Thermal Properties of some Legume Seeds
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ABSTRACT

Specific heat, thermal conductivity and thermal diffusivity of three various varieties of faba bean (Giza 716, Giza 843 and Giza 3 mohsen) and three different varieties of lentil (Sina 1, Giza 9 and Giza 370) were determined as a function of moisture content and temperature. The specific heat and thermal conductivity were measured using the methods of mixture and transient state heat transfer. The experiments of work were done at five levels of seeds moisture content % (w. b.) and five temperature levels [40, 50, 60, 70 and 80°C] with 3 repetitions. The thermal diffusivity was calculated from measured specific heat, thermal conductivity and bulk density. Specific heat of faba bean seeds varieties (Giza 716, Giza 843) and (Giza 3 mohsen) and lentil seeds varieties (Sina 1, Giza 9 and Giza 370) were increased with the increase of moisture content and decreased with the increase of temperature. The thermal conductivity and thermal diffusivity of faba bean seeds increased with the increase of temperature and also with the increase of moisture content. The volumetric heat transfer coefficient was increased as the mass air flow rate and air temperature increased. Regression equations that could be used to express the relationship between thermal properties, moisture content and temperature were also presented.

Keywords: Thermal properties, Faba bean & lentil seeds, Specific heat, Thermal conductivity, Thermal diffusivity, heat transfer coefficient.

INTRODUCTION

Legumes are consumed as a high source of protein, mainly in the Middle East, replaced the expensive animal proteins, (Gharibzahedi et al., 2014). Faba bean (Vicia faba L.) is a major leguminous crop that grown in Egypt; it is an essential source of protein for human and animal consumption, (Abdellatif et al., 2012).

lentil (Lens culinaris Medik.) is an important traditional diet in developing countries like Egypt. Lentils are an excellent source of vitamins, energy, proteins, mineral elements, and carbohydrates, (Gharibzahedi et al., 2014). The main dimensions, density and bulk density and volume as some of physical and thermal properties is important in design machines and equipment can be used in harvesting, post harvesting and processing fields.

Many studies considered that temperatures and moisture contents is the most thermal properties effect on biological materials, Aviara et al., (2008) for guna seed; Jangi et al., (2011) for barley grains and Azadbakht et al., (2013) for soybean Pod. Moisture content in cereal material specific heat although this has been generally ignored in the early work with grains, (Tang et al., 1991). The linear relation is the best fit curve to describe specific heat expressed moisture content, (Mohsenin, 1980).

Temperature has an important effect on the organic material specific heat although this has been generally ignored in the early work with grains, (Tang et al., 1991).

The objective of this research work was to determine thermal properties of some varieties of faba bean and lentil seeds as a function of moisture content and temperature. The tested properties included thermal conductivity, specific heat and thermal diffusivity.

MATERIALS AND METHODS

Sample Preparation

The seeds of faba bean and lentil used in this study were obtained from the Agricultural Research Center (ARC), to ensure the purity of the selected varieties. The seeds were cleaned and sorted so that foreign matter, broken and immature seeds were removed. The initial moisture content was determined by drying the faba bean seeds samples in an electric oven at (103 °C) for 72 h.

and lentil seeds at (105°C) for 24 h which described by (ASAE, 2000c) and (ASAE, 1987) and then kept in a desiccator at the room temperature.

To achieve the favorite moisture levels for the studied, samples a calculated amount of water was added to the moisture conditioning unit using the following equation (Balasubramanian, 2001).

\[ Q = \frac{W_f (M_f - M_i)}{100 - M_i} \]

Where: Q is the mass of water to be added in kg; W_f is the initial moisture content of the sample % (w. b.), and M_f is the final moisture content % (w. b.).

Bulk density (ρ_b):
The bulk density (ρ) of faba bean and lentil seeds varieties were determined by filling a container with sample from a height of 150mm at a constant rate and weighing the contents. The volume of the container was estimated by filling the container with water and measuring it with 80ml measuring cylinder as recommended by (Matouk et al., 2004 b). The bulk density was determined as the ratio between the mass of sample and its total volume.

