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# Moisture Effect on Physical Properties of Knotweed (*Polygonum cognatum* Meissn.) seeds

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**Abstract:** In this study, the effects of moisture content on some of physical properties (seed dimension, geometric mean diameter, individual seed weight, sphericity, thousand-seed, weight, bulk and true density, porosity angle of repose and static coefficient of friction of knotweed (*Polygonum cognatum* Meissn.) seeds were investigated. Moisture contents of seeds were 7.95, 13.68 and 19.14% d.b. (dry basis), respectively. The average geometric mean diameter, individual seed weight, sphericity, thousand-seed weight and angle of repose ranged from 1.85 to 1.94 mm, 0.0040 to 0.0046 g, 66.21 to 67.37%, 3.32 to 3.74 g and 18.36 to 25.00˚ as the moisture content increased from 7.95 to 19.14% d.b., respectively. Bulk density and porosity were decreased from 696.11 to 707.73 kg m$^{-3}$, 57.93 to 40.16%, whereas the seed volume, true density and surface area were increased from 3.357 to 3.894 mm$^3$, 1654.69 to 1182.64 kg m$^{-3}$, and 10.786 to 11.867 mm$^2$ as the moisture content increased, respectively. The static coefficient of friction on various surfaces (plywood, glass, chipboard and galvanized metal) linearly increased with an increase in moisture content. Since *Polygonum cognatum* seeds are in small sizes, they can easily be separated at higher moisture contents which will also help sowing of small seed and enhance germination rate.

**Keywords:** Knotweed *(Polygonum cognatum* Meissn.), seeds, moisture content, physical properties

## Madımak tohumunun (*Polygonum cognatum* Meissn.) fiziksel özelliklerine nem içeriğinin etkisi

**Özet:** Bu çalışmada, madımak (*Polygonum cognatum* Meissn.) tohumunun nem içeriğinin bazı fiziksel özelliklerine (boyut, geometrik ortalama çap, yüzey alanı, küresellik, bin dane ağırlığı, tohum hacmi, yığın ve tek dane hacim ağırlığı, porozite, doğal yığılma açısı ile sürtünme katsayısı) etkisinin belirlenmesi amaçlanmıştır. Nem içerikleri sırasıyla %7,95; 13,68 ve 19.14 (kuru baza göre) olarak belirlenmiştir. Geometrik ortalama çap, birim ağırlık, küresellik, bin dane ağırlığı ve doğal yığılma açısı nem içeriğinin %7,95'den %19.14'e kadar artışına göre sırasıyla 1,85'den 1.94 mm'e, 0,0040'dan 0.0046 g'a, %66.21'den 67.37'e, 3,32'den 3,74 g'a kadar ve 18,36'dan 25,00˚'ye kadar değişiklik göstermiştir. Tohum hacmi, yığın hacim ağırlığı ve yüzey alanı değerleri nem içeriği artışına göre; 3,357 mm$^3$'den 3,894 mm$^3$'e, 696,11 kg m$^{-3}$'den 707,73 kg m$^{-3}$'e ve 10,786 mm$^2$'den 11,867 mm$^2$'ye artış gösterirken, tane hacim ağırlığı ve porozite değerleri; 1654,69 kg m$^{-3}$'den 1182,64 kg m$^{-3}$'e ve %57,93'den %40,16'a azalmıştır. Statik sürtünme katsayısı değerleri, farklı yüzeyler (kontrplak, cam, sunta ve galvaniz metal) için nem içeriği artışıyla artış göstermiştir. *Polygonum cognatum* tohumları çok küçük boyutlarda olduğu için yüksek nem içeriklerinde kolayca ayrılabilir, dolayısıyla bu küçük tohumların ekimini ve çimlenme oranının artışına yardımcı olabilir.

**Anahtar Kelimeler:** Madımak *(Polygonum cognatum* Meissn.), tohum, nem içeriği, fiziksel özellikler

## 1. Introduction

*Polygonum cognatum*, known locally as "*madımak*", is regularly consumed in central parts of Turkey, is a weed found in agricultural and non-agricultural areas such as field edges and roadsides, and industrial areas. The weed is a well known traditional edible plant in the Central Anatolia (Onen et al., 2011). *Polygonum cognatum* seeds have the highest dry matter ash, protein and nitrogen value. The researches have mainly focused on the origin and distribution of *Polygonum cognatum*, and determined some of biological characteristics and the process of consumption as a folk medicine (Davis, 1967). The antioxidant and antimicrobial effects and macro and micro mineral contents were superficially studied (Yıldırım et al. 2003). Since polygonum cognatum is rich in phenolic compounds (Onen et al., 2009), allelopathic potential of polygonum cognatum were also studied (Yılar et al, 2006).

The plant is traditionally collected in spring and sold in markets. Some of farmers in Central Anatolia Region of Turkey started cultivating polygonum cognatum to compensate the increasing demand (Onen et al., 2011; Yılar et al., 2006). In Turkey, the first scientific research paper on knotweed culture was studied by Yazgan and Sağlam (1992). The production of plant via seeds is quite difficult due to the seed dormancy. Recent studies on seed dormancy revealed that the germination rate of *Polygonum cognatum* seeds can be increased from 1% to %57 with scarification via concentrated sulfuric acid and giberrallic acid treatment (Onen et al., 2011). However, harvesting and separation of seeds from other plant material are still quite difficult.

