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Differentiation in Gravimetrical and Frictional Properties of Phaseolus Vulgaris L. by a Partial Least Square Regression Model

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ABSTRACT
This study was conducted to determine gravimetrical and frictional properties of four white kidney beans varieties (Karaman, Topçu, Karacaşehir and Akman), each having five different seed moisture contents (14.58 %, 24.32 %, 33.45 %, 42.54 % and 53.48 %). According to obtained results, the axial dimensions of all bean varieties increased by increasing the seed moisture content. In addition, there was a positive relationship between the thousand grain mass and seed moisture content and between the surface area and moisture content. The seed bulk densities negatively correlated with the seed moisture content. A partial least square regression (PLSR) model included all parameters successfully differentiated the varieties into 3 independent groups: Akman and Topçu were in the same group (group 1), and each of Karacaşehir (group 2) and Göynük (group 3) varieties significantly differed from all varieties. The result of PLSR score plot significantly differentiated the five different water contents of the seeds: the seeds with 25%, 35% and 45% moisture content were in the same group. It was concluded that both the grain water content and the grain variety had significant effects on engineering properties.

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Kuru Fasulye (Phaseolus vulgaris L.) Çeşitlerinin Gravimetrik ve Sürtünme Özelliklerinin Kısmi En Küçük Kareler Regresyon Modeli ile Gruplandırılması

ÖZET
Bu araştırmada 4 farklı kuru fasulye çeşidinin (Karaman, Topçu, Karacaşehir ve Akman) 5 farklı nem içeriğinde (%14.58, %24.32, %33.45, % 42.54 ve %53.48) fiziksel, mekanik ve sürtünme özellikleri araştırılmıştır. Elde edilen sonuçlara göre, tüm fasulye çeşitlerinin eksenel boyutları tohum nemi içeriğinin arttırılmasıyla artmıştır. Buna ilaveten bin dane ağırlığı, yüzey alanı ve tohum nem içeriği arasında pozitif bir ilişki belirlenmiştir. Ayrıca tohum hacim ağırlığı ile tohum nem içeriği arasında negatif bir ilişki olduğu saptanmıştır. Araştırmada kısmi en küçük kareler regresyon modeli tüm parametreleri bağımsız bir şekilde 3 bağımsız gruba ayırmış ve Karacaşehir ve Göynük çeşitleri diğer çeşitlerden önemli düzeyde farklı bulunmuştur. Modele ait skor grafiğine göre %25, %35 ve %45 nem içeriğine sahip tohumlar aynı grupta yer almıştır. Sonuç olarak hem tohum nem içeriği hem de çeşitler arasındaki farklılıklar tohumların mühendislik parametreleri üzerin önemli düzeyde etkili olmuştur.

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INTRODUCTION

White kidney bean (WKB) has important nutritional qualities; it is high in protein and low in fat content. The product also contains some key nutrients, vitamins, fiber, zinc, and copper. WKB has been produced in Turkey for over a century (Sehirali 1988). Currently, Turkey has a 4938 ha cultivation land of WKB with an annual production of 630347 tons.

During the cultivation process from sowing to transportation, the size, shape and mechanical behaviors of bean seeds or grains need to be known for selecting appropriate types of machinery for separating, harvesting, sizing and grinding. Furthermore, these properties are used to develop and design new machineries. Previous study reported that the size and mass values are crucial for spreaders machines (Altuntaş and Yıldız 2007).

Surface area and grain volume should be known for designing drying equipment, and frictional properties of the grain are needed for designing the hoppers and conveyors (Kalkan and Kara 2011). Also, it is necessary to know the deformation characteristics of the grains for milling equipment.

The physical properties of the crops were studied in such species including edible squash seeds, rice, garlic, Jatropha fruith, niger seed, soybean and barley (Pradhan et al 2009; Paksoy and Aydin 2004; Tavakoli et al 2009; Haciseferoğullari et al 2005; Zareiforoush et al 2009; Tavakoli et al 2009;Solomon and Zewdu 2009; Öztürk and Esen 2008).

To the best of our knowledge, no studies are available to determine the engineering properties of WKB varieties with different seed moisture contents. A minor change in seed moisture content could have a great effect on the storage life of the seeds. Consequently, it is important to know the moisture content in order to make a reasonably accurate prediction of the possible storage life of the seeds. Therefore, the aim of this study was to test the effects of various seed moisture contents on the engineering properties of different WKB varieties (two of which are newly authorized in Turkey).

