J. BIOL. ENVIRON. SCI.,
2022, 16(46), 18-26

Original Research Article

Physical and Classification Characteristics of Soybean (*Glycine max* CV.) Varieties

Hilal Erdogan[1], Halil Unal[1*] and Ismayil Safa Gurcan[2]
[1]Bursa Uludağ University, Faculty of Agriculture, Department of Biosystems Engineering, Bursa, TÜRKİYE
[2]Ankara University, Faculty of Veterinary Medicine, Department of Biostatistics, Ankara, TÜRKİYE

Received: 27.06.2021; Accepted: 19.10.2022; Published Online:09.11.2022

ABSTRACT

In this study, physical and classification characteristics of 10 different soybean grains (*Glycine max* cv. A-3127, Ataem-7, Dery, Galina, Rubin, S-1, Umut-2002, Vojvodjanka, Yemsoy and Yeşilsoy) in storage moisture content were examined. These physical characteristics such as: average length, weight, thickness, geometric mean diameter, sphericity, surface area, volume, weight of thousand grains, bulk and true densities, porosity, terminal velocity, rupture force and coefficient of static friction. Results showed that 'Umut-2002' variety had highest length (8.07 mm), width (7.00 mm) and heavy (205.2 mg) than the other varieties, while 'Yeşilsoy' variety had the highest thickness (5.80 mm) and the roundest (91.4%). The grain variety with the highest bulk density was identified as 'Dery'. True density and porosity values were observed to be the highest grain variety 'Ataem-7'. 'Dery' variety which is the highest terminal velocity and rupture force value among other varieties. The 'Rubin' variety has been found to have the highest static coefficient of friction on all surfaces among all other varieties. Used dendrogram from single linkage nearest neighbour agglomerative cluster analysis which groups ten soybean varieties. Four different clusters of soybean varieties were obtained. The 'Ataem-7' variety can be regarded as a separate species from the others.

Keywords: Soybean, Gravimetrical properties, Aerodynamic properties, Static friction coefficient, Dendrogram

INTRODUCTION

The soybean (*Glycine max*) is a member of the Fabaceae family and is thought to have spread from northern China, where it originated, to Asia, the USA, Brazil, and then to Argentina (Ekka and Lal 2016). Soybean stands out as a source of protein in response to the rising prices of other protein-derived foods (meat, milk, fish, eggs, etc.) in the world (Davies and El-Okene 2009, Gomes *et al.* 2014). Soybean, with its superior alimentary properties, is a highly nutritional leguminous source of vitamins and minerals. Due to the structure of the soybean, it has many functional characteristics. Soybeans are found in many colors, including yellow, black, green, brown and spotted varieties. The dark-colored beans have become popular worldwide due to their applicable properties, in addition to being harder than the light-colored varieties (Zhou *et al.* 2010, Liu *et al.* 2017).

It is necessary to know the rheological, mechanical and physical properties of the beans to design machinery and equipment to be used in sowing, harvesting, transportation, packaging systems, storage and all food processing areas (Jaliliantabar *et al.* 2013). Knowing the porosity and true, and bulk density values of the beans are necessary when designing the ventilation, separation, transport, grading and cleaning systems and at the same time for determining the quality parameters of the beans. Rheological properties of the beans, such as rupture force, are important in the design of food processing systems for oil extraction and milling (Tavakoli *et al.* 2009). In recent years, physical properties have been determined for various seeds such as soybean (Kibar and Ozturk 2008, Shirkole *et al.* 2011, Alibas and Koksal 2015), canola seed (Razavi *et al.* 2009), rapeseed (Izli *et al.* 2009), safflower (Tarighi *et al.* 2011) and and rice bean (Bhushan and Raigar 2020).

In the literature, there is a lack of research dealing with the physical properties of the large number of soybean varieties regarding their moisture content or classifying them in their own right. For this reason, the aim of the present study was to determine the physical properties of ten different varieties of soybean and apply a dendrogram to establish the classification of these varieties among themselves and thus provide resources for industry and other researchers.

