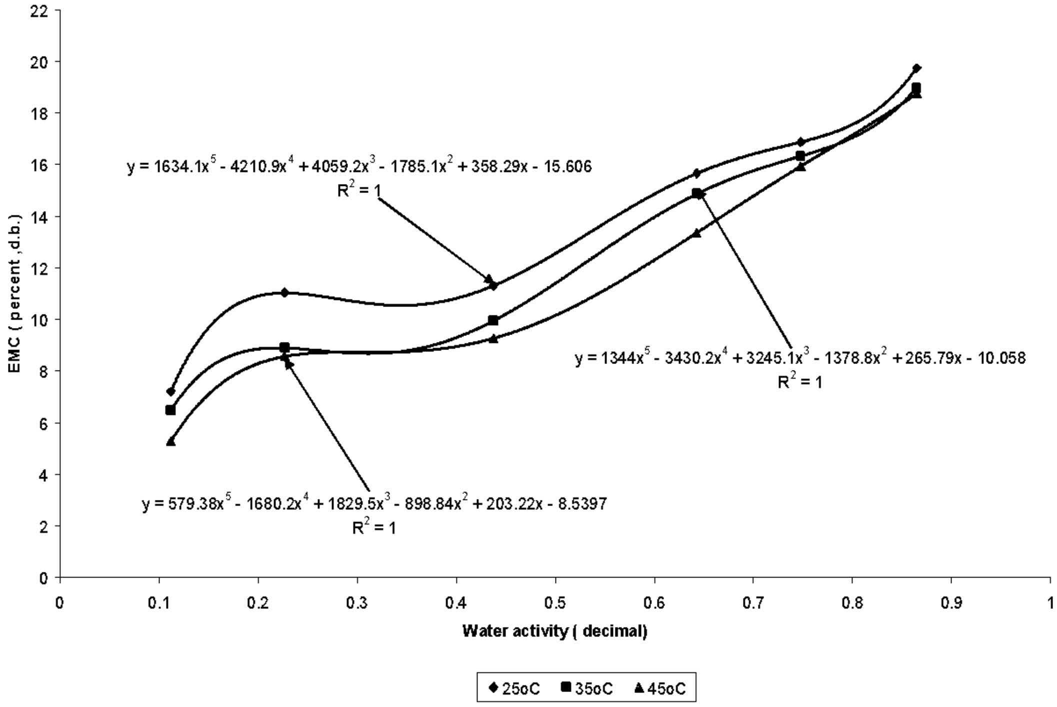

Fig 4.2 Adsorption isotherms of Wad Ahmad cultivar at temperatures (25oC,35oC and 45oC)