MATERIALS and METHODS

WKB varieties of Akman, Topcu, Karacaşehir and Göynük (*Phesolous vulgaris*) each sustaining five different seed moisture contents (14.28, 24.32, 33.45, 42.54 and 53.48%) were used as the study material. All the WBK varieties were produced in Turkey. The initial moisture content of the seeds were determined by the ASAE method (ASAE, 1999). Approximately 10 g of the bean was dried in an oven (for 20 h at 130 °C) to reach a constant the sample weight. The initial seed moisture content was calculated as 14.28 % for all of the varieties. Then the following equation (1) was used to obtain a 24.32, 33.45, 42.54 and 53.48 % water contents.

$$Q = \frac{Bi(Mf - Mi)}{Mi + 100} \quad (1)$$

In this equation; Q: Q = mass of water to suffix (kg), Bi: The initial samples mass (kg); Mi: the initial moisture content (% db) and Mf: the final content of the samples (% db).

Moistening was performed by preserving the sample primed with the essential amount of water in each status in a hermetic container and turning around periodically over a period of 48 h. These samples were laid in plastic cases in a freezer at 4 °C for a week to allow an uniform moisture content within the seeds (Sun and Woods, 1994). Eventually, the final moisture levels of the samples were determined as 24.32, 33.45, 42.54 and 53.48 %. All the physical and engineering specifications of the samples were determined for each of five moisture levels in the range of 14.28 to 53.48%.

In order to define the physical specification of the seeds, three sub-samples of 0.5 kg each were arbitrary separated from the entire samples. Two hundred seeds were collected from each of three sub-samples and thus 600 seeds were acquired and combined, and 50 seeds were arbitrarily selected at the end of this process (Sologubik et al 2013). A digital micrometer was used to measure the size of the seeds. The arithmetic (Da) and geometric (Dg) mean of seed diameters were calculated by the following equation2 and 3 (Işık and Ünal 2007):

$$Da = \frac{L + W + T}{3}. \quad (2)$$

$$Dg = \sqrt[3]{L * W * T}. \quad (3)$$

The sphericity (Φ) was calculated with following equation 4 (Işık and Ünal 2007). In this equation L, W, and T are seed length, width and thickness, respectively.

$$\theta = \left(\frac{\sqrt[3]{L * W * T}}{L}\right) x100 \quad (4)$$

A thousand grain weight was arbitrarily determined by selecting 100 grains from the all sample, measuring their weight on a digital electronic balance with an accuracy of 0.0001 g and multiplying by 10 to get a mass based on 1000 grains (Coşkuner and Karababa 2007). Bulk density (db %) was considered as the ratio between the mass of a grain and its total volume (Vilche et al, 2003). The grain volume, as a function of moisture content, was determined using a liquid displacement method where Toluene (C_7H_8) was used (Altuntaş and Yıldız, 2007). The porosity (ε), bulk density (ρ_b), true density (ρ_t) and surface area of the samples (S) were determined by the following equations 5 and 6, respectively (Sologubik et al 2013, Nimkar et al 2005).

$$\varepsilon = \frac{1 - \rho_b}{\rho_t} * 100 \quad (5)$$

$$S = \pi * Dg^2 \quad (6)$$

where S is the surface area (mm^2). surface; PVC, MDF, Galvanized iron and rubber (Sologubik et al 2013).

The coefficient of friction was calculated by the following equation.

$\mu = \tan\alpha$

The measurements of each test parameter were obtained from four WKB varieties by five humidity levels of 10 replicates and the data were subjected to ANOVA. All the parameters were regressed against to the varieties and water contents by PLSR model (non-cross validation) using a statistical software of MINITAP (Minitab Inc., 2018). The model used was as following equation 7:

$$Y = b0 + b1X_1 + b2X_2 + \ldots + bpXp \quad (7)$$

Where Y, the variety or the seed water content; b0 is the regression coefficient for the intercept; the bi values are the regression coefficients (for variables 1 through p) computed from a total of twelve gravimetric and frictional properties. PLSR model is used in order to reduce 12 measured parameters into a few components which explains most of the variance scattered around the varieties or seed water content. The PLSR models generated from the measurements of 12 parameters were graphically spotted on the score plots to demonstrate whether the differences between the varieties or water contents are significant or not, only by 2 components (component 1 versus component 2). This way of analysis provides an accurate and simple interpretation of differences between the varieties or water contents in two components merged from 12 parameters by the models generated from PLSR analysis.

RESULTS AND DISCUSSION

Grain Dimensions

The main seed size (length, width and thickness) is essential to design the hole sizes in seed handling material. In this study, the main dimensions of seeds differed significantly ($p < 0.001$) between the varieties.