Information on various physico-mechanical properties as a function of moisture content is needed to design the equipment used in plantation, harvesting, transportation, storaging and processing of dried polygonum seeds. The size and shape of polygonum cognatum seeds are important to design the seperating, harvesting, sizing and granding machines. Bulk density and porosity affect the structure loads, and the angle of repose is required in the design of storaging and transporting structures. The coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting and storing structures.

In recent years, physical and mechanical properties of various crops have been studied for locust bean seed (Ogunjimi et al., 2002); millet (Baryeh, 2002); quiona seed (Vilche et al., 2003) and hemp seed (Sacılık et al., 2003); wheat (Tabatabeefar, 2003); sesame seed (Tunde-Akintunde and Akintunde, 2004); safflower seed (Baümler et al., 2006); linseed (Selvi et al. 2006) and flax seed (Coşkuner and Karababa, 2007). However, the physical and mechanical properties of polygonum cognatum seeds as affected by moisture content have not been studied. There is a paucity of technical information and data in the scientific literature with regards to the effect of moisture content on some physico-mechanical properties of polygonum cognatum seeds. Thus, the objective of this study is to examine of the effects of moisture on some physico-mechanical properties of polygonum cognatum seeds, namely, size dimension, sphericity, thousand seeds weight, bulk density, angle of repose, volume, true density, porosity, surface area and the static coefficients of friction on plywood, glass, chipboard and galvanized metal surfaces.

## 2. Materials And Methods

The polygonum cognatum seeds used in this study were obtained from Plant Protection Department of Gaziosmanpasa University, Tokat, Turkey. *Polygonum cognatum* Meissn. seeds are shown in Fig.1. The samples were manually cleaned to remove foreign matters, soil, broken and immature seeds. The initial moisture content of the samples was determined by oven drying at 105 ± 1°C for 24 h (Suthar and Das, 1996). The samples at the desired moisture levels (13.68 and 19.14%) were prepared by adding calculated amounts of distilled water, thorough mixing and sealing in separate polyethylene bags.

***Figure 1.****Polygonum cognatum Meissn'knotweed' seeds*

The moisture contents were calculated from the following equation (Balasubramanian, 2001; Sacilik et al. 2003; Saiedirad et al. 2008):

$$Q = \left[ \frac{W_i (M_f - M_i)}{(100 - M_f)} \right] \quad (1)$$

where $Q$ is the mass of water to be added (kg), $W_i$ is the initial weight of a sample (kg), $M_i$ is the initial moisture content of a sample (% dry basis), and $M_f$ is the final moisture content of the sample (% dry basis).

The samples were kept at 5 °C in a refrigerator for 7 days to allow uniform distribution of moisture throughout the sample. Before starting the test, required quantities of samples were taken out of the refrigerator and allowed to warm up to room temperature (Deshpande et al., 1993; Visvanathan et al., 1996; Öğüt, 1998). The physico-mechanical properties of polygonum cognatum seeds were determined at 7.95 to 19.14% moisture contents d.b. (dry basis). Ten replications of each test were made at each moisture level. The length, width, thickness and weight of polygonum cognatum seeds were measured in randomly selected 100 polygonum cognatum seeds. The length, width and thickness of materials were measured by a dial-micrometer to an accuracy of 0.001 mm.

The geometric mean diameter $D_g$ and sphericity $\Phi$ of polygonum cognatum seeds were calculated using the following relationships (Mohsenin, 1970):

$$D_g = (LWT)^{1/3} \quad (2)$$

$$\Phi = \left[ \frac{LWT^{1/3}}{L} \right] \times 100 \quad (3)$$

where $L$ is the length, $W$ is the width and $T$ is the thickness in mm.

To determine the unit weight of the seeds, thousand seeds weight were measured by an electronic balance to an accuracy of 0.001g. To evaluate thousand seed weight, 100 randomly selected seeds from the bulk were averaged. The true density of a seed is defined as the ratio of a sample weight to the solid volume occupied by a sample (Deshpande et al. 1993). The seeds volume and true density, as a function of moisture content, were determined using the liquid displacement method. Toluen ($C_7H_8$) was used rather than water because of its low surface tension and toluene is absorbed by seeds to a lesser extent as compared to the water. The dissolution power of toluen is also low, so that it fills even at shallow dips in a seed (Sitkei, 1976; Mohsenin, 1970). Bulk density is the weight ratio of a sample to its total volume and determined with a weight per hectolitre tester which was calibrated in kg $m^{-3}$ (Deshpande et al. 1993; Suthar and Das, 1996).