Bulk density was calculated as shown in equation

\[ \text{Bulk density} = \frac{W}{V_b} \]

Where: W =Weight of seeds bulk, kg.,
V_b = Volume of seeds bulk, m³.

Specific Heat (Cp):
The specific heat of samples was determined using a copper calorimeter placed inside a flask in the method of mixtures as described by Ogunjimi et al., (2002) and Matouk et al., (2006c). A sample of known weight and temperature was poured into the calorimeter containing water of known weight and temperature. The mixture was stirred with a copper stirrer until the equilibrium condition was attained. The final temperature was noted and the specific heat of the sample crops was calculated using the following equation.

\[ C_p = \frac{W_w + W_{eq} (T_w - T_f)}{5P_w} \]

Where: Weq is the water equivalent (Kg), Ww is the sample of mass (Kg), Ww is the mass of water (Kg), Cpg is the specific heat of the sample (J. Kg⁻¹°C⁻¹),
Cpw is the specific heat of water (J. Kg⁻¹°C⁻¹), Tg is the initial temperature of the sample °C and Tw is the initial temperature of Water °C.
Thermal Conductivity (K):
A thermal conductivity meter with heating probe which was used to determine the thermal conductivity of the seeds bulk (k), fig. (1). The thermal conductivity of the studied crops was determined using a line heat source method as the most commonly used transient-state heat transfer method. For an infinitely long line heater in an infinite, homogeneous, and isotropic medium the temperature rises at a radial distance (r) from the line, heat source can be represented by the following equation:

$$k = \frac{Q}{4\pi \alpha r^2} \ln \frac{T_2}{T_1} \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (4)$$

According to (Matouk, et al., 2006a)

Where:
- k = thermal conductivity (W.m⁻¹°C⁻¹), Q = heat input (W),
- T = temperature (°C), ∆T = T₂ - T₁,
- T₂ = seeds temperature at time t₂ (°C),
- T₁ = seeds temperature at time t₁ (°C),
- t₁ = time at (600 sec.) and t₂ = time at (240 sec.).

**RESULTS AND DISCUSSION**

**Bulk density of seeds:**
The experimental results of the bulk density for faba bean and lentil seeds varieties at different levels of moisture content are presented in fig. (2). As shown in the figure, the bulk density of faba bean varieties (Giza 716), (Giza 843) and (Giza 3 mohsen) were decreased from 763.6 to 706 kg.m⁻³, 763.5 to 696.4 kg.m⁻³ and 775.9 to 0.727.4 kg.m⁻³ with the increasing of moisture content from 11.67 to 23.52, 11.73 to 24.17 and 11.72 to 23.9 % (w. b.), respectively. Meanwhile, the bulk density of lentil varieties (Sina 1, Giza 9, Giza 370) were decreased from 882.6 to 790.3, 911.6 to 799.9 and 897.8 to 785.9 kg.m⁻³, with the increasing of moisture content from 10.44 to 24.72, 10.63 to 24.59 and 10.54 to 24.6 % (w. b.), respectively. The decrease in bulk density for the studied varieties may be due the increase in mass resulting from the increasing in moisture of seeds in a rate lower than the accompanying volumetric expansion of the seeds bulk. Similar results were obtained by Pradhan et al., (2008) for corn. A simple regression analysis was processed to assess the relationship existing between bulk density and seeds moisture content. The following regression equations was obtained:

$$B_d = a e^{-b x} \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (7)$$

Where: B_d = Bulk density, (kg. m⁻³), and a and b= constants.