Mean values of the size dimensions of seeds at various moisture levels are shown in Table 1. There was generally a positive relationship between the axial dimensions and seed moisture contents. The dimensions of the seeds increased which was linearly proportional to the increase in moisture content (Table 1). The geometric mean diameter is used to define the specific dimension for chaotically shaped solids. Additionally, it is used to estimate the projected area of a particle moving in the turbulent space (Gharibzahedi et al 2010). The arithmetic and geometric mean values are also given in Table 1. In the study, the mean diameters increased with the increase in moisture content throughout the axial dimensions of all the seeds.

One Thousand Grain Mass

A linear relationship was observed between the seed moisture content and the thousand grain mass in the study, and this relationship was statistically significant ($p<0.001$) (Figure 1). As moisture content increased from 14.28 % to 53.42 %, the values of one thousand grain mass increased to 256.00, 263.00, 214.00 and 250.00 g for Akman, Topçu, Karacaşehir and Göynük varieties, respectively. Similar results were reported for soybean, Bombay bean, faba and barbunia by Deshpande et al 1993; Tekin et al 2006; Altuntas and Yıldız 2007 and Cetin 2007, respectively.

Bulk Density

In the study, the highest bulk density values were obtained from Akman and this was followed by Karacaşehir, Topçu and Göynük varieties (Figure 2). Increasing moisture content in seeds decreased bulk densities of the seeds (Figure 2). This pattern could explain that the volume of air entrained between the wet grains was larger than the volume of the inter-grain air in the dry grains. Thus, this resulted in an effect of having greater compaction in dry grains as compared to wet ones. A similar result was reported by Aviara et al 1999, Dutta et al 1988, Deshpande et al 1993, Gupta and Das 1997, Öztürk and Esen 2008 and Tavakoli et al 2009.

True Density

In the study, the highest true density value was obtained from the variety of Topçu (1440 kgm^{-3}) and the lowest value in Göynük with 1183 kgm^{-3} (Figure 2). We also found a linear relationship between the seed moisture content and true density. True density values were determined as 1290 kgm^{-3} and 1347 kgm^{-3} for 14.28% and 53.48% seed moisture content, respectively (Figure 3). Similar relationship was reported for canola (Çalışır et al 2005), soybean (Deshpande et al 1993) and sorghum (Mwithiga and Sifuna, 2006).

Porosity

In the study, the highest porosity value was obtained from the Topçu (45%), which was followed by the Karacaşehir, Göynük and Akman (40%, 38% and 38%) varieties, respectively (Figure 3). Furthermore, there was a positive linear relationship between the seed moisture content and porosity values. The porosity values of 40% and 41% were obtained for the moisture contents of 14.28 and 53.48%, respectively (Figure 3). These results were in agreement with the previous studies conducted on sorghum (Mwithiga and Sifuna 2006) and niger seed (Solomon and Zewdu 2009).

Surface Area of Grain

The highest surface area in the study was determined for the variety of Göynük with 198 mm^2.

In addition, the surface area values were determined for the varieties of Topçu, Akman and Karacaşehir as

188, 174 and 117 mm², respectively (Figure 3).

Surface area increased due to the increase in moisture content of the seeds (Figure 3), resulting significant differences between surface area of the varieties (p<0.001). In general, there was a linear relationship between the seed varieties and seed moisture content (Figure 3), and the same relationship was confirmed by Deshpande et al (1993) and Tekin et al (2006).

Sphericity

The sphericity values were given in table 2. The maximum and minimum sphericity values were observed for the varieties of Karacaşehir, Göynük, respectively. In the study, no positive relationship between the seed moisture content and sphericity values was found. In contrast, there was an overall negative relationship between the seed moisture content and sphericity, as this was confirmed also by Tekin et al (2006), Altuntas and Yıldız (2007) and Cetin (2007).

Table 1. Means of the dry bean seed dimensions at different moisture content levels

Seed varieties		Length, (L)	Width, (W)	Thickness, (T)	Arithmetic mean, (Da)	Geometric mean, (Dg)
Akman		11.32	7.26	4.99	7.86	7.42
Topçu		11.84	7.26	5.39	8.17	7.73
Karacaşehir		9.12	5.53	4.49	6.38	5.94
Göynük		13.81	7.03	5.11	8.65	7.91
	P	0.001	0.001	0.001	0.001	0.001
Seed moisture Content (%)		Length, (L)	Width, (W)	Thickness, (T)	Arithmetic mean, (Da)	Geometric mean, (Dg)
14.28		11.00	6.41	4.77	7.40	6.76
24.32		11.27	6.68	4.91	7.62	7.16
33.45		11.53	6.80	5.08	7.80	7.34
42.54		11.69	6.94	5.06	7.90	7.41
53.48		12.13	7.04	5.16	8.11	7.59
	P	0.001	0.001	0.001	0.001	0.001