The volume ($V$) of polygonum cognatum seeds in $mm^3$ was determined from the following relationship given by Ozarslan (2002):

$$V = \left[ \frac{w}{\rho_t} \right] \times 10^6 \quad (4)$$

where $w$ is the individual weight of the seed in g and $\rho_t$ is the true density in kg $m^{-3}$. The porosity ($\varepsilon$) was determined by the following equation:

$$\varepsilon = \left[1 - \frac{\rho_b}{\rho_t}\right] \times 100 \quad (5)$$

where $\rho_b$ and $\rho_t$ are the bulk and true densities, respectively (Mohsenin, 1970). The surface area of a polygonum cognatum seed was found by analogy with a sphere of the same geometric mean diameter, using expression cited by Olajide and Ade-Omowaye, (1999); Sacilik et al. (2003); Tunde-Akintunde and Akintunde (2004):

$$S = \pi D_g^{\ 2} \quad (6)$$

where S is the surface area in $mm^2$ and $D_g$ is the geometric mean diameter in mm.

Angle of repose ($\theta$) is the angle with horizontal at which the material will stand when piled. Angle of repose was determined using a topless and bottomless cylinder of 300 mm diameter and 500 mm height. The cylinder was placed at the center of a raised circular plate and filled with polygonum cognatum seeds. The cylinder was raised slowly until it formed a cone on a circular plate. The angle of repose was calculated from the measurement of the cone height and the diameter of cone (Kaleemullah and Gunasekar, 2002).

To determine of the static coefficient of friction, the polygonum cognatum seed sample box was placed on the friction surface, and then gradually raised by the screw. While the sample box started sliding, the coefficient of friction was found (Nimkar and Chattopadhyay, 2001). For each treatment, the sample box was emptied and refilled with a different sample. The static coefficient of friction ($\mu_s$) was calculated from the following equation (Mohsenin, 1970):

$$\mu_s = \frac{F}{N_f} \quad (7)$$

where $\mu_s$ is the coefficient of friction; F is the measured friction in N and $N_f$ is the normal force in N.

The experiment was conducted using friction surfaces of rubber, galvanized steel, chipboard and plywood. These materials are commonly used for handling and processing of polygonum cognatum seeds and construction of storage and drying bins. For each experiment, the sample box was empited and refilled with a different sample at the same moisture content (Sacilik et al., 2003).

The linear equations for static coefficient of friction on all three surfaces were formulated as:

$$\mu_s = \mathrm{A} + \mathrm{B}M_c \quad (8)$$

where μ is the coefficient of friction, and A and B are the regression coefficients.

## 3. Results and Discussion

### *Seed dimensions*

Frequency distribution curves of *Polygonum cognatum* seed length, width, thickness and individual weight of the seed at 7.95% moisture content (d.b) were presented in Fig. 2. The length of approximately 77.0% of *Polygonum cognatum* seeds ranged from 2.621 to 3.093 mm, the width of 82.0% of seeds ranged from 1.436 to 1.864 mm, 75.0% of the seed thicknesses varied between 1.275 to 1.475 mm and 76.0% of individual seed weight changed from 0.0036 to 0.0050 g at 7.95% d.b moisture content, respectively (Table 1). The average length, width and thickness, geometric mean diameter and individual weight of the polygonum cognatum seeds varied from 2.804 to 2.915 mm, 1.659 to 1.774 mm, 1.372 to 1.427 mm, 1.849 to 1.936 mm and 0.00403 to 0.00458 g, respectively as the moisture content increased from 7.95% to 19.14% d.b. The reason for increases in geometric and gravimetric attributes presented were due to swelling of the seeds.

The correlation coefficients (R) between *L/W*, *L/T* and *L/w* were not statistically significant, whereas $L/D_g$, $L/\phi$, *L/S* and *L/V* relations were statistically significant (Table 2). Following general calculation can be used to determine the relationships between the major dimension (length) at initial moisture content.

$L$ = -0.071 $W = 0.081\ T = 0.121\ w = 0.421\ D_g = -0.667\ \Phi = 0.428\ S$ = 0.436 $V$ (9)

Simillar results were reported by Joshi et al. (1993); Gupta and Das (1997); Balasubramanian (2001); Gezer et al. (2002) for pumpkin seed, soybean seed, raw cashew nut, apricot pit and kernel, respectively.

***Table 1.*** *Frequency distribution curves of Polygonum cognatum seed dimensions and individual weight of the seed at three different moisture contents*

