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EFFECTIVE THERMAL PROPERTIES OF PEANUT AS A FUNCTION OF MOISTURE CONTENT

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ABSTRACT

The study was carried out to determine thermal properties of peanut as a function of moisture content. The studied properties included specific heat, thermal conductivity and thermal diffusivity of pods, seeds and shells. The results showed that, the studied thermal properties increased with the increasing of moisture content for pods, seeds and shells. For peanut pods at moisture content ranged from 7.41 to 37.19% w.b, The specific heat was ranged from 2.291 to 2.404 kJ/kg.°K. While, it was ranged from 2.854 to 3.675 kJ/kg.°K for peanut seeds at moisture content ranged from 6.07 to 35.35% w.b. and from 1.612 to 2.012 kJ/kg.°K for peanut shells at moisture content ranged from 10.91 to 41.82% w.b.

The thermal conductivity was also ranged from 0.15 to 0.368 W/m.°K for peanut pods at moisture content ranged from 7.41 to 37.19% w.b. While, the corresponded values of thermal conductivity for seeds were ranged from 0.183 to 0.513 W/m.°K at moisture content ranged from 6.07 to 35.35% w.b. and it was ranged from 0.123 to 0.258 W/m.°K for shells at moisture content from 10.91 to 41.82% w.b.

Meanwhile, the thermal diffusivity was ranged from 2.8 * 10^{-4} to 5.4 * 10^{-4} m^2/s, from 1.1 * 10^{-4} to 2.7 * 10^{-4} m^2/s and from 1.2 * 10^{-3} to 1.8 * 10^{-3} m^2/s for peanut pods, seeds and shells at the similar levels of moisture content, respectively. Mathematical relationships were also developed to relate the change in specific heat, thermal conductivity and diffusivity with the change in moisture content of peanut pods, seeds and shells.

INTRODUCTION

Peanut is generally recognized as one of the most important oil crops in the world because peanut oil is considered one of the best for cooking because of its high smoke point (Zafar et al., 1997). In Egypt, peanut is an important economical crop in terms of human feeding and for different industrial aspects. The planted area of peanut in Egypt was 150767 feddan in 2001, which yielded 205066 tons with an average of 1.36 ton/feddan (Agricultural Statistics, 2006).

The main use of peanut is as a source of edible oil, but the high oil and protein contents also make it an important food crop. Peanut is a valuable source of E, K and B vitamins, it is the richest plant source of thiamin (B1), and also rich in niacin. About two-thirds of world peanut production is crushed for oil and the remaining one-third is consumed as food. The shells of peanut may be used to make a vast variety of non-food products such as in wallboard. Peanuts also are used as an ingredient in other products such as ink, shaving cream, shampoo and some medicines.

Arlington (2002) reported that, people eating peanuts and nuts two or more times per week had a 47% reduced risk of sudden cardiac death and a 30% reduced risk of coronary heart disease death, compared to those who rarely or never ate them.

The freshly harvested peanut pods have moisture content in the range of 40 % to 55 % wet basis (Sirvastava et al., 1982). Therefore, peanut drying is the most important processes before shelling and handling to consistently produce good quality peanuts

Thermal conductivity, thermal diffusivity and specific heat capacity are three important engineering properties of material related to heat transfer characteristics. These parameters are essential in studying heating, drying and cooling processes for agricultural material. Thermal conductivity, thermal diffusivity and specific heat capacity each can be measured by several well-established methods and measuring any two of them would lead to the third one (Yang et al., 2002).

Also, Irtwange and Igbeka (2002) reported that, most of processing operation for agricultural products involve the addition and removal of heat. Many gains and seeds are subjected to disposal of the consumer. The thermal process may include heating , cooling, drying and freezing. The rate of addition and removal of heat is determined by the thermal properties of the products. Measurement of thermal conductivity is therefore important owing to its application for processing and storage.

Specific heat capacity is one of the most important thermal properties of a material related to heat transfer characteristics. This parameter is essential in studying heating, drying and cooling processes for cereal seeds. (Yong et al., 2002).

The most common method reported in literature for specific heat determination of seeds and grain is the method of mixture. Some investigators have calculated the specific heat of grain from the experimental values of other thermal properties such as thermal conductivity and thermal diffusivity while others have made direct measurement of the specific heat.

Hwang and Haykawa (1979) reported the use of vacuum bottle calorimeter in measuring the specific heat of foods, while Lund (1983) described the differential scanning calorimeter (DSC).

