Determination of Physical Properties of some Legume Crops
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ABSTRACT

Physical properties such as principal dimensions, surface area, projected area, volume, mass of 1000 seeds, true and bulk densities and porosity for faba bean and lentil seeds were measured and calculated at different levels of seed moisture contents. The obtained results showed that, the principal dimensions, geometric and arithmetic diameter, surface area, actual and calculated volume, sphericity, mass of 1000 seed and porosity of faba bean (pods and seeds) and lentil seeds generally increased linearly with the increasing of moisture content. For faba bean pods and seeds, shape parameters (flakiness ratio $F_{r}$ and elongation ratio $E_{r}$) increased with the increase of moisture content but aspect ratios $R_{1}$ (W/L), $R_{2}$ (L/T$_{0}$) and $R_{3}$ (W/T$_{0}$) of faba bean pods and seeds decreased with the increasing of moisture content. The values of projected area for faba bean and lentil seeds were also increased with the increase of moisture content. On the other hand, the results also showed that, both of bulk and true densities decreased by increasing the moisture content. Mathematical relationships were also developed relating the obtained values of all physical properties with the change in seed moisture contents.

INTRODUCTION

Legume grains are very important in the diets of human being throughout the world. They are important source of proteins, carbohydrates and minerals. They are the sources of bioactive compounds (Liny et al., 2013). On the other hand, its self-sufficiency rate reduced from 92.21% in 1997 to 26% in 2011 for faba beans and from 16.64% in 1993 to about 1.62% in 2005 for lentils. (Central Agency for Public Mobilization and Statistics, 2012)

Recently, strengthen support for taking advantages of the modern biotechnology would be of major importance for Egypt to attain self-sufficiency of faba bean crop since it considers the first legume crop in Egypt with a cultivated area of 102 thousand hectares with an annual production of 357 thousand tones. As well, 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 knowledge of physical properties such as principal dimensions, surface area, projected area, volume, sphericity, true and bulk densities and porosity is required for the design of equipment for handling, harvesting, processing and storing. The information related physical properties pertinent to engineers, processors, scientists of food, and else scientists who may employ these resources. (Kumar, et. al., 2016)

Eissa, et. al., (2010) found that, whenever seed moisture contents increased from 11.6 to 25.4% (d.b.) the average length, width and thickness for chickpea seeds increased from (7.92 to 8.14 mm), (6.10 to 6.37 mm) and (4.29 to 4.60 mm) respectively. They also stated that, the increase of moisture content at the same range increased the average surface and projected area for chickpea seeds from (46.53 to 48.93 mm$^{2}$) and from (46.53 to 48.93 mm$^{2}$), respectively.

Isik and Izli, (2016) found that, when the moisture contents of yellow lentil seeds increased from (15.6 - 22.5 % d.b) the diameter and thickness of increased from 4.29 to 4.60 mm and from 1.22 to 1.42 mm, respectively with increasing the. They also found that, the porosity has a linear relationship with yellow lentil seed moisture contents. So, the results show that, the porosity increased from 37.49 to 53.18% with increasing of seeds moisture content from (15.6 - 22.5 % d.b).

Aghkhani, et. al., (2012) mentioned that, when the range of moisture contents increased from (8.12 - 29.22 % d.b) the geometric and arithmetic diameter for lima bean seeds increased from 11.3 to 12.2 mm and from 13.2 to 14.2 mm, respectively.

Eze, et. al., (2017) mentioned that, the increase in seeds volume may be due to the increase in size dimensions which was as a result of the displacement of more liquid. The volume of velvet bean seeds increased from 7.398 to 9.416 mm$^{3}$ when the seed moisture contents increased from (13 - 20 % w.b).

Dilmac, et. al., (2016) found that, when the seed moisture contents increased from 11.4 to 25.8 % (w.b) the sphericity percentage for faba bean seeds increased from 57.32 to 57.39 %. They also found that, the true and bulk densities of faba bean seeds decreased from 1094 to 1049 kg/m$^{3}$ and from 760 to 723.9 kg/m$^{3}$, respectively as the seed moisture contents increased from (11.4 - 25.8% w.b).

Marimuthu, et. al., (2013) mentioned that, the thousand grains mass increased linearly from 423 to 532 g, with increase in moisture content from 11.02± 0.05 to 24.1± 0.12 %.