| Moisture content, (% d.b) | Seed dimensions | | | | Number of seed | | | |
|---|---|---|---|---|---|---|---|---|
| | *L, mm* | *W, mm* | *T, mm* | *w, g* | *L* | *W* | *T* | *w* |
| 7.95 | 2.15-2.31 | 1.15-1.29 | 0.98-1.08 | 0.0026-0.0031 | 2 | 3 | 6 | 6 |
| | 2.31-2.46 | 1.29-1.44 | 1.08-1.18 | 0.0031-0.0036 | 9 | 5 | 3 | 14 |
| | 2.46-2.62 | 1.44-1.58 | 1.18-1.28 | 0.0036-0.0040 | 7 | 22 | 11 | 26 |
| | 2.62-2.78 | 1.58-1.72 | 1.28-1.38 | 0.0040-0.0045 | 16 | 39 | 23 | 30 |
| | 2.78-2.94 | 1.72-1.86 | 1.38-1.48 | 0.0045-0.0050 | 36 | 21 | 37 | 16 |
| | 2.94-3.09 | 1.86-2.01 | 1.48-1.58 | 0.0050-0.0054 | 25 | 8 | 15 | 2 |
| | 3.09-3.25 | 2.01-2.15 | 1.58-1.68 | 0.0054-0.0059 | 5 | 2 | 5 | 6 |
| 13.68 | 2.22-2.41 | 1.22-1.35 | 1.03-1.16 | 0.0029-0.0034 | 8 | 2 | 9 | 2 |
| | 2.41-2.59 | 1.35-1.49 | 1.16-1.28 | 0.0034-0.0039 | 18 | 12 | 13 | 4 |
| | 2.59-2.78 | 1.49-1.62 | 1.28-1.41 | 0.0039-0.0044 | 22 | 15 | 21 | 20 |
| | 2.78-2.97 | 1.62-1.75 | 1.41-1.53 | 0.0044-0.0049 | 18 | 19 | 26 | 30 |
| | 2.97-3.16 | 1.75-1.89 | 1.53-1.66 | 0.0049-0.0054 | 23 | 29 | 18 | 30 |
| | 3.16-3.34 | 1.89-2.02 | 1.66-1.78 | 0.0054-0.0059 | 10 | 20 | 10 | 8 |
| | 3.34-3.53 | 2.02-2.16 | 1.78-1.91 | 0.0059-0.0064 | 1 | 3 | 3 | 6 |
| 19.14 | 1.19-1.51 | 1.19-1.44 | 0.66-0.84 | 0.0019-0.0025 | 2 | 12 | 1 | 2 |
| | 1.51-1.83 | 1.44-1.69 | 0.84-1.03 | 0.0025-0.0032 | 2 | 21 | 1 | 2 |
| | 1.83-2.15 | 1.69-1.94 | 1.03-1.22 | 0.0032-0.0038 | 3 | 42 | 10 | 4 |
| | 2.15-2.47 | 1.94-2.19 | 1.22-1.41 | 0.0038-0.0045 | 4 | 19 | 36 | 25 |
| | 2.47-2.79 | 2.19-2.44 | 1.41-1.59 | 0.0045-0.0051 | 34 | 4 | 31 | 52 |
| | 2.79-3.12 | 2.44-2.69 | 1.59-1.78 | 0.0051-0.0057 | 36 | 1 | 17 | 13 |
| | 3.12-3.44 | 2.69-2.94 | 1.78-1.97 | 0.0057-0.0064 | 19 | 1 | 4 | 2 |

***Table 2.*** *The correlation coefficients of Polygonum cognatum seeds at three moisture contents (d.b.)*

| Particulars | Degrees of freedom | Moisture content, % d.b. | | | | | |
|---|---|---|---|---|---|---|---|
| | | 7.95 | | 13.68 | | 19.14 | |
| | | Ratio | Correlation coefficient (R) | Ratio | Correlation coefficient (R) | Ratio | Correlation coefficient (R) |
| *L/W* | 98 | 1.709 | -0.071 ns[b] | 1.682 | -0.173 ns | 1.684 | -0.051 ns |
| *L/T* | 98 | 2.066 | 0.081 ns | 2.020 | -0.129 ns | 2.092 | -0.130 ns |
| *L/w* | 98 | 712.11 | -0.121 ns | 620.62 | 0.133 ns | 651.05 | 0.119 ns |
| $L/D_g$ | 98 | 1.520 | 0.421**[a] | 1.500 | 0.359** | 1.515 | 0.421 ns |
| $L/\Phi$ | 98 | 0.0428 | -0.667 ** | 0.0434 | -0.583 ** | 0.0438 | -0.596 ** |
| *L/S* | 98 | 0.263 | -0.428 ** | 0.250 | 0.359 ** | 0.253 | 0.190 ns |
| *L/V* | 98 | 0.863 | 0.436 ** | 0.788 | 0.358 ** | 0.799 | 0.185 ns |

[a] **: Significant at 1% level. [b] ns: Non significant.

***Sphericity and 1000 seed weight***

The values of sphericity were calculated with Eq. (3) using the data on geometric mean diameter of the polygonum cognatum seed and the results were presented in Fig. 2. The sphericity of polygonum cognatum seeds slightly increased from 66.21% to 67.37% as the moisture content increased from 7.95% to 19.14% d.b. Greater lateral expansion compared to the thickness of polygonum cognatum seeds could be attributed to the increase in sphericity.

The thousand seed weight of polygonum cognatum ($w_{1000}$) linearly increased from 3.316 to 3.374 g with in increase moisture content from 7.95% to 19.14% d.b. (Fig. 3).