* Corresponding author: hunal@uludag.edu.tr

MATERIALS AND METHODS

In this study, 10 different types of soybeans obtained from the Department of Field Crops of Bursa Uludag University were used (A-3127, Ataem-7, Dery, Galina, Rubin, S-1, Umut-2002, Vojvodjanka, Yemsoy and Yeşilsoy) (Figure 1). The soybeans to be used in the experiments were cleaned of foreign matter, dirt, dust, and broken and immature beans. The drying oven method was used to determine the moisture values of the beans by ASAE standard S35-2 (ASAE 1997). For each variety, approximately 15 g of the sample was taken (for three replicates), deposited in a petri dish and then placed in a drying oven (Nuve, EN500S, accuracy ±1°C, Turkey) at 103°C for 72 h. When they were removed from the oven, the moisture values were determined from the initial and final weight values. Each of the samples was replicated three times and mean moisture content of A-3127, Ataem-7, Dery, Galina, Rubin, S-1, Umut-2002, Vojvodjanka, Yemsoy and Yeşilsoy varieties was found 8.69%, 8.83%, 8.53%, 7.97%, 7.74%, 8.33% 8.64%, 7.92%, 8.27% and 8.02% d.b., respectively.

Figure 1. Types of soybean grains used in the research.

To determine the average size of the soybean grains, 100 grains were randomly picked and their three axial dimensions, namely length, width and thickness were measured using a digital calliper with a sensitivity of 0.01 mm. The geometric mean diameter, sphericity, surface area and grain volume were computed according to Shirkole *et al.* (2011) and Unal *et al.* (2009).

The thousand grain weights of the soybeans were measured with an electronic balance (RADWAG PS4500/C/2, sensitivity 0.01 g, Poland). To evaluate thousand grain weights, 100 randomly selected grains from the bulk were averaged.

Bulk density is the ratio of grain weight to the volume of the sample container. True density was determined using the toluene displacement method (Mohsenin 1986). Porosity was computed from the values of the true and bulk density of beans using the relationship given by Shirkole *et al.* (2011). The estimation of bulk density and true density was carried out in ten replicates and average values were reported.

The terminal velocity which kept the grain in suspension was recorded by a digital anemometer (Thies clima, Germany) having a least count of 0.1 m s^{-1} (Unal *et al*. 2009). Ten replications were taken for each sample. A test stand with a 500 N capacity dynamometer was used to determine the rupture force of the soybeans. The loading velocity of the dynamometer was constant at 0.333 mm s^{-1} during measurements. For each test, a single bean was placed along its thickness axis on the plate and fractured with a 12 mm diameter probe. The peak value of the complete break was read and recorded on the screen. This process was repeated 20 times, and then the average value was taken as the representative value (Unal *et al*. 2006).

Coefficient of static fraction was measured by a frictional device with the rubber, plastic, plywood, galvanized iron and stainless steel surfaces. For this measurement, the material was placed on the surface and it was gradually raised by the screw. Vertical and horizontal height values were read from the ruler when the material started sliding over the surface and then, using the tangent value of the angle so that the coefficient of friction was found (Deshpande *et al*. 1993, Altuntaş and Yıldız 2007). All the observations were replicated twenty times and the average values were reported.

The dendrogram method of hierarchical cluster analysis was applied to identify clustering in the different varieties of soybeans (Poljuha *et al*. 2008). Accordingly, the degree of closeness of the soybean varieties to each other was investigated using the "nearest neighbour" agglomerative cluster method to identify clusters in different data structures via the single link (SLINK). In the first phase of the clustering process, the first cluster was formed by taking the two beans nearest to each other in the matrix. In this method, each bean type was considered as a separate cluster at the beginning, and then the two nearest beans would form a cluster and so on, thus continuing to reduce the number of clusters. In the last stage, all the bean varieties were collected into one cluster. Subsequently, the closeness of bean varieties to each other was shown by the unifying dendrogram chart.

The difference between the means of soybean varieties was analysed by using the completely randomized design for the analysis of variance showing these physical properties of soybean. Ten varieties of soybean were the independent variables, and the physical properties were the dependent variables. The treatment effects were analysed using LSD of JUMP software. Cluster analysis and dendrogram chart were performed using STATISTICA ver. 7.1 statistical package program.

RESULTS AND DISCUSSION

The size (length, width and thickness) distributions of the soybeans are given in Table 1. As seen in the table, the length distributions of all soybean varieties ranged from 5.88 to 9.73 mm, with 32.4% categorized as small, 64% as medium and 3.6% as large. The first three varieties in the medium-length category (7.17–8.44 mm) were 'Ataem-7' (86%), 'Dery' (84%) and 'S-1' (84%), respectively. The width distribution of the varieties was between 5.21 and 7.82 mm, with 62% determined in the medium-width category (in the range of 6.09-6.95 mm). The first three varieties in the medium-width category were 'S-1' (80%), 'Galina' (74%) and 'Dery' (70%), respectively. The thickness distribution of the varieties varied from 3.84 to 6.67 mm. When the distribution of the varieties according to thickness was examined, 57.4% were determined in the medium category (between 4.79-5.72 mm), with 'Dery' (84%), 'Galina' (76%) and 'Vojvodjanka' (70%) varieties appearing as the first three, respectively. When all soybean varieties are compared, 'Umut-2002' variety is the most distinctive in length and width dimensions, and 'Yeşilsoy' variety in thickness dimension. Davies and El-Okene (2009), Tavakoli *et al.* (2009), Shirkole *et al.* (2011), and Alibas and Koksal (2015) reported similar trends for different varieties of soybeans.