**Specific Heat:**
The specific heat of faba bean and lentil seeds increased linearly with the increase of moisture content and decreased with the increase of temperature. These results are similar to the results reported by staple, (Arku, et al., 2012).
For faba bean seeds varieties (Giza 716, Giza 843 and Giza 3 mohsen) at seeds temperature of 40°C, the specific heat increased from (3.1218 to 3.5088 kJ.kg⁻¹°C⁻¹), (3.1017 to 3.5304 kJ.kg⁻¹°C⁻¹) and (3.0157 to 3.427 kJ.kg⁻¹°C⁻¹) as the moisture content increased from 11.67 to 23.52, 11.73 to 24.17 and 11.72 to 23.90 % (w. b.), respectively. While, the corresponding values at seeds temperature of 80°C were increased from (2.5619 to 2.7631 kJ.kg⁻¹°C⁻¹), (2.515 to 2.8052 kJ.kg⁻¹°C⁻¹) and (2.547 to 2.7947 kJ.kg⁻¹°C⁻¹), respectively. The variation of specific heat of faba bean seeds varieties with moisture content at different temperature levels is shown in Fig. (3).

For variety (Giza 716),
\[ C_{pg} = 3.4545 + 0.0278 (M.C.) - 0.0169 (Tg) \]… (8)
\( R^2 = 0.9438, \text{S.E.} = 0.0696 \)

For variety (Giza 843),
\[ C_{pg} = 3.4372 + 0.02586 (M.C.) - 0.0154(Tg) \]… (9)
\( R^2 = 0.9792, \text{S.E.} = 0.0382 \)

For variety (Giza 3 mohsen),
\[ C_{pg} = 3.1171 + 0.02661(M.C.) - 0.0143(Tg) \]… (10)
\( R^2 = 0.9637, \text{S.E.} = 0.0483 \)

For lentil seeds varieties (Sina 1, Giza 9, Giza 370) at seeds temperature of 40°C, the specific heat increased from 2.4057 to 2.7056 kJ.kg⁻¹°C⁻¹, 2.423 to 2.8012 kJ.kg⁻¹°C⁻¹ and 2.3569 to 2.7193 kJ.kg⁻¹°C⁻¹ as the moisture content increased from 10.44 to 24.72, 10.63 to 24.59 and 10.54 to 24.6 % (w. b.), respectively. While, the corresponding values at seeds temperature of 80°C were increased from 1.9564 to 2.4222 kJ.kg⁻¹°C⁻¹, 1.8722 to 2.465 kJ.kg⁻¹°C⁻¹ and 2.0655 to 2.3615 kJ.kg⁻¹°C⁻¹, respectively. The variation of specific heat of lentil varieties seeds with moisture content at different temperature levels is shown in Fig. (4).

Fig. 3. Effect moisture content on specific heat of faba bean seeds varieties at different temperature levels.

The specific heat of faba bean seeds was related to seeds moisture content and temperature by the following multiple regression equations:

Fig. 4. Effect moisture content on specific heat of lentil varieties seeds at different temperature levels.
Multiple regression analysis relating the specific heat of lentil seeds with the moisture content and temperature were fitted to the experimental data. The obtained relationships could be represented as follow:

For variety (Sina1),

\[ C_{pg} = 2.4038 + 0.02592(M.C.) - 0.00914(T_g) \quad (11) \]

\( R^2 = 0.9799, \text{S.E.} = 0.0287 \)

For variety (Giza 9),

\[ C_{pg} = 2.4865 + 0.0331(M.C.) - 0.0111(T_g) \quad (12) \]

\( R^2 = 0.9829, \text{S.E.} = 0.0326 \)

For variety (Giza 370),

\[ C_{pg} = 2.3356 + 0.0277(M.C.) - 0.0071(T_g) \quad (13) \]

\( R^2 = 0.9711, \text{S.E.} = 0.0316 \)