Linear relationship was obtained between moisture content ($M_c$) and sphericity ($\phi$) and 1000 seed weight ($w_{1000}$) represented by the following regression equation:

$$\phi = 65.75 + 0.58M_c \quad (R^2 = 0.881) \quad (10)$$

$$w_{1000} = 3.169 + 0.21M_c \quad (R^2 = 0.789) \quad (11)$$

Similar increasing for sphericity trends have been reported for soybean seed (Desphande et al., 1993), for green gram (Nimkar and Chattopadhyay, 2001), for cotton seeds (Özarslan, 2002), for quinoa seed (Vilche et al., 2003) and for safflower seeds (Baümler et al., 2006).

The positive linear relationship of thousand seed weight and moisture content were also reported by Aviara et al. (1999) for guna seeds, by Ozarslan (2002) for cotton seed, by Baryeh (2002) for millet, Baryeh and Mangope (2002) for QP-38 variety pigeon pea, by Vilche et al. (2003) for quinoa seeds, by Coşkuner (2007) for flaxseed, by Garnayak et al. (2008) for jatropha seeds, respectively.

**Bulk density and true density**

The bulk density of polygonum cognatum seeds at different moisture contents varied from 696.1 to 707.7 kg m$^{-3}$ and indicated an increase in bulk density with an increase in moisture content (Fig. 3). The true density of polygonum cognatum seeds was decreased from 1654.7 to 1182.6 kg m$^{-3}$ (Fig. 4) with increase in moisture content. This decrease was due to greater increase in volume relative to that of weight. The relationship between moisture content and bulk density ($\rho_b$) was linear and represented by the following regression equation:

$$\rho_b = 691.4 + 5.808M_c \quad (R^2 = 0.889) \quad (12)$$

Although similar results were reported for vetch seed (Yalcin and Ozarslan, 2004) and jatropha seed (Garnayak et al., 2008), decline in bulk density were also reported by for pumpkin seed (Joshi et al., 1993), cottonseed (Özarslan, 2002), fenugreek (Altuntas et al., 2005) and jatropha seed (Garnayak et al., 2008).

The linear increase in true density ($\rho_t$) was represented by the regression equation:

$$\rho_t = 1884.5 - 236.0M_c \quad (R^2 = 0.998) \quad (13)$$

Similar relationships have been reported by Deshpande et al. (1993) for sunflower seed, Baryeh (2002) for millet, Vilche et al. (2003) for quinoa seeds, Gupta and Das (1997) for sunflower kernel, Yalçın and Özarslan (2004) for vetch seed and Garnayak et al. (2008) for jatropha seed, respectively.