Table 1. Size distribution of soybean varieties based on length, width, and thickness.

Variety	Ungraded	Size category		
		Small	Medium	Large
Length		(≤7.16 mm)	(7.17-8.44 mm)	(>8.44 mm)
A-3127	6.20-8.27 (100)[a]	6.20-7.15 (24)[b]	7.17-8.27 (76)	(0)
Ataem-7	6.96-8.60 (100)	6.96-7.14 (8)	7.24-8.42 (86)	8.50-8.60 (6)
Dery	6.85-8.98 (100)	6.85-7.16 (12)	7.22-8.35 (84)	8.67-8.98 (4)
Galina	6.05-8.93 (100)	6.05-7.16 (60)	7.21-8.39 (38)	8.93 (2)
Rubin	6.10-8.13 (100)	6.10-7.16 (56)	7.20-8.13 (44)	(0)
S-1	6.60-8.55 (100)	6.60-7.14 (12)	7.17-8.43 (84)	8.46-8.55 (4)
Umut-2002	7.00-9.73 (100)	7.00-7.07 (4)	7.22- 8.41 (78)	8.49-9.73 (18)
Vojvodjanka	6.12-8.16 (100)	6.12-7.16 (54)	7.18-8.16 (46)	(0)
Yemsoy	6.65-8.52 (100)	6.65-7.14 (28)	7.23-8.20 (70)	8.52 (2)

Yeşilsoy	5.88-8.21 (100)	5.88-7.11 (66)	7.22-8.21 (34)	(0)
Total	*5.88-9.73 (1000)*	*5.88-7.16 (324)*	*7.17-8.43 (640)*	*8.46-9.73 (36)*
Width		(≤6.08 mm)	(6.09-6.95 mm)	(>6.95 mm)
A-3127	5.89-7.51 (100)	5.89-6.07 (8)	6.10-6.87 (54)	6.98-7.51 (38)
Ataem-7	6.03-7.81 (100)	6.03 (2)	6.10-6.95 (64)	6.96-7.81 (34)
Dery	6.08-7.21 (100)	6.08 (2)	6.19-6.95 (70)	6.96-7.21 (28)
Galina	5.57-7.38 (100)	5.57-5.97 (12)	6.09-6.94 (74)	6.96-7.38 (14)
Rubin	5.60-7.03 (100)	5.60-6.07 (26)	6.13-6.93 (66)	6.98-7.03 (8)
S-1	5.88-7.21 (100)	5.88 (2)	6.15-6.95 (80)	7.04-7.21 (18)
Umut-2002	6.08-7.53 (100)	6.08 (2)	6.12-6.94 (38)	7.01-7.53 (60)
Vojvodjanka	5.21-6.77 (100)	5.21-6.08 (46)	6.09-6.77 (54)	(0)
Yemsoy	6.10-7.82 (100)	(0)	6.10-6.94 (52)	6.99-7.82 (48)
Yeşilsoy	5.65-7.11 (100)	5.65-6.08 (26)	6.09-6.94 (68)	6.96-7.11 (6)
Total	*5.21-7.82 (1000)*	*5.21-6.08 (126)*	*6.09-6.95 (620)*	*6.96-7.82 (254)*
Thickness		(≤4.78 mm)	(4.79-5.72 mm)	(>5.72 mm)
A-3127	4.64-6.67 (100)	4.64 (2)	4.81-5.70 (44)	5.74-6.67 (54)
Ataem-7	4.77-6.54 (100)	4.77 (2)	4.80-5.72 (58)	5.76-6.54 (40)
Dery	4.77-6.13 (100)	4.77 (2)	5.04-5.70 (84)	5.77-6.13 (14)
Galina	4.24-5.95 (100)	4.24-4.77 (22)	4.79-5.70 (76)	5.95 (2)
Rubin	3.84-5.97 (100)	3.84-4.76 (30)	4.82-5.72 (66)	5.74-5.97 (4)
S-1	4.62-6.16 (100)	4.62-4.78 (8)	4.90-5.67 (56)	5.74-6.16 (36)
Umut-2002	3.88-6.28 (100)	3.88-4.01 (4)	5.13-5.72 (44)	5.75-6.28 (52)
Vojvodjanka	4.17-5.86 (100)	4.17-4.78 (28)	4.81-5.65 (70)	5.86 (2)
Yemsoy	4.45-6.62 (100)	4.45 (2)	5.06-5.70 (32)	5.73-6.62 (66)
Yeşilsoy	5.00-6.47 (100)	(0)	5.00-5.69 (44)	5.73-6.47 (56)
Total	*3.84-6.67 (1000)*	*3.84-4.78 (100)*	*4.79-5.72 (574)*	*5.73-6.67 (326)*