Interaction values

Varieties	Moisture content (% d.b.)	Axial dimensions (mm)			Average diameters (mm)	
		Length, (L)	Width, (W)	Thickness, (T)	Arithmetic mean, (Da)	Geometric mean, (Dg)
Akman	14.28	10.89 b	6.69 c	4.74 c	7.44 c	7,00 a
	24.32	10.97 b	7.23 b	4.87 bc	7.69 b	7.27 b
	33.45	11.63 a	7.39 ab	5.26 a	8.09 a	7.66 a
	42.54	11.50 a	7.66 a	5.08 ab	8.08 a	7.64 a
	53.48	11.62 a	7.35 b	5.01 b	7.99 a	7.52 a
P		0.001	0.001	0.001	0.001	0.001
Topçu	14.28	11.43 b	6.91 d	5.21 b	7.88 c	7.43 c
	24.32	11.52 b	7.00 cd	5.28 b	7.93 c	7.52 bc
	33.45	11.77 ab	7.23 bc	5.38 ab	8.13 bc	7.70 b
	42.54	12.26 a	7.45 ab	5.51 a	8.41 ab	7.94 a
	53.48	12.21 a	7.69 a	5.55 a	8.49 a	8.04 a
P		0.001	0.001	0.001	0.001	0.001
Karacaşehir	14.28	8.54 c	5.38 b	4.26 b	6.06 c	5.08 c
	24.32	8.62 c	5.40 b	4.42 b	6.15 c	5.90 bc
	33.45	8.86 bc	5.50 b	4.49 b	6.28 bc	6.02 b
	42.54	9.08 b	5.56 ab	4.50 b	6.38 b	6.09 b
	53.48	10.51 a	5.82 a	4.78 a	7.04 a	6.63 a
P		0.001	0.001	0.001	0.001	0.001
Göynük	14.28	13.13 b	6.64 b	4.88 a	8.21 b	7.51 b
	24.32	13.95 a	7.10 a	5.07 ab	8.71 a	7.94 a
	33.45	13.87 ab	7.069 a	5.17 a	8.70 a	7.96 a
	42.54	13.91 a	7.08 a	5.15 a	8.71 a	7.96 a
	53.48	14.18 a	7.28 a	5.29 a	8.91 a	8.17 a
P		0.001	0.001	0.001	0.001	0.001

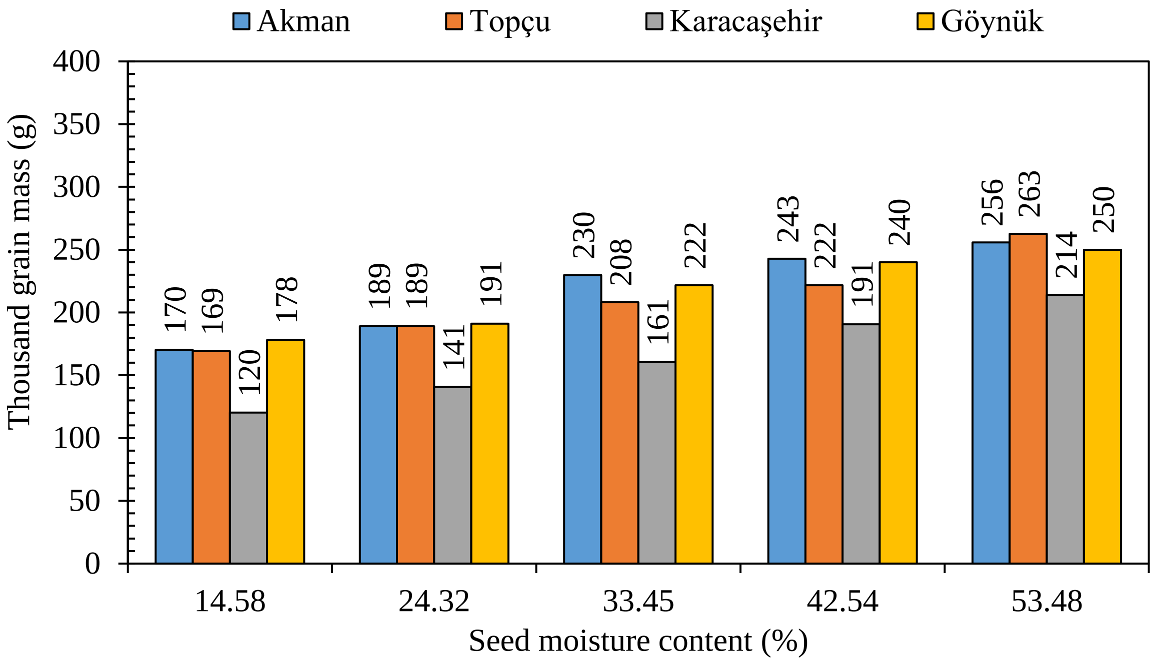


Figure 1. The effects of the seed moisture content and seed varieties on the thousand grain mass