Thermal conductivity

In general, thermal conductivity increased linearly with the increasing of moisture content for both studied crops. Variation of thermal conductivity with moisture content is depicted in Fig. (5). For faba bean seeds (Giza 716, Giza 843 and Giza 3 mohsen), the thermal conductivity increased from 0.223 to 0.3259 W.m\(^{-1}\).°C\(^{-1}\), 0.2266 to 0.3053 W.m\(^{-1}\).°C\(^{-1}\) and 0.2576 to 0.3390 W.m\(^{-1}\).°C\(^{-1}\), respectively as the moisture content increased from 11.67 to 23.52, 11.73 to 24.17 and 11.72 to 23.9% (w. b.). However, for lentil seeds (Sina 1, Giza 9, Giza 370), the thermal conductivity increased from 0.2356 to 0.3198 W.m\(^{-1}\).°C\(^{-1}\), 0.2291 to 0.3259 W.m\(^{-1}\).°C\(^{-1}\) and 0.2387 to 0.3328 W.m\(^{-1}\).°C\(^{-1}\), respectively with the increasing of moisture content from 10.44 to 24.72; 10.63 to 24.59 and 10.54 to 24.6% (w. b.) and temperature from 40 to 80 °C, respectively.

Also, the increasing of thermal diffusivity with moisture content and temperature exhibited positive linear relationships. Thermal diffusivity of faba bean seeds (Giza 716), (Giza 843) and (Giza 3 mohsen) increased from 0.935 \(\times 10^{-4}\) to 1.35 \(\times 10^{-4}\) m\(^2\).s\(^{-1}\), 0.957 \(\times 10^{-4}\) to 1.24 \(\times 10^{-4}\) m\(^2\).s\(^{-1}\) and 1.1 \(\times 10^{-4}\) to 1.36 \(\times 10^{-4}\) m\(^2\).s\(^{-1}\), respectively with the increasing of moisture content from 11.67 to 23.52, 11.73 to 24.17 and 11.72 to 23.9% (w. b.) at seeds temperature of 40°C, respectively. While, the corresponding values at seeds temperature of 80°C were increased from 1.14 \(\times 10^{-4}\) to 1.67 \(\times 10^{-4}\) m\(^2\).s\(^{-1}\), 1.18 \(\times 10^{-4}\) to 1.56 \(\times 10^{-4}\) m\(^2\).s\(^{-1}\) and 1.3 \(\times 10^{-4}\) to 1.67 \(\times 10^{-4}\) m\(^2\).s\(^{-1}\), respectively as presented in Fig. (6).

Thermal diffusivity

Thermal diffusivity of seeds varieties was increased with the increasing of moisture content and temperature.

Multiple regression analysis relating the thermal diffusivity of faba bean seeds with moisture content (M.C.) and seeds temperature (Tg) were fitted to the experimental data and the following equations were obtained:

For variety (Giza 716),

\[ \alpha = 1.9998 \times 10^{-3} + 3.7039\times10^{-4}(M.C.) + 0.738\times10^{-5}(T_g) \quad (15) \]

\( R^2 = 0.9708, \text{S.E.} = 3.5010 \times 10^{-6} \)

For variety (Giza 843),

\[ \alpha = 3.45 \times 10^{-2} + 2.85 \times 10^{-3}(M.C.) + 6.44 \times 10^{-5}(T_g) \quad (16) \]

\( R^2 = 0.9550, \text{S.E.} = 3.59 \times 10^{-6} \)

For variety Giza (3 mohsen),

\[ \alpha = 5.49 \times 10^{-3} + 2.39 \times 10^{-5}(M.C.) + 6.6 \times 10^{-7}(T_g) \quad (17) \]

\( R^2 = 0.9524, \text{S.E.} = 3.34 \times 10^{-6} \)

Where: \( \alpha \) is the thermal diffusivity, (m\(^2\).s\(^{-1}\)).

Fig. 5. Thermal conductivity of faba bean and faba bean seeds varieties as a function of moisture content.

The obtained equation relating thermal conductivity of faba bean seeds with moisture content could be presented as follows:

\[ K = b + c(M.C.) \quad (14) \]

Where:

\( K \) is the thermal conductivity, (W.m\(^{-1}\).°C\(^{-1}\)), and \( b \) and \( c \) are constants.