[a]Numbers in parenthesis are no. of observation; [b]Numbers in parenthesis are percentages.

The length, thickness and width values of the soybeans depending on their geometric mean diameter (GMD), sphericity, surface area and bean volume are given in Table 2. A 1% probability difference was found among the specified characteristics of the beans. As seen in the table, 'Umut-2002' was the largest (8.07 mm), followed by the 'Ataem-7' (7.85 mm) and 'S-1' (7.65 mm) type beans, respectively. The 'Yeşilsoy' (6.94 mm) variety was determined to have the smallest bean length. On the other hand, the bean with the largest width was Umut-2002 with 7.00 mm, while the bean with the smallest width was the 'Vojvodjanka' (6.11 mm) variety. Davies and El-Okene (2009) reported the length, thickness and width of soybeans as 6.53, 5.21 and 4.28 mm, respectively, at the moisture level of 9.5%. However, Alibas and Koksal (2015) found the same dimensions for the 'Ataem-II' type as 7.04, 6.30 and 6.02 mm, respectively. The average bean size of the varieties used in this study was higher than those reported by Davies and El-Okene (2009) and Alibas and Koksal (2015). The 'Umut-2002' (6.84 mm) variety was found to have the highest geometric mean diameter value. The smallest bean variety regarding geometric mean diameter was determined to be 'Vojvodjanka' (6.00 mm). Davies and El-Okene (2009) found similar results regarding length (6.53 mm), thickness (4.28 mm), width (5.21 mm), and geometric mean diameter (5.26 mm) in their studies with soybeans. Among the varieties, 'Yeşilsoy' (91.4%) variety was found to be the nearest to 100% in terms of sphericity, while least sphericity was the 'Vojvodjanka', with a value of 84.5%. In terms of the characteristics of surface area (147.5 mm^2) and volume (169.1 mm^3), it was concluded that the 'Umut-2002' bean type values were higher than those of the other varieties. The varieties having the smallest surface area and volume was 'Vojvodjanka' (113.6 mm^2-114.4 mm^3). The sphericity (80.6%), surface area (81.3 mm^2) and volume (91 mm^3) results for 'JS-7244' soybeans reported by Despande et al. (1993) showed differences compared with the varieties used in this study. However, the sphericity (91.5%), surface area (130.32 mm^2) and grain volume (133.16 mm^3) values in the 'Ataem-II' soybean variety used by Alibas and Koksal (2015) were found to be close to the values in the present study. Also, Davies and El-Okene (2009), Tavakoli *et al*. (2009), Shirkole *et al*. (2011) and Kuźniar *et al*. (2016) all reported similar trends for soybeans. Under approximately the same operating conditions, grain size may play a significant role in processing (Gupta and Das 1997) therefore, the bulk seed sample can be classified into three categories, namely large, medium and small using ASTM sorting sieves (Fritsch, Germany).

There was a 1% probability difference among the 1000 grain weight, bulk and true densities and porosity values of the beans (Table 2). The ‘Umut-2002’ (205.2 g) had the highest thousand grain weight, while ‘Vojvodjanka’ (131.1 g) variety had the lowest. The bulk density value was the highest in the ‘Dery’ (599.6 kg m^{-3}) and the lowest in the ‘Yeşilsoy’ (517.5 kg m^{-3}) beans. Furthermore, the ‘Ataem-7’ (1600.0 kg m^{-3}) variety was found to be the highest regarding the true density value, followed by the ‘Umut-2002’ bean variety with a value of 1268.0 kg m^{-3}. The true density values of the ‘S-1’ (934.8 kg m^{-3}) bean was the lowest. Examination of the porosity values showed the highest to be the ‘Ataem-7’ (0.63) and the lowest to be the ‘S-1’ (0.36) bean varieties. Kibar and Oztürk (2008) and Alibas and Koksal (2015) reported several findings that differed from the present study in terms of the thousand grain weight, bulk density, true density and porosity characteristics. It is believed that these differences were due to the variety of bean used and the working humidity.