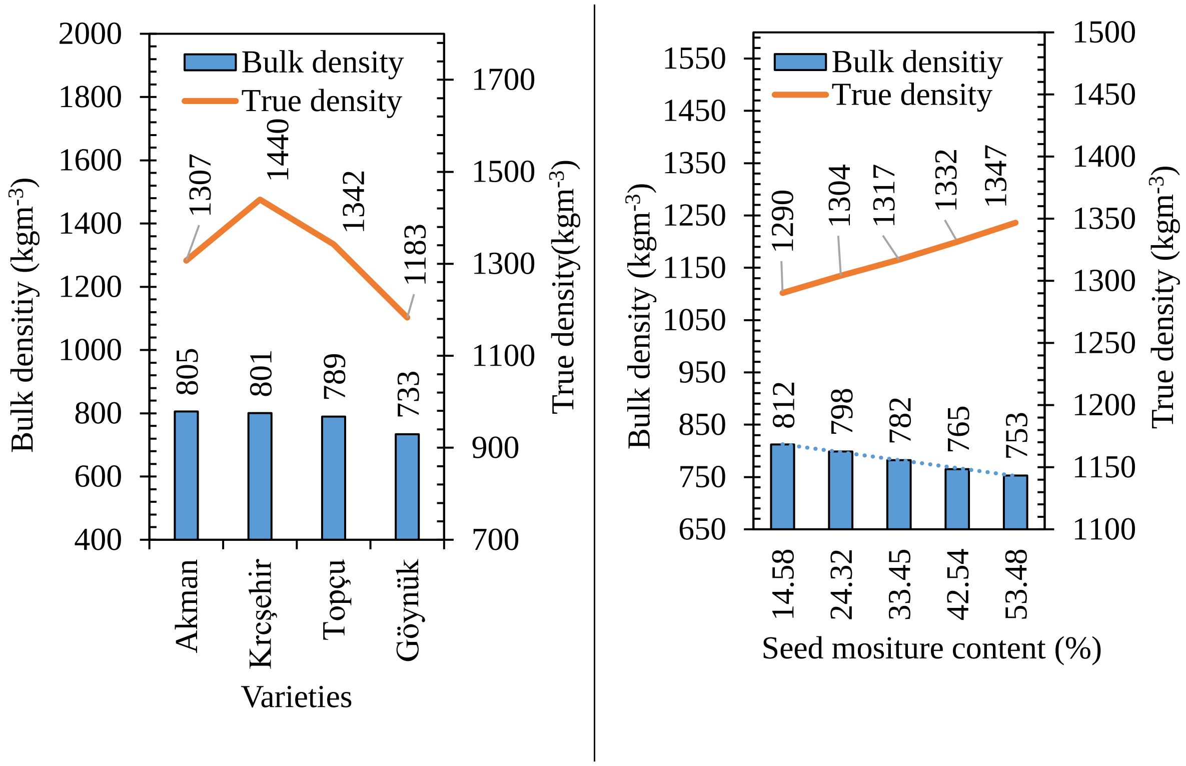


Figure 2. The effects of seed moisture and seed variety on the bulk density and true density

Static Coefficient of Friction

Having considered different surface materials (PVC, MDF, galvanized iron and rubber) the static coefficient of friction of bean varieties were presented in Figure 4. In the study, the minimum static coefficient of friction values was obtained from the using galvanized iron surface for all bean varieties. In addition, the maximum static coefficient of friction was observed for rubber surface with all bean varieties (Figure 4). Coskun et al (2006), Cetin (2007), Nimkar et al (2005) and Tekin et al (2006) determined maximum static coefficient of friction on the MDF surface for sweet corn, barbunia, moth gram and bombay bean, respectively. In our study, the minimum static coefficient of friction was observed for the surface of galvanized iron. This might be due to the fact that the galvanized iron has smoother and more refined surface compared to the other types of surfaces.