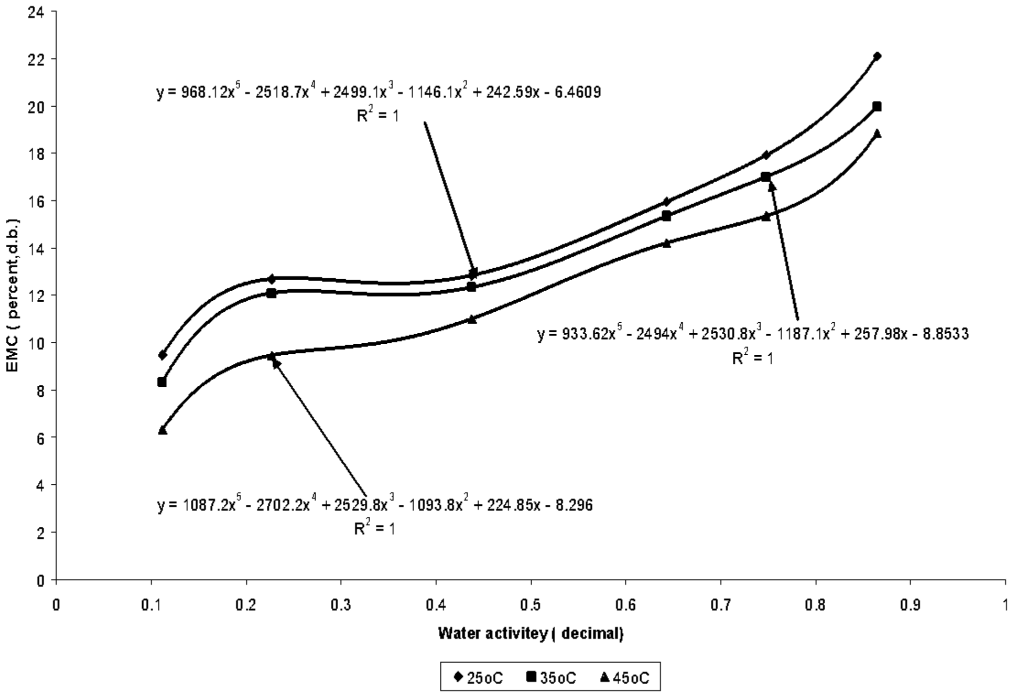

Fig 4.3 Desorption isotherms of Tabat cultivar at temperatures (25oC,35 oCand 45oC)

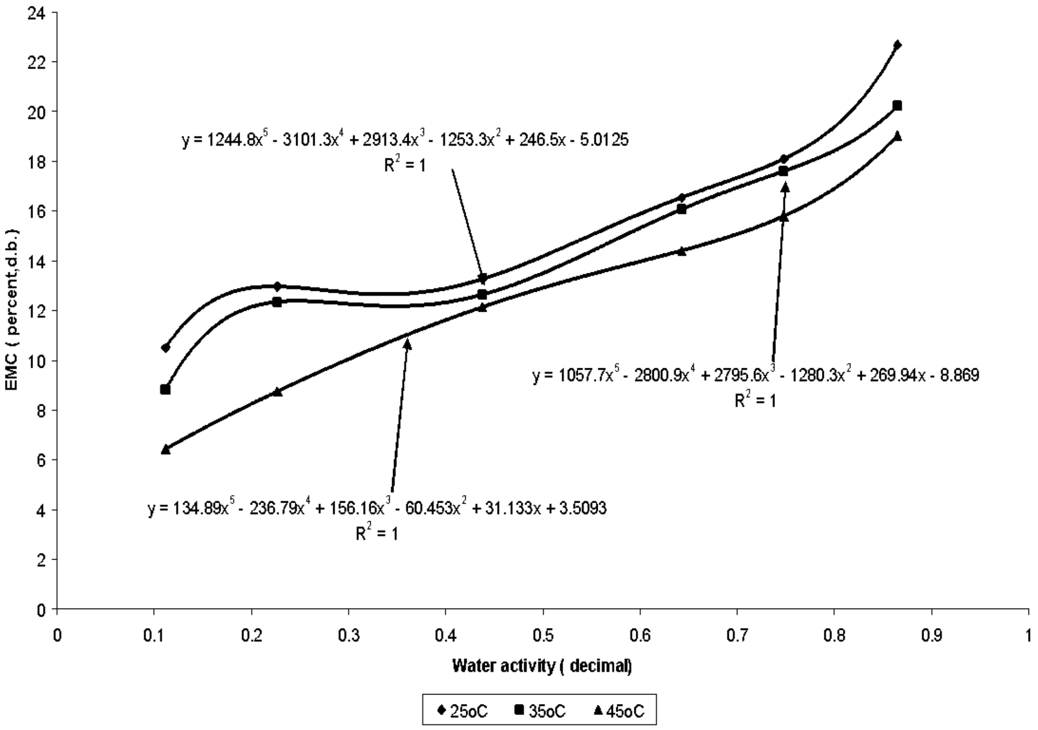

Fig 4.4 Desorption isotherms of Wad Ahmad cultivar at temperatures (25oC,35oC and 45oC)

VI. CONCLUSION

In the semi arid conditions of Sudan, the determination of moisture sorption isotherms at different temperatures and water activities to establish the correctly storage conditions for crops grains is highly needed. Wad Ahmed cultivar gave the highest values of adsorption and desorption equilibrium compared to Tabat cultivar at the same temperature and water activities. So, increasing temperature from 25°C to 45°C decreased the sorption isotherms at a constant water activity, while increasing water activities from 0.112 to 0.865 increased the sorption isotherms for both adsorption and desorption equilibrium at a constant temperature.

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