The objective of this study is to select the physical properties of bean seeds and lentil seeds as well as their relationship with the moisture content of seeds. The tested properties included principal dimensions, projected area, volume, mass of 1000 seeds, true and bulk densities and porosity.

MATERIALS AND METHODS

1. Materials

The current study was devoted to specific types of legumes, namely faba bean variety Giza 716 and lentils variety Giza 370 which were obtained from the Agricultural Research Center (ARC). While, the green beans were bought at farm land in Damietta City, Egypt. The samples were randomly chosen with cleaning them manually. The method of oven drying has used to determine sample initial moisture contents at 105°C for 72h and 103°C for 72h for faba bean and lentil, respectively according to (ASAE, 2000c) and (ASAE, 1993).

To obtain the desired moisture levels for the studied, samples all seeds were conditioned by adding a
calculated amount of water to the moisture conditioning apparatus based on Equation (3.1) (Sacilik, et. al., 2003)

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

Where:  
- \( Q \): mass of water to be added, g;  
- \( W_i \): Initial mass of the sample, g;  
- \( M_i \): Initial moisture content of the sample, % (d.b.) and  
- \( M_f \): Final (desired) moisture content of the sample, % (d.b.)

2. Methods

Physical properties of faba bean and lentil seeds were measured and calculated at different levels of seeds moisture content. The measured properties included seeds principal dimensions, surface area, projected area, volume, mass of 1000 seeds, true and bulk densities and porosity.

**Principal Dimensions**

A digital caliper with accuracy of 0.01 mm, was used to measure the length (L), width (W) and thickness (Tb) for faba bean pods and seeds as shown in fig. (1) at different levels of seeds moisture content after selecting 100 seeds randomly for each test. As well, the diameter (2a) and thickness (2h) of lentil seeds was measured as shown in fig. (2).

**Geometric mean diameter (Dg)**

Geometric mean diameter of faba bean pods and seeds and lentil seeds was calculated by using the following equations, respectively:

\[ D_g = \left( \frac{L \cdot W \cdot T_b}{8} \right)^{1/3}, \text{mm} \]  

\[ D_g = \left( \frac{D^2 \cdot T_b}{3} \right)^{1/3}, \text{mm} \]  

(Sharma et. al., 1985 and Mohsenin 1986)

**Arithmetic mean diameter (Da)**

Arithmetic mean diameter of faba bean pods and seeds and lentil seeds was calculated by using the following equations, respectively:

\[ D_a = \frac{L + W + T_b}{3}, \text{mm} \]  

\[ D_a = \frac{2D + T_b}{3}, \text{mm} \]  

(Mohsenin 1970 and Mohsenin 1986)

**Surface area (As)**

The surface area of faba bean pods and seeds and lentil seeds was measured by using the following equation, respectively:

\[ A_s = \pi D_g^2, \text{mm}^2 \]  

\[ A_s = 2\pi \left( a^2 + h^2 \right) \]  

(Sacilik et. al., 2003 and Tang and Sokhansanj, 1993)

**Volume (V)**

The actual volume of faba bean pods and seeds and lentil seeds was determined by measuring the displaced volume of toluene and using the graduated flask and pipette (100 ml capacity and 0.1 ml accuracy) fixed with a tube holder. On other hand, calculated volume of faba bean (pods and seeds) and lentil seeds was calculated by using the following equations, respectively:

\[ V = \frac{\pi}{6} D_g^4, \text{mm}^3 \]  

\[ V = \frac{\pi h}{3} \left( 3a^2 + h^2 \right) \]  

(Ozarslan, 2002 and Carman, 1996)

**Sphericity (\( \theta \))**

The percentage of sphericity of seeds was calculated by using the function of the three principal dimensions as shown below: (Mohsenin, 1980)

\[ \theta = \frac{D_g}{L} \times \frac{100}{\%} \]  

**Shape Parameters (Fr & Er)**

The shape parameters (flakiness ratio Fr and elongation ratio Er) of seeds were measured by using the following equations according to (Mora and Kwan, 2000)

\[ Fr = \frac{T_b}{W}, \% \]  

\[ Er = \frac{L}{W}, \% \]  