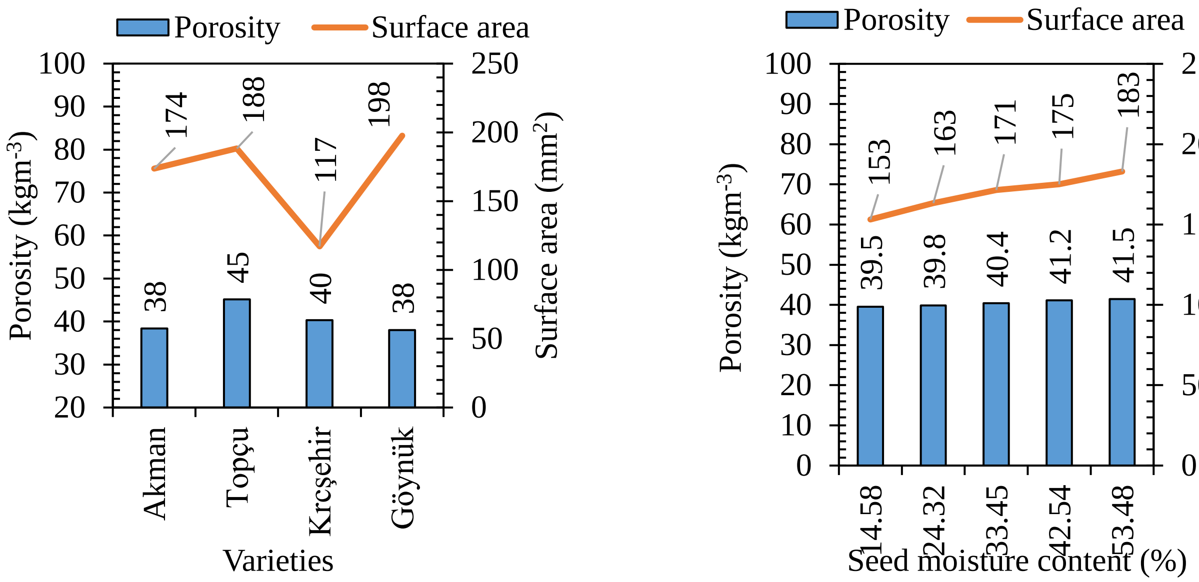


Figure 3. Variations of seed moisture content and seed varieties on the porosity and surface area

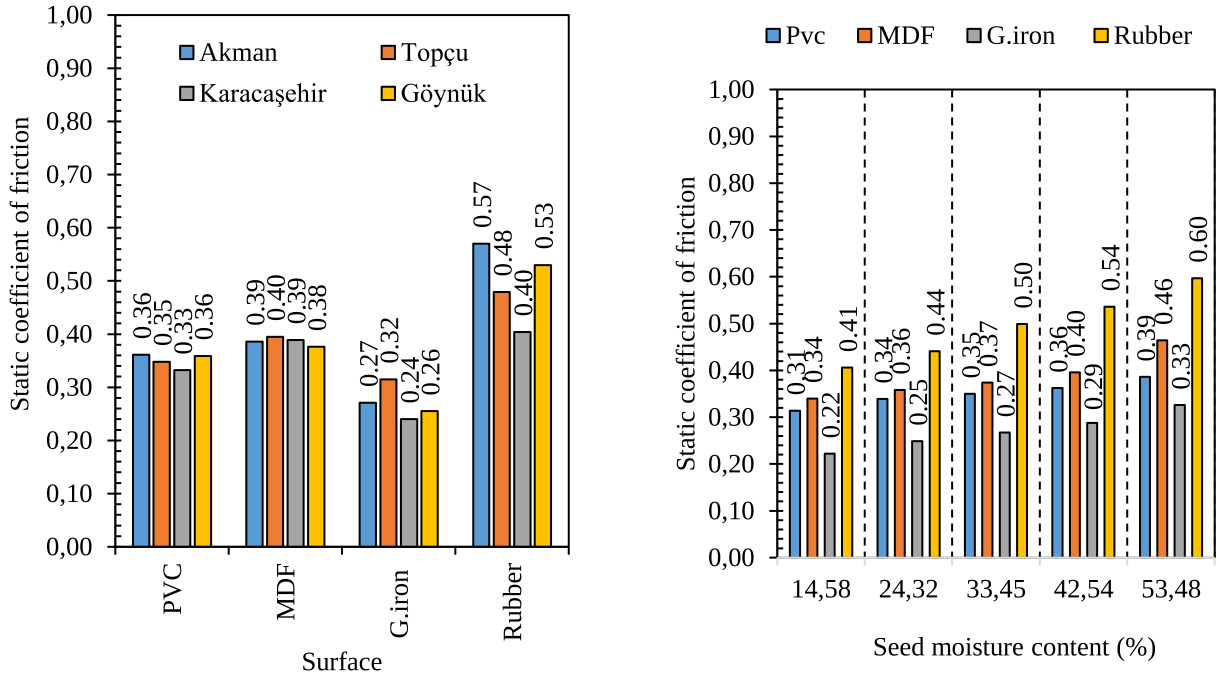


Figure 4. The effects of fraction surface and seed moisture content on the static coefficient of friction