Ezeike (1987) presented a technique for measuring the specific heat of agricultural products with a modified adiabatic drop calorimeter. Other workers who have used the method of mixture in determining the specific heat included, Matouk (1976); Tang et al. (1991) and yang et al. (1997).

Murata et al. (1987) measured the specific heat of wheat, rice, barley and Soya bean at grain moisture content ranged from 0 – 35% w.b. The results showed a linear increase of specific heat with grain moisture content, and a quadratic increase with grain temperature.

Aviara and Haque (2001) determined the values of specific heat and their variation with moisture content of Shea nut kernel. Specific heat was found to be both moisture and temperature dependent. Its value increased linearly with moisture content and temperature.

Yang et al. (2002) measured the specific heat of borage (Borago officinalis) seeds at temperature ranging from 6 to 20°C and moisture content from 1.2 to 30.3% (w.b.) using the differential scanning calorimetric procedure. The results showed that, specific heat was ranged from 0.77 to 1.99 kJ/kg.°K. He also developed a mathematical model for predicting the specific heat as a function of both moisture content and temperature.

On the other hand, different methods for measuring thermal conductivity and diffusivity of food and biological materials are described in literature by Mohesnin (1980), Nesvadba (1982) and Opoku et al. (2006). The heated probe method based on the line heat source as a non-steady stat method. It has become a commonly acceptable method to researches in determining the thermal conductivity and diffusivity of food and biological materials compared to the steady state methods, since it eliminates moisture loss and moisture migration within the material.

On the same time , the tests using steady-state method often require a long time to complete and moisture migration may introduce significant measurement errors. Mohsenin (1980), Dutta et al. (1988) reported that, the line source method is the most widely used transient-state method. This method uses either a bare wire or a thermal conductivity probe as a heating source, and estimates the thermal conductivity based on the relation between the sample core temperature and the heating time

Yang et al. (2002) determined thermal conductivity, and thermal diffusivity of borage seeds at temperature ranging from 6 to 20 °c and moisture content from 12 to 30.3% w.b, The thermal conductivity was measured by the transient technique using a line heat source. The thermal conductivity of borage seeds ranged from 0.11 to 0.28 w/m. °k and increased with moisture content in the range of 1.2-30.3% w.b. The thermal diffusivity ranged from $2.32\text{x}10^{-7}$ to $3.18\text{x}10^{-7}$ m^2/sec.

Jekendra et al. (1995) conducted a laboratory experiments to determine the thermal diffusivity of wheat, corn, soya bean and sesem at different levels of moisture content. The results show that, the thermal diffusivity of all studied crops decreased with the increase of moisture content.

The present study aims to determine the specific heat, thermal conductivity and thermal diffusivity for peanut pods, seeds and shells at different levels of moisture contents. Mathematical models relating the change specific heat, thermal conductivity and thermal diffusivity of pods, seeds and shells with moisture content were also developed.

MATERIALS AND METHODS

Materials

Peanut pods variety (Giza-5) were collected from the farmers in Ismailia governorate and the experimental work was conducted at the Agric. Eng. Dept., Fac. of Agric., Mansoura University. Unfilled pods and other impurities were discarded from the pods. The initial moisture content of the pods, seeds and shells was determined by the oven drying method at 130^o C for 6 h as recommended by (ASAE Standard, 2003). Seven desired moisture levels of peanut pods were obtained by adding calculated amounts of tap water to the pods thorough mixing in a grain conditioning apparatus for 72 hours. Structure detailed of the moisture conditioning apparatus has been given by Matouk et al. (2002) and shown in Fig. (1). The conditioned samples of pods moisture content were sealed in a separate polyethylene bag. The bags were stored in a refrigerator adjusted at temperature of - 5 ± 1º C to prevent moisture loss and fungal growth throughout the storage period. Before each test, the required quantities of peanut pods were taken out from the refrigerator and allowed to reach the normal room temperature. Sub-sample of peanut pods for each levels of moisture content were dehulled. Moisture content and bulk density of the peanut pods, seeds and shells were determined just before each test (table 1).