**Aspect ratios (R1, R2 and R3)**

The aspect ratios were determined by using the three principal dimensions according to (Mohsenin 1986)

\[ R_1 = \frac{W}{L}, \text{decimal} \]  

\[ R_2 = \frac{L}{T_b}, \text{decimal} \]  

\[ R_3 = \frac{W}{T_b}, \text{decimal} \]  

**Projected area:**

The projected area (Ap) of faba bean and lentil seeds at different levels of moisture content were determined by using a laptop computer (LENOVO, ideapad 110, China) equipped with Matlab 9.4 (MCR_R2018a) software package specially, the image processing tool box as the following steps: images of seeds were scanned with a scanner for all samples (100 seeds) which distributed on the screen, the image of each sample was uploaded to the program separately then pressing the scan icon to convert image to black and white, the program deals with the white area only to calculate pixel values for its area. So, to select this white an invert icon was used. Finally, press the process icon to conduct the measurement. The number of pixels representing the area (Ap) of the faba bean and lentil seeds.

**Mass of 1000 seeds**

To measure the 1000 seeds mass, samples of one hundred seed were randomly selected and weighing it by a digital balance with accuracy of 0.01 gm. And so on, for 10 samples to obtain the average weight of 1000 seeds mass.

**True density**

The toluene liquid (C7H8) was used for the displacement process instead of water in order that it is
absorbed by seeds to a less limit. Besides it fills even shallow dips in a seed and its dissolution is low because of lowering of surface tension. For that, the true density was calculated by using the following equation (Mohsenin, 1980)

$$\rho_t = \frac{M_s}{V_d} \times \text{kg/m}^3$$  \hspace{1cm} (16)

Where: $\rho_t$: true density of sample, kg/m$^3$; $M_s$: mass of simple, kg; $V_d$: displaced volume of toluene, m$^3$

**Bulk density**

The bulk density was determined by filling a vessel of known mass and volume with seeds. To obtain the mass of seeds, the mass of the container was subtracted from the mass of the container. Then the bulk density was calculated by using that equation (Irwange and Igbeka, 2002)

$$\rho_b = \frac{M_s}{V_c} \times \text{kg/m}^3$$  \hspace{1cm} (17)

Where: $\rho_b$: bulk density of sample, (kg/m$^3$); $M_s$: mass of sample, kg; $V_c$: volume occupied, m$^3$

**Porosity**

Porosity of faba bean and lentil seeds was determined as a percentage of volume of inters - seed space into the volume of seeds bulk using porosity measuring device as shown in fig. (3). The apparatus was designed by (Matouk et al., 2002). Seeds were filled in tank (2) before closing both of valves (2 and 3). The air was supplied to tank (1), when a suitable manometer displacement was achieved, valve (1) was closed and the steady state pressure ($p_1$) was recorded. After that, valve (2) was opened keeping valves (1 and 3) closed. A steady state manometer reading ($p_2$) was recorded. Then, the porosity of seeds was calculated as follow:

$$P = \frac{P_1 - P_2}{P_1} \times 100$$  \hspace{1cm} (18)

Where: $P$: Porosity of seeds, %; $p_1$: Steady state pressure inside tank (1), bar; $p_2$: Steady state pressure in both tank (1) and (2), bar

**RESULTS AND DISCUSSION**

1. **Principal Dimensions**

   The effect of seeds moisture content on seeds principal dimensions is shown in figs. (4) and (5).

   For faba bean pods, variety Giza 716 the pods length increased from 119.47 to 125.33 mm, the width increased from 16.42 to 16.89 mm, while, the thickness increased from 11.46 to 12.05 mm when the moisture contents increased from 79.85 to 85.91 % (w.b).

   On the other hand, the faba bean seeds, length increased from 15.76 to 18.81 mm when the seed moisture contents increased from 11.74 to 79.43% (w.b). As well, the seeds width increased from 11.48 to 12.72 mm and the seeds thickness increased from 6.64 to 8.78 mm.

   Mean while, the diameter and thickness of lentil seeds variety Giza 370 were increased from 4.31 to 4.38 mm and 2.39 to 2.47 mm when the seed moisture contents increased from 12.18 to 22.33 % (w.b).