The ‘Dery’ (8.75 m s^{-1}) and ‘A-3127’ (8.63 m s^{-1}) beans had the highest terminal velocity (V_t) values, while the lowest was seen for the ‘Vojvodjanka’ (7.76 m s^{-1}) variety (Table 2). Since the characteristics of the beans used and the measured moisture values in the present study were not the same, the results differed in terms of terminal velocity.

The rupture force properties of varieties were found to have statistically significant ($p < 0.01$) (Table 2). In soybean varieties; the force applied for ‘Dery’ (157.2 N) was the highest, while lowest was ‘Galina’ (111.8 N). This difference may be attributed to physical properties of soybean varieties. The results are similar to those reported by Alibas and Koksal (2015) for soybean and Unal *et al*. (2009) for rapeseed.

Table 2. Physical and mechanical properties of soybean varieties.

Characteristics	A-3127	Ataem-7	Dery	Galina	Rubin	S-1	Umut-2002	Vojvodjanka	Yemsoy	Yeşilsoy
Moisture (% d.b.)	8.69±0.03^{ns}	8.83±0.05^{ns}	8.53±0.05^{ns}	7.97±0.06^{ns}	7.74±0.07^{ns}	8.33±0.04^{ns}	8.64±0.03^{ns}	7.92±0.06^{ns}	8.27±0.07^{ns}	8.02±0.04^{ns}
Length (mm)	7.43±0.06^{d}	7.85±0.06^{b}	7.60±0.06^{cd}	7.14±0.08^{e}	7.13±0.08^{e}	7.65±0.06^{c}	8.07±0.07^{a}	7.11±0.06^{ef}	7.43±0.06^{d}	6.94±0.07^{f}
Width (mm)	6.76±0.06^{c}	6.81±0.05^{bc}	6.74±0.04^{c}	6.45±0.06^{d}	6.39±0.06^{d}	6.69±0.05^{c}	7.00±0.05^{a}	6.11±0.05^{e}	6.93±0.05^{ab}	6.31±0.05^{d}
Thickness (mm)	5.78±0.06^{a}	5.65±0.05^{ab}	5.50±0.03^{b}	5.02±0.05^{c}	4.99±0.06^{c}	5.52±0.06^{b}	5.69±0.06^{a}	4.99±0.05^{c}	5.79±0.06^{a}	5.80±0.05^{a}
GMD (mm)	6.62±0.05^{bc}	6.71±0.05^{ab}	6.56±0.04^{c}	6.13±0.05^{e}	6.10±0.06^{e}	6.56±0.05^{c}	6.84±0.05^{a}	6.00±0.05^{e}	6.68±0.05^{bc}	6.33±0.05^{d}
Sphericity (%)	89.1±0.5^{b}	85.5±0.3^{cde}	86.3±0.4^{c}	86.1±0.5^{cd}	85.7±0.4^{cde}	85.7±0.3^{cde}	85.0±0.5^{de}	84.5±0.5^{e}	89.9±0.4^{b}	91.4±0.5^{a}
Surface area (mm^2)	137.9±2.1^{bc}	141.8±2.1^{b}	135.2±1.4^{c}	118.5±2.0^{e}	117.3±2.3^{e}	135.6±2.1^{c}	147.6±2.0^{a}	113.6±1.8^{e}	140.4±2.0^{bc}	126.3±2.0^{d}
Volume (mm^3)	153.0±3.4^{bc}	159.4±3.6^{b}	148.2±2.4^{c}	122.0±3.1^{e}	120.2±3.5^{e}	149.1±3.4^{c}	169.1±3.4^{a}	114.4±2.7^{e}	157.0±3.3^{bc}	134.1±3.3^{d}
1000 grain weight (g)	179.3±2.0^{d}	192.6±3.1^{b}	173.7±0.7^{de}	131.4±2.2^{h}	137.9±2.4^{g}	172.4±2.2^{e}	205.2±1.6^{a}	131.1±1.9^{h}	186.0±2.7^{c}	155.7±2.5^{f}
Bulk density (kg m^{-3})	554.3±6.3^{de}	588.1±6.8^{ab}	599.6±7.3a	536.7±4.3^{ef}	538.1±6.3^{e}	565.6±6.3^{cd}	593.5±7.2^{ab}	553.7±10.8^{de}	577.2±7.1^{bc}	517.5±6.9^{f}
True density (kg m^{-3})	1241.0±103.1^{bc}	1600.0±40.4^{a}	1256.0±54.1^{bc}	1064.0±42.7^{cd}	1240.0±68.5^{bc}	934.8±70.9^{d}	1268.0±108.6^{b}	1161.3±59.3^{bc}	1154.6±65.8^{bc}	940.0±67.7^{d}
Porosity (-)	0.53±0.03^{bc}	0.63±0.01^{a}	0.52±0.02^{bc}	0.49±0.02^{bc}	0.55±0.02^{ab}	0.36±0.05^{d}	0.49±0.05^{bc}	0.51±0.03^{bc}	0.48±0.04^{bc}	0.43±0.04^{cd}
V_t (m s^{-1})	8.63±0.07^{a}	8.28±0.07^{b}	8.75±0.08^{a}	8.15±0.11^{b}	8.27±0.08^{b}	8.34±0.10^{b}	8.19±0.07^{b}	7.76±0.11^{c}	8.21±0.09^{b}	8.30±0.09^{b}
Rupture force (N)	150.5±8.1^{abc}	150.5±6.2^{abc}	157.2±5.9^{a}	111.8±4.5^{f}	129.9±4.8^{de}	133.1±5.0^{cde}	151.2±6.2^{ab}	118.6±5.0^{ef}	136.4±10.3^{bcd}	129.4±2.9^{de}