$$V = 1.794 + 0.716M_c \quad (R^2 = 0.970) \quad (14)$$

$$S = 10.385 + 0.541M_c \quad (R^2 = 0.834) \quad (15)$$

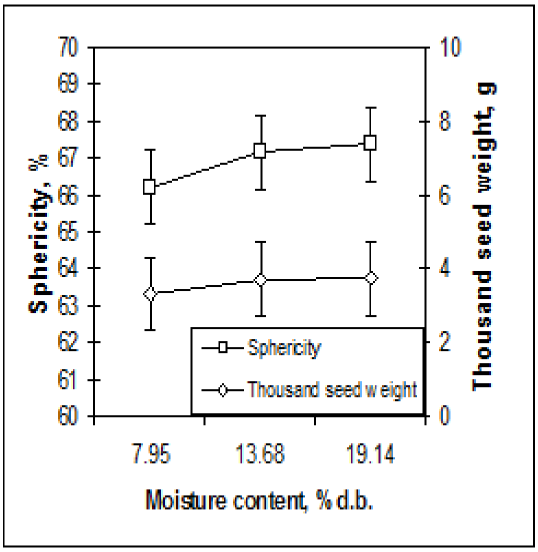


***Figure 2.*** *Effect of moisture content on sphericity and thousand seed weight*

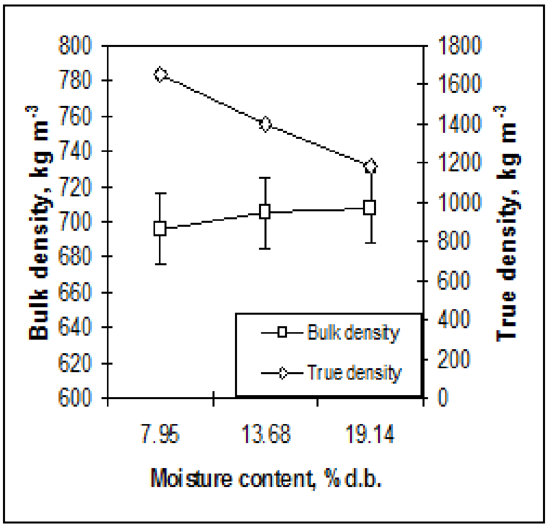


***Figure 3.*** *Effect of moisture content on bulk density and true density*

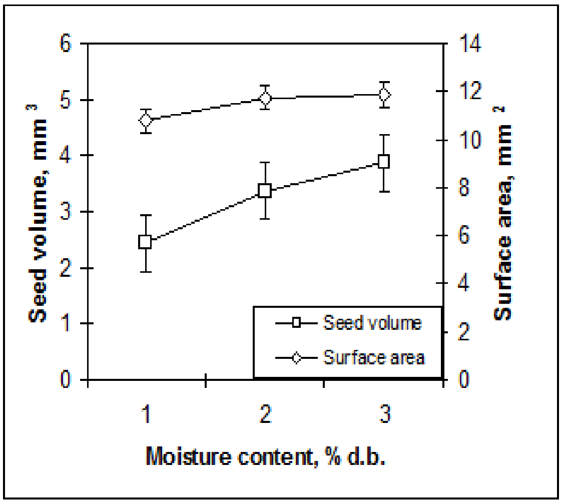


***Figure 4.*** *Effect of moisture content on seed volume and surface area*

***Seed volume and surface area***

The seed volume was calculated using the data on unit seed weight and true density of the polygonum cognatum seed, and the results were presented in Fig. 4. The volume of polygonum cognatum seed linearly increased from 2.437 to 3.869 mm$^3$ with in increase of moisture content from 7.95 to 19.14%.

The values of surface area were calculated through Eq. (6) using the data on geometric mean diameter and major axis of the polygonum cognatum seed and the results were presented in Fig. 5. The surface area of the polygonum cognatum seed increased from 10.786 to 11.867 mm$^2$ as the moisture content increased from 7.95 to 19.14%. Characteristic length of a seed is defined as the ratio between volume and surface area. Increasing the characteristic length of a seed results in increasing the heat and weight transfer rates from seeds, facilitating drying, cooling, and heating operations (Vishwakarma et al., 2012).

The relationship between moisture content and single seed volume ($V$) and surface area ($S$) can be represented by following equation:

$V = 1.794 + 0.716M_c$ ($R^2 = 0.970$) (14)

$S = 10.385 + 0.541M_c$ ($R^2 = 0.834$) (15)

Similar increasing trends for seed volume have been reported by Desphande et al. (1993); Öğüt (1998); Aviara et al. (1999); Baryeh (2002); Özarslan (2002); Sacilik et al. (2003) for soybean, white lupin seed, guna seed, millet, cotton, and hemp seed, respectively. Similar trends for surface area have been reported for millet (Baryeh, 2002), linseed (Selvi et al., 2006) and jatropha seed (Garnayak et al., 2008).

***Angle of repose and porosity***

The experimental results for angle of repose with respect to moisture content were presented in Fig. 6. The angle of repose was linearly increased from 18.35 to 25.20° with an increase in the moisture content. The seeds tend to stick together which causes impeded flowability and posseses higher angle of repose at higher moisture content. Therefore, the data would be useful in designing storage bins for polygonum cognatum seed.

The porosity was calculated through Eq. (5) using the data on bulk and true densities of the polygonum cognatum seed and the results were presented in Fig. 5. The porosity of the polygonum cognatum seed was decreased from 57.93 to 40.16% as the moisture content increased from 7.95 to 19.14% (Fig. 6). The reduction in inter granular seed spaces due to the lower porosity values at high moisture content leads to compacted arrangement of the seeds.

The relationship between moisture content and angle of repose ($\theta$) and porosity ($\varepsilon$) can be represented by the following equation, respectively:

$$\theta = 15.219 + 3.422M_c \quad (R^2 = 0.980) \qquad (16)$$

$$\varepsilon = 67.012 - 8.887M_c \quad (R^2 = 0.999) \qquad (17)$$

The angle repose results were similar to those reported by Joshi et al. (1993) for pumpkin seed, by Gupta and Das (1997) for sunflower seed, by Aviara et al. (1999) for guna seed, by Nimkar and Chattopadhyay (2001) for green gram, by Baryeh (2002) for millet, by Baryeh and Mangope (2002) for pigeon pea, by Sacilik et al. (2003) for hemp seeds and Amin et al. (2004) for lentil seed, respectively.

The negative linear relationships between porosity and moisture content have been reported by Suthar and Das (1996); Gupta and Das (1997) and Aviara et al. (1999) for karingda kernel, sunflower kernel and guna seeds, respectively.

***Static coefficient of friction***

The variation of static coefficient of friction for polygonum cognatum seed on various test surfaces, namely, plywood, glass, chipboard and galvanized metal were shown in Fig. 6. The static coefficient of friction linearly increased with increase in moisture content for the three surfaces.

The higher coefficient of friction values at greater moisture contents probably due to the increased adhesion between the seed and the friction surfaces. Due to the smoother and polisher surface of galvanized metal compared to the other test surfaces, the static coefficient of frictions were the highest in rubber, followed plywood, chipboard and galvanized metal at all moisture contents. The static coefficient of friction ranged from 0.327 to 0.360 for glass; 0.377 to 0.392 for plywood; 0.478 to 0.495 for chipboard and 0.371 to 0.380 for galvanized metal in the experimental moisture content range (Table 3 and Fig. 6). The chipborad as a surface for sliding offered the maximum friction followed by plywood, galvanized metal and glass. Similar results were reported by the other researchers (Carman, 1996; Omobuwajo et al., 2000; Baryeh, 2002; Sacilik et al., 2003).