   This finding is supported by other searchers like, Thonga et al., (2010); Kumar et al., (2016) and Mansouri, et. al., (2017) for green bean, red lentil and melon seeds, respectively.

| Table 1.Values of constants (a and b) of eq. (19) |
| --- | --- | --- |
| Crop | Dimension | a | b | $R^2$ |
| Faba bean seeds | Length, L, (mm) | 15.077 | 0.0487 | 0.988 |
| | Width, W, (mm) | 11.187 | 0.0204 | 0.981 |
| | Thickness, Th, (mm) | 6.1873 | 0.0305 | 0.982 |
| Lentil seeds | Diameter, D, (mm) | 4.2337 | 0.0066 | 0.9704 |
| | Thickness, Th, (mm) | 2.895 | 0.0084 | 0.9433 |

2. **Geometric mean diameter ($D_g$) and Arithmetic mean diameter ($D_a$)**

   For faba bean pods, variety Giza 716 the geometric and arithmetic mean diameter increased from 28.194 to 29.350 mm and 49.118 to 51.424 mm, respectively when the moisture contents increased from 79.85 to 85.91 % (w.b).

   As well, the geometric and arithmetic mean diameter for faba bean seeds, increased from 10.621 to 12.72 mm and the seeds thickness increased from 6.64 to 8.78 mm.
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12.797 mm and 11.295 to 13.438, respectively when the seed moisture contents increased from 11.74 to 79.43% (w.b) as shown in fig. (6).

Also, as shown in fig. (7) both geometric and arithmetic mean diameter of lentil seeds were increased from 3.538 to 3.616 mm and from 3.669 to 3.742 mm, respectively with an increase in moisture contents from 12.18 to 22.33 % (w.b). Eze, et al., (2017) and Amin, et. al., (2004) reashed to same results for velvet bean and lentil seeds.

For describing the nature of the relationship between the geometric and arithmetic mean diameter and the moisture content of faba bean and lentil seeds, a regression analysis was performed. So the relationship could be expressed as follows:

\[ D_g = c + d \cdot M.C. \]  

Where:
- \( D_g \): The geometric mean diameter
- \( D_a \): The arithmetic mean diameter
- M.C.: Moisture content, % (w.b);
- C and d: constants

The values of the constants c and d are presented in table (2).

**Table 2. Values of constants (c and d) of eq. (20):**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Mean diameter, mm</th>
<th>c</th>
<th>d</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba beans</td>
<td>( D_g )</td>
<td>10.142</td>
<td>0.0331</td>
<td>0.9949</td>
</tr>
<tr>
<td>Seeds</td>
<td>( D_g )</td>
<td>10.817</td>
<td>0.0332</td>
<td>0.9939</td>
</tr>
<tr>
<td>Lentil</td>
<td>( D_g )</td>
<td>3.4472</td>
<td>0.0078</td>
<td>0.9696</td>
</tr>
<tr>
<td>seeds</td>
<td>( D_a )</td>
<td>3.5858</td>
<td>0.0072</td>
<td>0.9753</td>
</tr>
</tbody>
</table>

For describing the nature of the relationship between the geometric and arithmetic mean diameter and the moisture content of faba bean and lentil seeds.

3. Surface area (A_s)

The surface area for faba bean pods increased from 2504.05 to 2719.76 mm² with an increase in moisture contents from 79.85 to 85.91 % (w.b) followed by faba bean seeds which increased from 354.82 to 516.77 mm² when the seed moisture contents increased from 11.74 to 79.43 % (w.b) as shown in fig. (8).

Meanwhile, fig. (9) shows that, the surface area of lentil seeds increased from 38.2584 to 39.781 mm² with increasing of the seed moisture contents from 12.18 to 22.33 % (w.b).

This result indicates that the increase in the surface area values may be depend on the size dimensions of the seeds which are similar to those report by Ghamari et. al., (2014); Alibas and Koksal, (2015); (Eze, et. al., 2017) for chickpea Seeds, soybean seeds and velvet bean, respectively.

4. Volume (V)

For faba bean pods, the actual volume (\( V_a \)), the geometric volume (\( V_{Dg} \)) and the arithmetic volume (\( V_{Da} \)) increased from 18800 to 21100 mm³, 11830 to 13439.9 mm³ and 62813.7 to 72672.2 mm³, respectively with the increase of moisture content from 79.85 to 85.91 % (w.b).