Fig. 6. Effect of moisture content on thermal diffusivity of faba bean seeds varieties at different temperature levels.
For lentil seeds (Sina 1), (Giza 9) and (Giza 370) at seeds temperature of 40 °C, thermal diffusivity increased linearly from $1.11 \times 10^{-4}$ to $1.50 \times 10^{-4}$ m$^2$. s$^{-1}$; $1.04 \times 10^{-4}$ to $1.45 \times 10^{-4}$ m$^2$. s$^{-1}$ and $1.13 \times 10^{-4}$ to $1.56 \times 10^{-4}$ m$^2$. s$^{-1}$ with the increasing of moisture content from 10.44 to 24.72; 10.63 to 24.59 and 10.54 to 24.6% (w. b.), respectively. While, the corresponding values at seeds temperature of 80 °C were increased from $1.36 \times 10^{-4}$ to $1.67 \times 10^{-4}$ m$^2$. s$^{-1}$; $1.32 \times 10^{-4}$ to $1.65 \times 10^{-4}$ m$^2$. s$^{-1}$ and $1.29 \times 10^{-4}$ to $1.79 \times 10^{-4}$ m$^2$. s$^{-1}$, respectively as presented in Fig. (6).

**Volumetric heat transfer coefficient**

The volumetric heat transfer coefficient was increased as the mass air flow rate and air temperature increased. The measured values of the volumetric heat transfer coefficient of faba beans seeds varieties (Giza 716, Giza 843 and Giza 3 mohsen) were increased from 8810.33 to 12199 W/m$^3$. °K, 9699.48 to 13372.8 W/m$^3$. °K, and 8300.02 to 13394 W/m$^3$. °K, respectively as the mass air flow rate increased from 0.0035 to 0.0087 Kg / m$^2$. s at seeds temperature of 40 °C. While, the corresponding values at seeds temperature of 80 °C were increased from 15603 to 19488.6 W/m$^3$. °K, 14238.6 to 18312.4 W/m$^3$. °K, and 14423.4 to 17861 W/m$^3$. °K, respectively.

Multiple regression models relating the thermal diffusivity of lentil seeds with moisture content (M.C.) and seeds temperature (Tg) were fitted to the experimental data and the following equations were obtained:

For variety (Sina 1),

$$\theta = 6.76 \times 10^{-5} + 2.51 \times 10^{-4} \text{(M.C.)} + 5.44 \times 10^{-7} \text{(Tg)}$$  \hspace{1cm} (18)

($R^2 = 0.9409, \text{S.E.} = 4.1 \times 10^{-6}$).

For variety (Giza 9),

$$\theta = 5.57 \times 10^{-5} + 2.49 \times 10^{-4} \text{(M.C.)} + 6.36 \times 10^{-7} \text{(Tg)}$$  \hspace{1cm} (19)

($R^2 = 0.9679, \text{S.E.} = 3.02 \times 10^{-6}$).

For variety (Giza 370),

$$\theta = 6.44 \times 10^{-5} + 2.99 \times 10^{-4} \text{(M.C.)} + 4.2 \times 10^{-7} \text{(Tg)}$$  \hspace{1cm} (20)

($R^2 = 0.9789, \text{S.E.} = 2.6 \times 10^{-6}$).

Meanwhile, the measured values of the volumetric heat transfer coefficient of lentil seeds varieties (Sina1, Giza 9 and Giza 370) were increased from 9114.88 to 13103.1 W/m$^3$. °K, 7543.11 to 11045.8 W/m$^3$. °K, and 9778.11 to 15781.2 W/m$^3$. °K, respectively as the mass air flow rate increased from 0.0035 to 0.0087 Kg / m$^2$. s at seeds temperature of 40 °C. The corresponding values at seeds temperature of 80 °C were increased from 13204.9 to 18312.4 W/m$^3$. °K, respectively.
16152.8 W/m$^3$. °K, 12624.4 to 17954.9 W/m$^3$. °K, and 14085.9 to 18571.6 W/m$^3$. °K, respectively.