In the study, we found a positive relationship between the moisture level and static friction for all seed varieties (Figure 4). The maximum static friction was obtained from the rubber friction surface and 53.48 % seed moisture content. A possible reason for this could be the increased adhesion between the grain and the material surfaces at the higher moisture level.

Shelling Resistance

There were statistically significant differences ($p<0.001$) among the bean varieties in shelling resistance values (Table 2). In the study, the variety Göynük sustained maximum shelling resistance and this was followed by the varieties of Karacaşehir, Akman and Topçu. We found that there was a negative relationship between seed moisture content and shelling resistance. As overall, increasing seed moisture content decreased shelling resistance. The small shelling resistance at higher moisture content might have resulted from the fact that the grain became more sensitive for cracking at low moisture. The similar results stated that Konak et al (2002), Ozarslan (2002) and Tekin et al (2006).

Table 2. The surface area, Shelling resistance and sphericity values of the dry bean seed at different moisture content levels

Seed varieties		Surface area (mm^2)	Shelling resistance(N)	Sphericity (%)
Akman		173.5 c	213.7 c	65.7 b
Topçu		188.3 b	171.7 d	65.5 b
Karacaşehir		117.1 c	242.7 b	67.1 a
Göynük		197.6 a	303.4 a	57.4 c
	P	**0.001**	**0.001**	**0.001**
Seed moisture content (%)		**Surface area (mm^2)**	**Shelling resistance (N)**	**Sphericity (%)**
14.28		153.1 d	191.5 d	63.8 ab
24.32		162.2 c	211.1 c	64.4 a
33.45		171.4 b	239.4 b	64.3 a
42.54		174.9 b	258.9 a	64.1 a
53.48		183.0 a	263.4 a	63.0 b
	P	**0.001**	**0.001**	**0.001**

Interaction values

Varieties	Moisture content (% d.b.)	Surface area (mm^2)	Shelling resistance (N)	Sphericity (%)
Akman	14.28	154.4 e	182.6 gh	64.6 ef
	24.32	166.5 d	195.9 fg	66.5 bcde
	33.45	184.8 bc	215.3 ef	66.1 bcde
	42.54	183.8 bc	236.9 cd	66.5 bcde
	53.48	178.5 bc	237.9 cd	65.0 bcde
P	0.001	**0.001**	**0.001**	**0.001**
Topçu	14.28	173.8 cd	126.1 j	65.1 ef
	24.32	177.9bcd	151.8 ı	65.5 de
	33.45	186.7 b	165.4 hı	65.6 de
	42.54	199.1 a	201.7 fg	65.1 ef
	53.48	204.1 a	213.4 ef	66.0 cde
P	0.001	**0.001**	**0.001**	**0.001**
Karacaşehir	14.28	106.2 g	200.9 fg	68.0 abc
	24.32	109.5 g	221.4 de	68.6 a
	33.45	114.1 g	257.8 b	68.2 ab
	42.54	116.8 g	265.1 b	67.4 bcd
	53.48	139.2 f	268.3 b	63.3 f
P	0.001	**0.001**	**0.001**	**0.001**
Göynük	14.28	178.1bcd	256.5 bc	57.5 g
	24.32	199.2 a	275.4 b	57.1 g
	33.45	200.3 a	319.3 a	57.5 g
	42.54	200.2 a	332.0 a	57.4 g
	53.48	210.3 a	334.1 a	57.8 g
P	0.001	**0.001**	**0.001**	**0.001**

Partial Least Square Regression Model to Differentiate the Varieties With Varying Levels of Seed Moisture Content

Twelve experimentally tested parameters were combined and subjected to a PLSR analysis to establish a model in order to observe whether the varieties and the seed water contents differed from each other. In Table 3, the results of regression analysis were presented. The model had explained about 82 per cent of total variance using only 4 components with high regression coefficients, 65 and 67 % for the variety and the seed water content, respectively.