Table (1): Moisture content and bulk density for peanut pods, seeds and shells

Pods M.C, % w.b	Pods bulk density, kg/m^3	Seeds M.C, % w.b.	Seeds bulk density, kg/m^3	Shells M.C, % w.b.	Shells bulk density, kg/m^3
7.41	231.51	6.07	567.09	10.91	64.32
9.73	237.51	8.49	565.23	12.97	65.09
14.73	241.12	14.02	558.54	16.56	66.98
19.35	244.95	19.47	557.23	19.02	67.20
24.36	255.36	24.35	54877	24.94	67.91
28.30	271.55	29.07	535.39	26.30	69.18
37.19	281.76	35.35	524.76	41.82	71.31

Measuring Equipment

Specific heat apparatus

The method of mixture was used for determining the specific heat of peanut pods, seeds and shells at different levels of moisture content. This method based on determining the temperature change of the water contained in a calorimeter when a known quantity of tested materials is added to it at a known temperature after equilibrium state between the test material and water is attained.

The apparatus used for the experimental work (Fig. 2) was consists of the following items:

1- Calorimeter of an ordinary 1.5 litter thermos flask having an insulation added between the vacuum bottle and the outer metal walls of the container.
2- A water path for raising the sample temperature with a capacity of 15 litter and a temperature range of 0 – 120°C.
3- Glass tubes of 5 cm diameter and 20 cm length.
4- Zink balls of 99.99 % purity for determining the water equivalent of the calorimeter.
5- One point digital temperature meter for measuring the sample and the mixture temperature.

Thermal conductivity meter

A digital thermal conductivity meter (Fig. 3) provided with line heat source probe developed by Matouk et al. (2002) was used for determining the thermal conductivity of peanut pods, seeds and shells. The meter consists of the following parts:

F1+2

A- The meter probe

The meter probe consists of an aluminium tube 250 mm length, 4.7 mm inside diameter and 5.7 mm outside diameter, inside of which there was an axial constantan electrical resistance wire (0.03863 ohms/cm) insulated over its length and grounded to a steel tip at the lower end of the tube. The resistor leads were taken out through a seal at the upper as diagrammatically shown in Fig. (4)

B- Power supply circuit

A stabilized power supply circuit to provide a DC voltage at a range of 0-30 volts and a maximum current of 0.5 amps, or 0-15 volts at a maximum current of 1 amp. The electric power delivered by the power supply circuit was used for heating the constantan wire of the sensing probe.

C- Current control circuit and thermo-couple signal enlargement

The current of the power supply circuit was maintained constant through out the test period using voltage regulate and signal enlargement circuits. These circuits preciously enlarging the discharged volt 1000 times and remain it without any deflection.

D- Temperature measurement:

The temperature measurement was conducted using a digital measuring circuit connected to copper-constantan thermocouples (28-gauge) whose hot junctions were located within the tube of the meter probe. The electric potential of the thermocouples circuit was displayed as (°C) on the meter display.

Test Procedure and Measurements

Specific heat

The specific heat determination of pods, seeds, and shells was carried out at each level of moisture content by placing 50 g sample in glass test tubes (5cm diameter, 20cm length) and sealed with a rubber stopper. The thermometer probe was inserted through the center of the stopper into the tube to the middle of the tested sample and was used for temperature measurement. The glass test tubes were then heated by placing them vertically inside the water path at temperature of 50°C and it was left until reaching a constant final temperature. The sample was then rapidly transferred into the thermos flask which contained 80g water (the required amount to cover the sample) at room temperature and immediately sealed while allowing the temperature meter probe to pass inside it. The thermos flask and contents were then shaken for about 5 to 10 seconds to ensure that the sample and the water had mixed evenly.

The temperature of the sample-water mixture was recorded every second until reaching a final steady mixture temperature which usually take from 30–40 seconds. Three replicate of each test were made and the specific heat was taken as average of the three replicates.

It should be mentioned that, since the thermos flask is a composite of different materials (glass, metal and insulated material) it was preferable to determine the water equivalent, which is defined as the weight of water having a thermal capacity equal to that of the thermal flask.

F3+4

The water equivalent was determined experimentally using Zink balls with a known specific heat and applying the energy balance equation.

Heat lost by zink balls = heat gained by water + heat gained by thermo flask

$$m_z\ C_{pz}\ (t_{il} - t_{fz}) = m_W\ C_{pw}\ (t_{fw} - t_{iw}) + m_f\ C_{pf}\ (t_{ff} - t_{if})$$

Or

$$m_f\ C_{pf}\ (t_{ff} - t_{if}) = m_z\ C_{pz}\ (t_{il} - t_{fz}) - m_W\ C_{pw}\ (t_{fw} - t_{iw}) \ldots\ldots\ldots\ldots(1)$$