In the same vein, fig. (10) shows that, the actual (\( V_a \)), the geometric (\( V_{Dg} \)) and the arithmetic volume (\( V_{Da} \)) increased from 910 to 1730 mm³, from 629.632 to 1112.2 mm³ and from 757.563 to 1288.3 mm³, respectively when the moisture content increased from 11.74 to 79.43 % (w.b).

Also, the actual volume (\( V_a \)) and calculated volume (\( V_{c} \)) for lentil seeds increased from 22.773 to 30 mm³ and from 23.027 to 24.624 mm³, respectively with the increase of moisture content from 12.18 to 22.33 % (w.b) as shown in fig. (11).

These results are also in line with those of (Shoughy and Amer, 2006) for faba bean seeds; Alibas and Koksal, (2015) for soybean seeds.
A simple regression analysis was examined for describing the relationship between the actual and the calculated volume and moisture content for the studied crops. The relationship was found to be as the following equation:

$$ V = g + h (M.C) \quad \text{(21)} $$

Where:

- $V$: Volume of seeds, mm$^3$.
- $M.C$: Moisture content, % (wb).
- $g$ and $h$: Constants.

The values of constants $g$ and $h$ are shown in table (3).

**Table 3. Values of constants (g and h) of eq. (21)**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Seeds volume, mm$^3$</th>
<th>g</th>
<th>h</th>
<th>R$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba bean</td>
<td>$V_a$</td>
<td>736.69</td>
<td>12.262</td>
<td>0.9956</td>
</tr>
<tr>
<td>Seeds</td>
<td>$V_b$</td>
<td>520.75</td>
<td>7.2689</td>
<td>0.9924</td>
</tr>
<tr>
<td>Lentil</td>
<td>$V_c$</td>
<td>636.72</td>
<td>8.1632</td>
<td>0.9938</td>
</tr>
<tr>
<td>Seeds</td>
<td>$V_d$</td>
<td>13.907</td>
<td>0.7043</td>
<td>0.9748</td>
</tr>
</tbody>
</table>

The sphericity ($\phi$) of seeds, was increased from 66.3573 to 68.7 % with the increase of moisture content from 11.74 to 79.43 % (w.b) as shown in the fig. (12). Also, the sphericity of lentil seeds increased from 82.15 to 82.67 % with the increasing of moisture content from 12.18 to 22.33 % (w.b) as shown in fig. (13).

**Table 4. Values of constants (i and j) of eq. (22)**

<table>
<thead>
<tr>
<th>Crop</th>
<th>MoistureContent % (w.b.)</th>
<th>i</th>
<th>j</th>
<th>R$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba bean seeds</td>
<td>11.72 – 79.43</td>
<td>65.887</td>
<td>0.0348</td>
<td>0.9953</td>
</tr>
<tr>
<td>Lentil seeds</td>
<td>12.18 – 22.33</td>
<td>81.423</td>
<td>0.0559</td>
<td>0.9587</td>
</tr>
</tbody>
</table>

**6. Shape Parameters (Fr & Er)**

Table (5) shows that, the values of flakiness ratio $Fr$ and elongation ratio $Er$ for faba bean pods were increased from 0.6995 to 0.7163 and from 7.298 to 7.477 as the moisture content increased from 79.85 to 85.91 % (w.b), respectively.