For instance, the models for the variety and seed water content obtained from this particular PLSR analysis were as follows:

Y (the variety) = 6.68 + Wide (-0.52) + Length (0.10) + Thickness (0.34) + AMD (0.030) + GMD (-0.031) + Surface area (0.00079) + Sphericity (-0.058) + static coefficient friction (0.00877) + Friction on wood (0.238) + Friction on PVC (-2.277) + Friction on galvanized iron (-0.628) + Friction on rubber (-2.35).

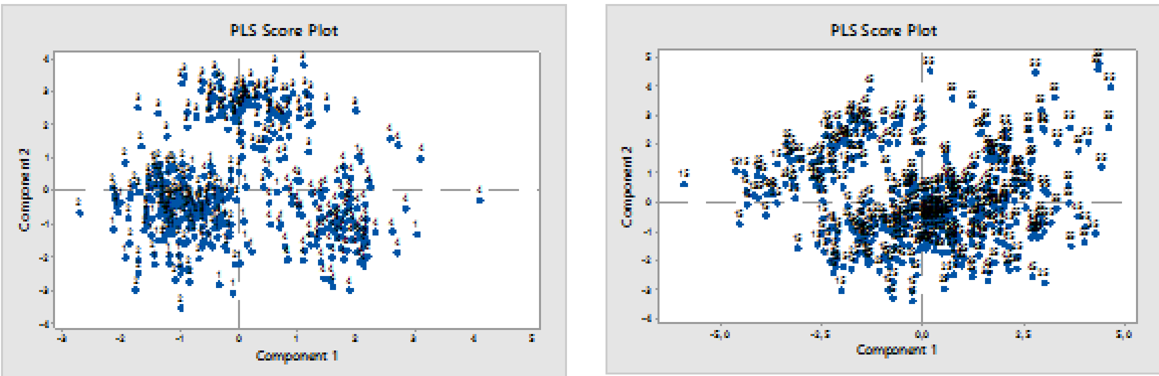
Table 3. Results of PLS regression analysis

	Number of components used in the model	Total variance explained by the model	R-sq	P (level of significance)	Pooled Standard error (SE)
Variety	4	81.43%	65.36%	0.0000	0.44
Seed water content	4	81.90%	67.38%	0.0000	66.1

Y (the seed water content) = -70.99 + Wide (-0.62) + Length (-0.48) + Thickness (3.37) + AMD (-0.49) + GMD (-0.11) + Surface area (0.0031) + Sphericity (0.242) + static coefficient friction (0.079) + Friction on wood (53.52) + Friction on PVC (48.63) + Friction on galvanized iron (69.21) + Friction on rubber (25.35).

In this study, the model well defined the differentiations of both varieties and seed water contents under the influence of 12 combined parameters. Having carefully examined Figure 5a and Figure 5b, it can be seen that the varieties were significantly (P<0.000) different from each other and that there were quiet remarkable differences in the seed water contents. In the score plot (Figure 5), the varieties were separated by 2 components only, and there were significant differences between the varieties in terms of 2 components. Topçu and Akman were in the same group, which were largely differed from the Karacaşehir and Göynük, where both are independently falling into different groups. In figure 5, the score plot based on only two components was successful to differentiate the seed water contents: In general, the water contents of 25, 35 and 45% were in the same group, while there were remarkable differences between the seed water contents of 15, 35 and 55% in our study. According to these results, each of WKB varieties may behave differently during the sowing process due to the great influence of the water content. Therefore, the best WKB varieties with these characteristics could be selected for cultivation.

In currentstudy, we have successfully shown that a single analysis of 12 combined parameters can be used to establish a good differentiation of the seed varieties and even with different water contents.



a b

Figure 5. a) The score plot of seed varieties by component 1 and component 2 (Varieties of 1, 2, 3 and 4 were Akman, Topçu, Karacaşehir and Göynük, respectively). b) The score plot of seed water contents by component 1 and component 2.

CONCLUSION

The results of the studied physical and mechanical properties of dry beans seeds can be summarized as follows;

1. Range of the dimensions increased with increase in seed moisture content for all of bean varieties with various moisture contents. Increasing seed moisture content increased one thousand grain mass, true density, porosity, surface area and static coefficient of friction. The bulk density values were negatively correlated with seed moisture content. In addition, the variety of Topçu had the minimum bulk density with maximum porosity.
2. Maximum static coefficients of friction were obtained for rubber surface for all bean varieties. The study indicated that Göynük had the maximum shelling resistance value which was followed by the varieties of Karacaşehir, Akman and Topçu. Besides, there was a negative relationship between the seed moisture content and shelling resistance.
3. In the study, PLSR model was able to make good differentiations of grain varieties and their water contents with high regression coefficients.

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