GMD: Geometric mean diameter, V_t: Terminal velocity

ns: not significant. Standard error values are in ±. a and h letters indicate the statistical difference in rows.

Means followed by the same letter are not significantly different at the p = 0.01 level using LSD test.

The study investigated the possible presence of statistically significant relationships between each bean variety and all five surfaces individually and between all the beans with each surface separately (with a probability level difference of 1% in both cases) (Table 3). For all varieties, coefficient of static friction was greatest against rubber and the least for stainless steel. On the rubber surface, the highest coefficient of friction among the beans was determined in Rubin variety with value of 0.310. 'Yeşilsoy' were last in order with value of 0.194. The bean type with the highest static friction coefficient on all surfaces were 'Rubin'. The 'Yeşilsoy' variety had the lowest coefficient of friction on all surfaces. Shirkole *et al*. (2011), when working on six different surfaces (rubber, plywood, mild steel, galvanized iron, aluminium and stainless steel), found that the rubber surface gave the highest static coefficient of friction. Tavakoli *et al*. (2009) achieved similar results in their study.

Altuntaş et al. (2021) determined the static friction coefficients of 'Yeşilsoy' variety soybean seeds with a moisture content of 7.41% on galvanized, plywood and rubber surfaces as 0.35, 0.33 and 0.37, respectively. The highest static friction coefficient value for soybean varieties on the rubber surface is similar to the results reported in the literature. The friction coefficients of the products vary according to different contact surfaces. Therefore, the exact determination of the friction coefficients on the different contact surfaces of the products is beneficial for the performance optimization of mechanical equipment (conveyors, separation, cleaning, drying and storage vehicles) and consequently for the reduction of damages and economic efficiency (Mohsenin, 1986).

Table 3. Static coefficient of friction for soybean varieties.