But for the same range of temperature

$$m_f\ C_{pf}\ (t_1 - t_2) = m_{eq}\ C_{pw}\ (t_1 - t_2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In which

$$m_{eq} = \frac{m_f\ C_{pf}}{C_{pw}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

m_{eq} = mass of water equivalent, kg.
m_z = mass of zink balls, kg
C_{pz} = specific heat of zink balls, kJ/kg.°K
t_{iz} = initial temperature of zink balls, °K
t_{fz} = final temperature of zink balls, °K
m_W = weight of water, kg
C_{pw} = specific heat of water, kJ/kg.°K
t_{iw} = initial temperature of water, °K
t_{fw} = final temperature of water, °K
m_f = total mass of the thermos flask, kg
C_{pf} = total specific heat of the thermos flask kJ/kg.°K
t_{if} = initial temperature of the thermos flask, °K
t_{ff} = final temperature of the thermos flask, °K

Equation (1) could be rewritten as:

$$C_{pg} = \frac{(m_w + m_{eq})\ (t_{wz} - t_w)\ C_{pw}}{m_z\ (t_{iz} - t_{wz})} \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where:

t_{wz} = equilibrium temperature between zink balls and water.

Knowing the specific heat of zink balls, the water equivalent was determined from equation (4).

The specific heat of the sample was then determined by modifying equation (4) to the form:

$$C_{pg} = \frac{(m_w + m_{eq})(t_{wg} - t_w)\ C_{pw}}{m_g\ (t_g - t_{wg})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where:

C_{pg} = specific heat of the sample kJ/kg.°K

t_{wg} = final sample-water temperature, °K
m_g = weight of sample, kg
t_g = initial sample temperature, °K

Thermal conductivity and diffusivity

The thermal conductivity of peanut pods, seeds and shells was determined at five different levels of moisture content.

The measuring procedure was dependent upon placing the sample in a hollow stainless-steel cylinder 300mm high and 150 mm in diameter. The sample was heated by inserting the thermal conductivity probe through the axis of the cylinder. The experimental procedure for the thermal conductivity determination may be summarized as follows:

1- The stainless-steel cylinder and the heating probe were enclosed inside a wooden box to avoid sample expose to a direct air stream. The whole apparatus was left to reach thermal equilibrium with the room temperature.
2- The electric current was connected to the heating element of the apparatus probe and maintained at 1.33 amp. Through the test period the heating current was adjusted when it was necessary using the current adjustment key of the apparatus.
3- The temperature of sample mass was measured before turning the current on by four thermo-couples placed at random inside the cylinder to ensure that the sample was at a uniform temperature.
4- Heating time was chosen as 10 minutes after the current was turned off. The temperature after 4 and 10 minutes were considered as the initial and final temperatures to be applied in the thermal conductivity equation.
5- Different sub-samples were used to avoid any possibility of properties changing due to heating. Five replicates for each test were conducted.

Theoretical analysis:

The theoretical analysis for determination of thermal conductivity was dependent upon the transit heat flow through an infinite mass initially at a uniform temperature heated by a line source of infinite length and constant strength. The basic equation which describes the heat flow from a line heat source is:

$$\frac{dT}{dt}=\alpha\left[\frac{d^2T}{dr^2}+\frac{1}{r}\times\frac{dT}{dr}\right] \quad \text{..............................} \ (6)$$

where:

T = temperature at radius r, °K
t = time, sec
r = radius from the heat source, m.
α = thermal diffusivity of the materials, m^2/sec.

The solution of equation (6) can be functioned to determine the thermal conductivity (k) according to Hooper and lapper cited by Matouk (1976) as:

$$k = \frac{Q}{4\pi (T_2 - T_1)} Ln(\frac{t_2}{t_1}) \quad \text{...(7)}$$

The term Q could be calculated as:

$$\mathbf{Q = I^2 R} \quad \text{.. (8)}$$

where:

T_1 = temperature at time t_1, °K
T_2 = temperature at time t_2, °K
I = current intensity, A
R= electrical resistance, Ω

The thermal conductivity was then calculated from the measured values of Q, T_1, T_2, t_1, t_2.

Thermal diffusivity

Thermal diffusivity of peanut pods, seeds and shells was calculated indirectly from the measured values of specific heat and bulk density as presented by Matouk et. al., 2004.