**Table 5. Values of flakiness ratio Fr, elongation ratio Er and ratios $R_1$, $R_2$ and $R_3$**

<table>
<thead>
<tr>
<th>Crop</th>
<th>M.C., % (w.b.)</th>
<th>Fr $T_h/W$</th>
<th>Er $L/W$</th>
<th>$R_1$ $W/L$</th>
<th>$R_1$ $L/T_h$</th>
<th>$R_3$ $W/T_h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba bean</td>
<td>79.85</td>
<td>0.6995</td>
<td>7.2984</td>
<td>0.138</td>
<td>10.569</td>
<td>1.436</td>
</tr>
<tr>
<td></td>
<td>85.91</td>
<td>0.7163</td>
<td>7.4765</td>
<td>0.1357</td>
<td>10.462</td>
<td>1.4099</td>
</tr>
<tr>
<td>Pods</td>
<td>11.74</td>
<td>0.5803</td>
<td>1.376</td>
<td>0.7305</td>
<td>2.3831</td>
<td>1.7350</td>
</tr>
<tr>
<td></td>
<td>22.13</td>
<td>0.5902</td>
<td>1.384</td>
<td>0.7257</td>
<td>2.3547</td>
<td>1.7039</td>
</tr>
<tr>
<td>Seeds</td>
<td>60.6</td>
<td>0.6348</td>
<td>1.45908</td>
<td>0.6878</td>
<td>2.311</td>
<td>1.5866</td>
</tr>
<tr>
<td></td>
<td>70.48</td>
<td>0.6553</td>
<td>1.46575</td>
<td>0.6858</td>
<td>2.2501</td>
<td>1.5388</td>
</tr>
<tr>
<td></td>
<td>79.43</td>
<td>0.691</td>
<td>1.481</td>
<td>0.6781</td>
<td>2.2267</td>
<td>1.4541</td>
</tr>
<tr>
<td>Lentil</td>
<td>60.6</td>
<td>0.6348</td>
<td>1.45908</td>
<td>0.6878</td>
<td>2.311</td>
<td>1.5866</td>
</tr>
<tr>
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<td>70.48</td>
<td>0.6553</td>
<td>1.46575</td>
<td>0.6858</td>
<td>2.2501</td>
<td>1.5388</td>
</tr>
<tr>
<td></td>
<td>79.43</td>
<td>0.691</td>
<td>1.481</td>
<td>0.6781</td>
<td>2.2267</td>
<td>1.4541</td>
</tr>
</tbody>
</table>

These results are like to those reported by (Eze, et al., 2017) for velvet bean; Alibas and Koksal, (2015) for soybean seeds.
8- Projected area:

The projected area of seeds which obtained by using Matlab software generally increased with the increasing of moisture content.

For faba bean seeds, fig. (14) show that, the seeds projected area increased from 161.6521 to 238.0033 mm$^2$, respectively with the increasing of seeds moisture content from 11.74 to 79.43% (w.b).

Meanwhile, the lentil seeds projected area were increased from 22.59 to 24.002 mm$^2$, respectively with the increasing of seeds moisture content from 12.18 to 22.33% (w.b) as shown fig. (15).

Similar trends have also been reported by Aghkhani, et. al., (2012) for lima bean seeds, by Isik and Iizil, (2016) for yellow lentil seed, by Dilmac, et. al., (2016) for faba bean seeds. This may be due to the extension in principal dimensions with increasing in moisture content.

A simple regression analysis was also achieved to relate the change in the projected area with the change in moisture content of seeds. The nature of dependence could be explicated by the following equation:

$$A_p = k + l (MC)$$  (23)

Where:
- $A_p$: projection area, mm$^3$.
- $MC$: seeds moisture content, % (w.b).
- $k$ and $l$: Constants.

The regression parameters for the obtained regression equation were tabulated for both studied crops in table (6).

<table>
<thead>
<tr>
<th>Table 6. Values of constants (k and l) of Eq. (23)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crop</strong></td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Faba bean seeds</td>
</tr>
<tr>
<td>Lentil seeds</td>
</tr>
</tbody>
</table>

9- Mass of 1000 seeds

As for the faba beans pods varity Giza 716, the mass of 1000 pods increased from 14575.6 to 15683.8 g with an increase in moisture content from 79.85 to 85.91 % (w.b).

Meanwhile, for faba bean seeds, varity Giza 716 fig. (16) shows that, the mass of 1000 seeds increased from 1033.9 to 1736.4 g when the moisture content increased from 11.74 to 79.43 % (w.b).

Also, the mass of 1000 seeds for lentil seeds increased from 29.7 to 32.9 g when the moisture content increased from 12.18 to 22.33 % (w.b) for the varity Giza 370 as shown in fig. (17).

Such linear relationship between M1000 and moisture content has been reported for cowpea seeds (Adelno, et. al., 2011); soybean (Wandkar, et. al., 2012) and cucumber seeds and kernels (Mirzabe, et. al., 2017).

10- Bulk density

The effect of moisture content on bulk density indicated that, the values of bulk density decreased with increasing of moisture content. For faba bean pods when the moisture content increased from 79.85 to 85.91 % (w.b), the bulk density decreased from 283.061 to 281.909 kg/m$^3$.

As well, the values of bulk density for faba bean seeds varity Giza 716 decreased from 742.880 to 571.384 kg/m$^3$ with an increase in moisture content from 11.74 to 79.43% (w.b) as shown in fig. (18).