Variety	Coefficient of static friction				
	Rubber	**Plastic**	**Plywood**	**Galvanized Iron**	**Stainless Steel**
A-3127	$0.233\pm0.003^{A,e}$	$0.215\pm0.005^{B,e}$	$0.214\pm0.003^{B,cd}$	$0.193\pm0.002^{C,f}$	$0.189\pm0.003^{C,d}$
Ataem-7	$0.263\pm0.005^{A,cd}$	$0.232\pm0.005^{B,d}$	$0.225\pm0.007^{BC,c}$	$0.211\pm0.010^{C,e}$	$0.209\pm0.004^{C,c}$
Dery	$0.254\pm0.003^{A,d}$	$0.229\pm0.002^{B,d}$	$0.220\pm0.002^{C,c}$	$0.218\pm0.002^{C,de}$	$0.216\pm0.001^{C,bc}$
Galina	$0.291\pm0.004^{A,b}$	$0.279\pm0.004^{AB,ab}$	$0.275\pm0.005^{B,a}$	$0.239\pm0.003^{C,bc}$	$0.225\pm0.005^{D,b}$
Rubin	$0.310\pm0.004^{A,a}$	$0.286\pm0.007^{B,a}$	$0.277\pm0.008^{BC,a}$	$0.263\pm0.007^{CD,a}$	$0.247\pm0.006^{D,a}$
S-1	$0.268\pm0.006^{A,c}$	$0.237\pm0.003^{B,cd}$	$0.228\pm0.002^{BC,c}$	$0.224\pm0.002^{CD,de}$	$0.214\pm0.003^{D,c}$
Umut-2002	$0.275\pm0.004^{A,c}$	$0.246\pm0.005^{B,c}$	$0.245\pm0.004^{B,b}$	$0.230\pm0.002^{C,cd}$	$0.218\pm0.002^{D,bc}$
Vojvodjanka	$0.295\pm0.005^{A,b}$	$0.269\pm0.005^{B,b}$	$0.259\pm0.010^{BC,b}$	$0.251\pm0.008^{BC,ab}$	$0.248\pm0.006^{C,a}$
Yemsoy	$0.219\pm0.001^{A,f}$	$0.203\pm0.002^{B,f}$	$0.201\pm0.001^{B,de}$	$0.194\pm0.002^{C,f}$	$0.225\pm0.005^{D,b}$
Yeşilsoy	$0.194\pm0.004^{A,g}$	$0.189\pm0.003^{A,g}$	$0.188\pm0.003^{A,e}$	$0.175\pm0.003^{B,g}$	$0.166\pm0.002^{B,e}$

Means followed by the same letter between rows ($^{A, B, C}$) and between columns ($^{a, b, c}$) within each surface are significant. ±SE. All data were obtained in 20 replicate results. **Significance levels at $p < 0.01$

The closeness of the soybean varieties to each other is shown by the unifying dendrogram chart (Figure 2). As a characteristic of the graph, the beans connected at the same place form a cluster. In Figure 2, it can be seen that there are four clusters. 'Dery', 'Umut-2002', 'A-3127' and 'Rubin' varieties form one cluster, 'Vojvodjanka', 'Yemsoy' and 'Galina' another, and 'Yeşilsoy' and 'S-1' beans constitute the third cluster. The 'Ataem-7' bean variety can be regarded as a separate species from the others. When the hierarchical clustering results are detailed, since the similarities between 'Der'y, 'Umut-2002', 'A-3127' and 'Rubin' varieties are very strong, these seed varieties formed groups at a distance of 1 unit. Likewise, 'Yeşilsoy' and 'S-1' bean varieties formed a group at a distance of 1 unit because of their strong similarities. On the other hand, 'Vojvodjanka', 'Yemsoy' and 'Galina' soybean varieties are very similar to each other, and they come together at a distance of 2 units in the dendogram. Soybean variety 'A-3127' showed similarity with this group and was included in the group at a distance of 2 units. In addition, 'Vojvodjanka' and 'Yeşilsoy' showed similarities among themselves and formed a group at a distance of 4 units. 'Ataem-7' variety, as a separate species from other soybean varieties, also formed a cluster with 'Vojvodjanka' and 'Yeşilsoy' groups at a distance of 25 units. These results also indicate that dendrogram method of hierarchical cluster analysis is useful in soybean varieties (Poljuha *et al*. 2008).