2. Thermal conductivity increased linearly with the increasing of moisture content for both studied crops. The thermal conductivity increased from 0.223 to 0.3259 W.m$^{-1}$. °C$^{-1}$, 0.2266 to 0.3053 W.m$^{-1}$. °C$^{-1}$ and 0.2576 to 0.3390 W.m$^{-1}$. °C$^{-1}$, respectively for faba bean seeds varieties (Giza 716, Giza 843 and Giza 3 mohsen). While, it was increased from 0.3356 to 0.3198 W.m$^{-1}$. °C$^{-1}$, 0.2291 to 0.3259 W.m$^{-1}$. °C$^{-1}$ and 0.2387 to 0.3328 W.m$^{-1}$. °C$^{-1}$ for lentil seeds varieties (Sina 1, Giza 9, Giza 370), respectively.

3. Thermal diffusivity of seeds varieties was increased with the increasing of moisture content and temperature. Also, the increasing of thermal diffusivity with moisture content and temperature exhibited positive linear relationships. Thermal diffusivity of faba bean seeds varieties (Giza 716, Giza 843 and Giza 3 mohsen), ranged from 0.935 ×10$^{-4}$ to 1.67 ×10$^{-4}$ m$^2$. S$^{-1}$; 0.957×10$^{-4}$ to 1.56 ×10$^{-4}$ m$^2$. S$^{-1}$ and 1.1 ×10$^{-4}$ to 1.67×10$^{-4}$ m$^2$. S$^{-1}$, respectively at seeds temperature 40 to 80 °C. While, it was ranged from 1.11 ×10$^{-4}$ to 1.67 ×10$^{-4}$ m$^2$. S$^{-1}$; 1.04×10$^{-4}$ to 1.65×10$^{-4}$ m$^2$. S$^{-1}$ and 1.13 ×10$^{-4}$ to 1.79 ×10$^{-4}$ m$^2$. S$^{-1}$ for lentil seeds varieties (Sina 1, Giza 9 and Giza 370), respectively.

4. The volumetric heat transfer coefficient was increased as the mass air flow rate and air temperature increased. The volumetric heat transfer coefficient of faba bean seeds varieties (Giza 716, Giza 843 and Giza 3 mohsen) were ranged from 8810.33 to 19488.6 W/m$^3$. °K; 9699.48 to 18312.4 W/m$^3$. °K and 8300.02 to 17861 W/m$^3$. °K, respectively. While, it was ranged from 9114.88 to 16152.8 W/m$^3$. °K, 7543.11 to 15287 W/m$^3$. °K, and 9778.11 to 18571.6 W/m$^3$. °K, for lentil seeds varieties (Sina 1, Giza 9 and Giza 370), respectively.

REFERENCES


الخصائص الحرارية لبعض المحاصيل البقولية

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2 فسم هندسة التصنيع والتكنولوجيا - معهد بحوث الهندسة الزراعية.

تم إجراء هذا البحث في معمل هندسة تصنيع وتداول المحاصيل الزراعية بقسم الهندسة الزراعية والعناصر المستخدمة لحساب معدل المحصول عليها من قسم المحاصيل البقولية بمركز 밝وح الزراعية بالقاهرة بهدف دراسة التأثير في المحصول الثقافي في الحالة الهواية للمحاصيل البقولية، واستفادت هذين المحاصيل البقولية. وGTKA المحمولة من مدرسة الفينيكس، وقد تم تحليل الأداء والخصائص الحرارية للزراعة باستخدام الأنشطة الحرارية، ودرجة العرية في الزراعة، حيث تكون على النتائج. 1. حذف الزراعة النموذجية لبذر القول البذور والعديد من زراعة المحصول البقي، بينما خفضت مع زيادة درجة الحرارة وتزايد المحمولة والشرب، حيث وزوّزت لون أكسيد من 2.56 إلى 3.58 وكم 4.98 كجم / كجم درجة مئوية التحويل بالذات، إلى 14.34 كجم / كجم درجة مئوية التحويل بالذات (2.716 مجم، 10 مجم / كجم 1.34 مجم، 1.5 مجم / كجم 1.28 مجم / كجم 1.4 مجم / كجم 1.34 مجم / كجم 1.5 مجم / كجم 1.28 مجم / كجم 1.4 مجم).