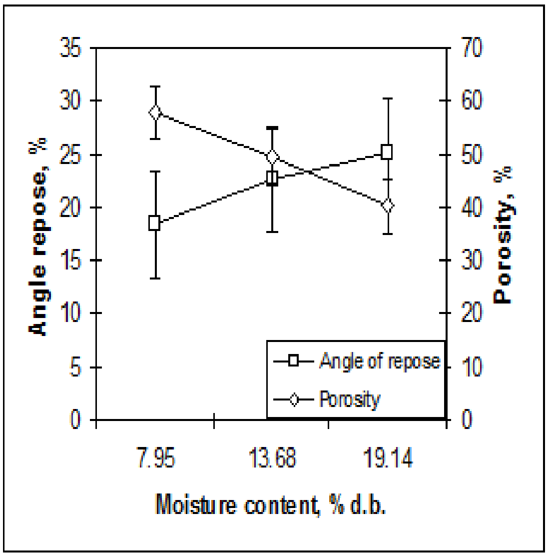


***Figure 5.*** *Effect of moisture content on angle repose and porosity*

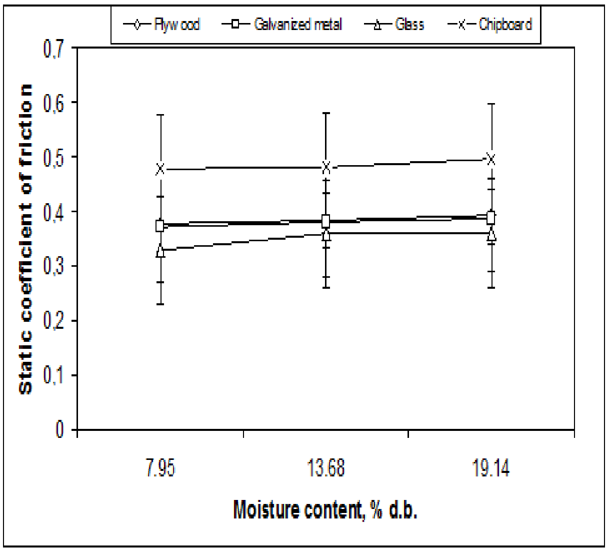


***Figure 6.*** *Effect of moisture content on static coefficient of friction*

***Table 3.*** *The linear equations for static coefficient of friction of Polygonum cognatum seed for various friction surfaces depending on moisture contents*

| Surface | Regression coefficients | | Coefficient of determination ($R^2$) |
|---|---|---|---|
| | A | B | |
| Static coefficient of friction | | | |
| Glass | 0.316 | 0.0161 | 0.786 |
| Plywood | 0.369 | 0.0075 | 0.976 |
| Chipboard | 0.468 | 0.0086 | 0.879 |
| Galvanized metal | 0.363 | 0.0085 | 0.996 |

## 4. Conclusions

The physical properties of polygonum cognatum seeds showed high variations between 7.95 to 19.14% d.b moisture content ranges. The average length, width, thickness, geometric mean diameter and individual weight of the polygonum cognatum seed increased as the moisture content increased. The polygonum cognatum seed sphericity, thousand seed weight, bulk density, seed volume, surface area, angle of repose were increased, the true density and porosity were decreased with increase in moisture content from 7.95 to 19.14% d.b. The increase in moisture content will help separating hard shelled seeds from other plant residues and obtaining cleen seeds for production. Increase in volumetric and gravimetric charecteristics of *Polygonum cognatum* seeds at higher moisture content optimizes the planting operation and ensures soil-seed contact for better germination. Improvements in germination rate of *Polygonum cognatum* seeds enable to utilize as much *Polygonum cognatum* as possible and encourage *Polygonum cognatum* production of farmers. The static coefficient of friction on various surfaces linearly increased with increase in moisture content. The chipboard as a surface for sliding offered the maximum friction followed by plywood, galvanized metal and glass. The results will provide valuable theoretical information for transporting, storing and sowing processes of *Polygonum cognatum* seeds.

## References


Altuntaş E, Özgöz E and Taşer ÖF (2005). Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. Journal of Food Engineering, 71: 37–43.

Amin MN, Hossain MA and Roy KC (2004). Effects of moisture content on some physical properties of lentil seeds. Journal of Food Engineering, 65: 83-87.

Aviara NA, Gwandzang MI and Haque M (1999). Physical properties of guna seeds. Journal of Agricultural Engineering Research, 73: 105-111.

Balasubramanian D (2001). Physical properties of raw cashew nut. Journal of Agricultural Engineering Research, 78: 291-297.

Baryeh EA (2002). Physical properties of millet. Journal of Food Engineering, 51: 39-46.

Baryeh EA and Mangope BK (2002). Some physical properties of QP-38 variety pigeon pea. Journal of Food Engineering, 56: 59-65.

Baümler E, Cuniberti A, Nolasco SM and Riccobene IC (2006). Moisture-dependent physical and compression properties of safflower seed. Journal of Food Engineering, 79: 134–140.

Coşkuner Y and Karababa E (2007). Some physical properties of flaxseed. Journal of Food Engineering, 78: 1067–1073.

Çarman K (1996). Some physical properties of lentil grains. Journal of Agricultural Engineering Research, 63: 87-92.