Equation relates the thermal diffusivity with these variables was as follows:

$$\alpha = \frac{k}{c_p \quad \rho} \quad \text{...(9)}$$

Where:

α = thermal diffusivity m^2/sec.
k = thermal conductivity, W/m.°K
C_p = specific heat kJ/kg.°K
ρ = bulk density of sample, kg/m^3

RESULTS AND DISCUSSION

1. Specific Heat

The effect of moisture content on specific heat of peanut pods, seeds and shells is shown in Fig. (5). As shown in the figure, the specific heat for peanut pods, seeds and shells increased with the increasing of moisture content. For peanut pods, the specific heat increased from 2.291 to 2.404 kJ/kg.°K as the moisture content increased from 7.41 to 37.19%. While it was increased from 2.854 to 3.675 kJ/kg.°K as the moisture content increased from 6.07 to 35.35% for seeds and from 1.612 to 2.012 kJ/kg.°K as the moisture content increased from 10.91 to 41.82% for shells. It can also seen from the figure that, the peanut seeds recorded the highest value of specific heat followed by peanut pods and shells. Meanwhile, a simple regression analysis was employed to relate the change in peanut pods, seeds and shells moisture content with the specific heat. The results of the analysis showed a linear positive relationship between the moisture content and the specific heat of pods, seeds and shells on the following form:

$$C = a + b\,Mc \quad \text{……………………………………} \quad (10)$$

Where:

C = specific heat, kJ/kg.°K
Mc = moisture content, % w.b.
a, b = constants

The regression parameters of Eq. 10 could be presented in table (2) as follows:

Table (2): Regression parameters of equations relating the change in moisture content with specific heat

Material	**M.C % w.b.**	**Regression parameters**		
		a	**b**	**R^2**
Pods	7.41 - 37.19	0.0236	2.8659	0.90
Seeds	6.07 - 35.35	0.0037	2.2719	0.97
Shells	10.91 - 41.82	0.0129	1.4934	0.97

2. Thermal Conductivity

Thermal conductivity was increased with the increasing of moisture content for pods, seeds and shells. As shown in Fig. (6), thermal conductivity of peanut pods increased from 0.15 to 0.368 W/m.°K with the increasing of moisture content from 7.41 to 37.19%, and it was increased from 0.183 to 0.513 W/m.°K as the moisture content increased from 6.07 to 35.35% for seeds. On the same time, peanut shells recorded the lowest thermal conductivity which increased from 0.123 to 0.258 W/m.°K with the increase of shells moisture content from 10.91to 41.82% w.b.

3. Thermal Diffusivity

Thermal diffusivity of peanut pods, seeds and shells was calculated for the samples after determining the bulk density of each component at loosely fill condition. Thermal diffusivity was increased with the increasing of moisture content for pods, seeds and shells. As shown in Fig. (7), for peanut pods, thermal diffusivity increased from $2.8 * 10^{-4}$ to $5.4 * 10^{-4}$ m^2/s as the moisture content increased from 7.41 to 37.19% w.b., and it was increased from $1.2 * 10^{-3}$ to $1.8 * 10^{-4}$ m^2/s as the moisture content increased from 10.91 to 41.82% w.b. for peanut shells. While peanut seeds recorded the lowest thermal diffusivity which increased from $1.1 * 10^{-4}$ to $2.7 * 10^{-4}$ m^2/s with the increasing of seeds moisture content from 6.07 to 35.35% w.b. The above mentioned results revealed that, the thermal diffusivity of peanut pods, seeds and shells depends upon the combined effects of thermal conductivity (k), bulk density (γ) and specific heat (C_{pg}). To relate the change in thermal conductivity and thermal diffusivity with the change in moisture content, a regression analysis was also employed.

F5+6+7

The results of analysis showed that both thermal conductivity and thermal diffusivity are linearly dependent upon moisture content. The obtained regression equations relating the change in thermal conductivity and moisture content are on the form of:

$$k = a + b\ Mc \qquad (11)$$

While:

The equations relating the change in thermal diffusivity with moisture content are on the form of:

$$\alpha = a + b\ Mc \qquad (12)$$

where:

k = thermal conductivity W/m.°K
α = thermal diffusivity m^2/s
a,b and c, = constants.

The regression parameters of Eq. (11) and (12) are presented in tables (3 and 4) as follows:

Table (3): Regression parameters of equations relating the change in moisture content with thermal conductivity

Material	M.C % w.b.	Regression parameters		
		a	b	R^2
Pods	7.41 - 37.19	0.0106	0.1065	0.95
Seeds	6.07 - 35.35	0.0078	0.0871	0.98
Shells	10.91 - 41.82	0.0041	0.0931	0.89

Table (4): Regression parameters of equations relating the change in moisture content with thermal diffusivity

Material	M.C % w.b.	Regression parameters		
		a	b	R^2
Pods	7.41 - 37.19	$2x10^{-5}$	0.0011	0.94
Seeds	6.07 - 35.35	$9x10^{-6}$	0.0002	0.96
Shells	10.91 - 41.82	$5x10^{-5}$	$7x10^{-5}$	0.92

CONCLUSIONS

1- Specific heat, thermal conductivity and thermal diffusivity of peanut pods, seeds and shells were linearly increase with the increasing of moisture content.