Meanwhile, for lentil seeds, varity Giza 370 fig. (19) shows that, the bulk density decreased from 828.244 to 784.880 kg/m$^3$ as the moisture content increased from 12.18 to 22.33% (w.b) because of the increasing in volume of seeds.
The bulk density (Bd) of seeds was found to bear the following relationship with moisture content (M.C.):

\[ Bd = a' + b' \cdot M.C. \]  \hspace{1cm} (24)

Where: Bd: Bulk density, kg/m$^3$; M.C: Seeds moisture content, % (w.b); $a'$ and $b'$: Constants.

The regression parameters for the obtained regression equations were tabulated for both studied crops as presented in Table (7).

### Table 7. Values of constants ($a'$ and $b'$) of eq. (24)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Moisture Content, % (w.b.)</th>
<th>Regression parameters</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba bean seeds</td>
<td>11.72 – 79.43</td>
<td>753.33 - 0.003</td>
<td>0.9471</td>
</tr>
<tr>
<td>Lentil seeds</td>
<td>12.18 – 22.33</td>
<td>884.85 - 0.005</td>
<td>0.9808</td>
</tr>
</tbody>
</table>

### 11- True density

The bulk density (Bd) of seeds was found to bear the following relationship with moisture content (M.C.):

\[ Bd = a' + b' \cdot M.C. \]  \hspace{1cm} (24)

Where: Bd: Bulk density, kg/m$^3$; M.C: Seeds moisture content, % (w.b); $a'$ and $b'$: Constants.

The regression parameters for the obtained regression equations were tabulated for both studied crops as presented in Table (7).

### Table 8. Regression parameters of eq. (25) relating the change in seeds moisture contents with the true density

<table>
<thead>
<tr>
<th>Crop</th>
<th>Moisture Content, % (w.b.)</th>
<th>Regression parameters</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba bean seeds</td>
<td>11.72 – 79.43</td>
<td>1146.8 - 2.411</td>
<td>0.9205</td>
</tr>
<tr>
<td>Lentil seeds</td>
<td>12.18 – 22.33</td>
<td>1558 - 25.01</td>
<td>0.969</td>
</tr>
</tbody>
</table>

### 12- Porosity

As shown in fig. (22), faba bean seeds porosity increased from 36.172 to 41.308 % with an increase in seed moisture contents from 11.74 to 79.43 % (w.b).

As well, fig. (23) points that, the seeds porosity of lentil was increased from 33.597 to 35.044 % as the seed moisture contents increased from 12.18 to 22.33 % (w.b), respectively.

This finding is supported from other investigators who have also similar observations for different seeds like Aderinlewo, et. al., (2011) for cowpea seeds; Wandkar, et. al., (2012) for soybean; Thong, et. al., (2010) for green bean and Mirzabe, et. al., (2018) for cucumber seeds and kernels.

A similar linear regression analyses was assigned to express the change in porosity of seeds at different levels of moisture content. The relation was expressed by the following equation:

\[ Po = e' + f' \cdot (M.C.) \]  \hspace{1cm} (26)

Where: Po: Seeds porosity, %; M.C: Moisture content, % (w.b); $e'$ and $f'$: Constants.

The regression parameters($e'$ and $f'$) for the obtained regression quations were tabulated for both studied crops as presented in Table (9).


REFERENCES


CONCLUSION

1- The principal dimensions of faba bean pods, seeds including length, width and thickness and lentil seeds including diameter and thickness were increased with the increase of moisture content.

2- The geometric and arithmetic mean diameter of faba bean pods, seeds and lentil seeds were increased with an increase in moisture content.

3- The surface area of faba bean pods, seeds and lentil seeds were increased with the increase in moisture content.

4- The actual and calculated volume of faba bean pods, seeds and lentil seeds were increased with the increase of moisture content.

5- Sphericity of faba bean and lentil seeds increased with the increase of moisture content.

6- Shape parameters (flakiness ratio Fr and elongation ratio Er) of faba bean pods and seeds increased but aspect ratios (R2, R3) decreased with the increase of moisture content.

7- By using the image processing tools (Matlab software), the values of projected area for faba bean and lentil seeds increased with the increase of moisture content.

8- Mass of 1000 seed and seeds porosity increased linearly by increasing the moisture content. While, both of bulk and true densities decreased by increasing the moisture content.