Davis, P.H. (1967). Flora of Turkey. Vol. 2, *University of Edinburg*, England.

Deshpande SD, Bal S and Ojha TP (1993). Physical properties of soybean grains. Journal of Agricultural Engineering Research, 56: 89-92.

Garnayak DK, Pradhan RC, Naik SN and Bhatnagar N (2008). Moisture-dependent physical properties of jatropha seed (Jatropha curcas L.). Industrial Crops and Production, 27: 123-129.

Gezer I, Haciseferogullari H and Demir F (2002). Some physical properties of Hacihaliloglu apricot pit and its kernel. Journal of Food Engineering, 56, 49-57.

Gupta RK and Das SK (1997). Physical properties of sunflower seeds. J. Agric. Eng. Res., 66, 1-8.

Joshi DC, Das SK and Mukherjee RK (1993). Physical properties of pumpkin grains. Journal of Agricultural Engineering Research, 54: 219-229.

Kaleemullah S and Gunasekar JJ (2002). Moisture-dependet physical properties of arecanut trues. Biosystems Engineering, 82: 331-338.

Mohsenin NN (1970). Physical properties of plant and animal materials. *Gordon and Breach Science Publishers*, New York.

Nimkar PM and Chattopadhyay PK (2001). Some physical properties of green gram. Journal of Agricultural Engineering Research, 80: 183-189.

Ogunjimi LAO, Aviara N.A and Aregbesola OA (2002). Some engineering properties of locust bean seed. Journal of Food Engineering, 55: 95-99.

Olajide JD and Ade-Omowaye BIO (1999). Some physical properties of locust bean seed. Journal of Agricultural Engineering Research, 74: 213-215.

Omobuwajo TO, Sanni LA and Balami YA (2000). Physical properties of sorrel (*Hibiscus sabdariffa*) seeds. Journal of Food Engineering, 45: 37-41.

Öğüt H (1998). Some physical properties of white lupin. Journal of Agricultural Engineering Research, 69: 273-277.

Onen H, Yılar M and Kaya C (2009). Phenoleic composition of madimak (Polygonum cognatum Meissn.) plants. 3rd Plant protection Congress. Abstract Book Page 275. Van, Turkey.

Onen H, Parmaksız I and Gebologlu N (2011). Reproduction capacity of Polygonum cognatum Meissn. (Knotweed). ASA, CSSA, and SSSA International Annual Meetings, Oct. 16-19, 2011, San Antonio, TX, ASA Section: Global Agronomy.

Özarslan C (2002). Some physical properties of cotton grain. Biosystems Engineering, 83: 169-174.

Sacilik K, Ozturk R and Keskin R (2003). Some physical properties of hemp grain. Biosystems Engineering, 86: 213-215.

Saiedirad MH, Tabatabaeefar A, Borghei A, Mirsalehi M, Badi F and Ghasemi VM (2008). Effects of moisture content, seed size, loading rate and seed orientation on force and energy required for fracturing cumin seed (Cuminum cyminum Linn.) under quasi-static loading. Journal of Food Engineering, 86: 56–572.

Selvi KC, Pinar, Y and Yeşiloğlu E (2006). Some physical properties of linseed. Biosystems Engineering, 95 (4), 607–612.

Sitkei G (1976). Mechanic of Agricultural Materials. *Akademia Kiado,* Budapest.

Suthar SH and Das SK (1996). Some physical properties of karingda [Citrus lanatus (thumb) mansf] grains. Journal of Agricultural Engineering Research, 65: 15-22.

Tabatabeefar A (2003). Moisture-dependent physical properties of wheat. International Agrophysics, 17: 207–211.

Tunde-Akintunde TY and Akintunde BO (2004). Some physical properties of sesame seed. Biosystems Engineering, 88: 127–129.

Vilche C, Gely M and Santalla E (2003). Physical properties of quinoa grains. Biosystems Engineering, 86: 59-65.

Visvanathan R, Palanisamy PT, Gothandapani L and Sreenarayanan VV (1996). Physical properties of neem nut. Journal of Agricultural Engineering Research, 63: 19-25.

Vishwakarma RK, Shivhare US and Nanda SK (2012). Physical Properties of Guar Seeds. Food and Bioprocess Technology, 5: 1364–1371.

Yazgan A ve Saglam N (1992). A research on culture of knotweed (*Polygonum cognatum* M.). Turkey I. National Horticulture Congress, Volume II, 21-23.

Yalcın I and Özarslan C (2004). Physical properties of vetch seed. Biosystems Engineering, 88: 507–512.

Yıldırım A, Mavi A and Kara AA (2003). Antioxidant and antimicrobial activities of *Polygonum cognatum* Meissn extracts. Journal of the Science of Food and Agriculture, 83: 64-69.

Yılar M, Özkurt M and Önen H (2006). Assessment the allelopathic potential of madimak (*Polygonum cognatum* Meissn.). *Workshop on Allelopathy (The utilization of allelopathy in Turkey, Recent, Today, Future) Symposium Proceedings*, pp. 57-58. Yalova.