2- The specific heat for different component of peanut it was ranged from 2.291 to 2.404 kJ/kg.°K for pods, 2.854 to 3.675 kJ/kg.°K for seeds, 1.612 to 2.012 kJ/kg.°K for shells.

3-The thermal conductivity of peanut pods ranged from 0.15 to 0.368 W/m.°K for pods, from 0.183 to 0.513 W/m.°K for seeds and from 0.123 to 0.258 W/m.°K for shells.

4-The thermal diffusivity of peanut pods ranged from $2.8 * 10^{-4}$ to $5.4 * 10^{-4}$ m^2/s for pods, from $1.1* 10^{-4}$ to $0.002.7 * 10^{-4}$ m^2/s for seeds and from $1.2 * 10^{-3}$ to $1.8 * 10^{-3}$ m^2/s for shells.

5- The regression analysis relating the change in moisture content with the change in specific heat, thermal conductivity and thermal diffusivity of pods, seeds and shells showed a linear simple relationship for all studied properties.

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الخواص الحرارية للفول السودانى كدالة للتغير فى المحتوى الرطوبى

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يحتل محصول الفول السودانى المرتبة الثالثة عالميا كمحصول زيتى بعد فول الصويا والقطن حيث تبلغ المساحة المنزرعة منه حوالى22023 مليون هيكتار (هيكتار = 10000 م^2) تنتج حوالى 39.22 مليون طن من القرون. يزرع الفول السودانى أساسا كمصدر للزيت وتبلغ نسبة الفول السودانى الذى يستخدم فى إنتاج الزيوت نحو الثلثين ويستخدم الثلث الباقى كغذاء نظرا لمحتواه العالى من الزيوت والبروتين وبالتالى فان ذلك يجعله محصول غذائى هام أيضا. وعادة يقلع نبات الفول السودانى من الأرض عند محتوى رطوبى مرتفع يتراوح من 40 إلى 50% ثم ينشر على الأرض للتجفيف لفترة زمنية قد تصل إلى أسبوعيين. وهذه فترة زمنية كبيرة مما يعرضه لمخاطر كثيرة مثل الإصابة بالفطريات والأفلاتوكسين لذلك ظهرت أهمية عملية تجفيف الفول السودانى قبل التقشير والتداول بغرض إنتاج حبوب عالية الجودة.

أجريت هذه الدراسة لتعيين الحرارة النوعية و معاملي التوصيل والإنتشار الحراري لقرون وحبوب وقشر الفول السودانى عند سبع محتويات رطوبية مختلفة. أظهرت النتائج زيادة قيم الحرارة النوعية بزيادة المحتوى الرطوبي للقرون والحبوب والقشر. وتراوحت قيم الحرارة النوعية بين 2.291 – 2.404 كيلوجول / كجم.كلفن° للقرون, 2.854 – 3.675 كيلوجول / كجم. كلفن° للبذور, 1.612 – 2.012 كيلوجول / كجم. كلفن ° للقشر.

كما زادت ايضا قيم كلا من معامل التوصيل الحراري والإنتشار الحراري بزيادة المحتوي الرطوبي، حيث تراوحت قيم معامل التوصيل الحراري بين 0.15 – 0.368 وات / م. كلفن°، 0.183- 0.513 وات / م. كلفن° ، 0.123- 0.258 وات/م. كلفن° للقرون والحبوب والقشر علي التوالي.

بينما تراوحت قيم معامل الانتشار الحراري بين 2.83×10^{-4} – 5.4×10^{-4} م^2/ث ، 1.1×10^{-4} – 2.7×10^{-4} م^2/ث ، 1.2×10^{-3} – 1.8×10^{-3} م^2/ث للقرون والحبوب والقشر علي التوالي.

تم أيضا إيجاد علاقات رياضية تربط بين التغير في المحتوى الرطوبي وقيم الحرارة النوعية ومعامل التوصيل الحراري ومعامل الإنتشار الحراري حيث كانت العلاقة خطية و يمكن تمثيلها بالمعادلة $y = a + bx$