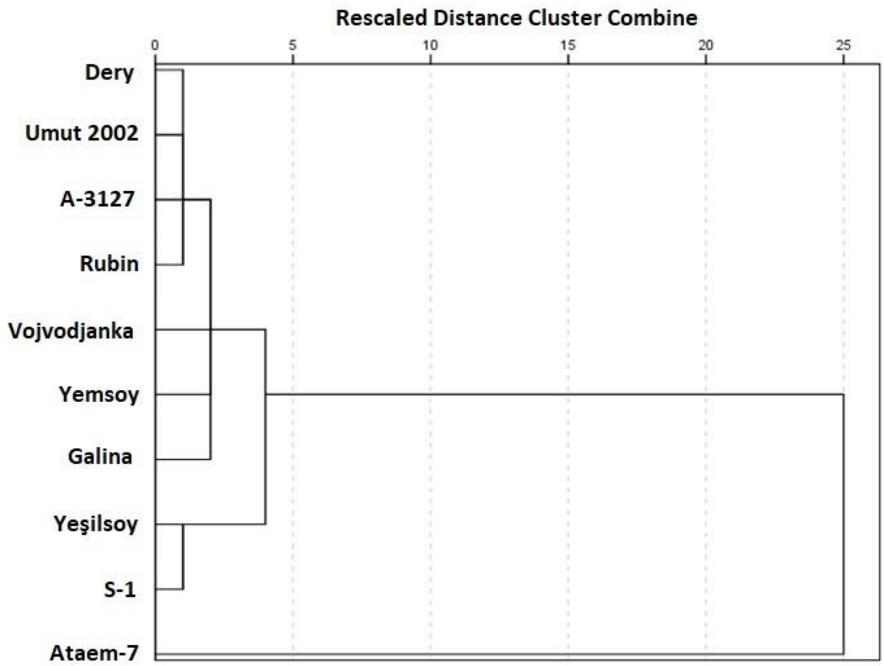

Figure 2. Dendrogram from single linkage nearest neighbour agglomerative cluster analysis which groups ten soybean varieties.

CONCLUSIONS

Some of the post-harvest biotechnical characteristics of soybean varieties, such as separation, classification, storage and mechanical processes, should be taken into account in the design of machinery and systems, the required machine performance and energy consumption during the project and operation stages.

Some of the physical properties of the ten different soybean varieties having moisture values of 7.74–8.83% d.b. were investigated and dendrograms were made depending on these properties. The bean variety 'Umut-2002' had the highest values regarding physical properties such as length (8.07 mm), width (7.00 mm), geometric mean diameter (6.84 mm), surface area (147.5 mm^2), bean volume (169.1 mm^3) and thousand grain weight (205.2 g). 'Yeşilsoy' was found to have the shortest length (6.94 mm), 'Rubin' the lowest geometric mean diameter (6.10 mm). Soybean 'Vojvodjanka' seeds were the smallest, with seeds 6.11 mm in width, 4.99 mm in thickness and the 84.5% in sphericty. Bulk density was the highest in 'Dery' with (599.6 kg m^{-3}) and the lowest in 'Yeşilsoy' (517.5 kg m^{-3}). The highest true density and porosity values (1600.0 kg m^{-3} and 0.63) were with 'Ataem-7', while the lowest values (934.8 kg m^{-3} and 0.36) were with 'Vojvodjanka'. The highest terminal velocity value (8.75 m s^{-1}) was found with 'Dery' and the lowest (7.76 m s^{-1}) with 'Vojvodjanka' varieties. The 'Dery' variety (157.2 N) had the highest rupture resistance value, while 'Galina' (111.8 N) had the lowest. When the results of the static friction coefficient on the individual surfaces of ten different varieties are examined, the highest value is seen on the rubber surface and the lowest value on the stainless-steel surface. The dendrogram was applied in order to classify the bean varieties, and four different clusters were formed among them.

ACKNOWLEDGMENTS

The authors are grateful to Professor Dr. Mehmet Sincik, researcher in Dept. of Field Crops, Agriculture Faculty, Bursa Uludag University, for kindly providing the seeds of *Glycine max*. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

Alibas I, and Koksal N (2015). The effect of moisture content on physical, mechanical and rheological properties of soybean (*Glycine max cv.* ATAEM-II) seed. *Legume Research*, 38, 324-333.

Altuntaş E, and Yıldız M (2007). Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. *Journal of Food Engineering*, 78, 174-183.

Altuntaş E, Gül EN, Olgaç M (2021). Determination of some post-harvest biotechnical properties of the different soybean varieties. (In Turkish: Farklı soya çeşitlerinde hasat sonrası bazı biyoteknik özelliklerin belirlenmesi). *Kahramanmaraş Sütçü İmam University Journal of Agriculture and Nature* 24(5),1037-1047.

ASAE (1997). S352.2 Moisture measurement - unground grain and seeds. American Society of Agricultural Engineers, St. Joseph, MI, USA.

Bhushan B, and Raigar RK (2020). Influence of moisture content on engineering properties of two varieties of rice bean. *Journal of Food Process Engineering*, e13507.

Davies RM, and El-Okene AM (2009). Moisture-dependent physical properties of soybeans. *Internatioanl Agrophysics*, 23, 299-303.

Deshpande SD, Bal S, and Ojha TP (1993). Physical properties of soybean. *Journal of Agricultural Engineering Research*, 56, 89-98.

Ekka NP, and Lal GM (2016). Study on genetic variability and character association in soybean (*Glycine max* L. *Merrill*) germplasm at vindhyan zone of Uttar Pradesh. *Agricultural Science Digest - A Research Journal*, 36, 69-71.

Gomes LS, Senna R, Sandim V, Silva-Neto MA, Perales JE, Zingali RB, Soares MR, and Fialho E (2014). Four conventional soybean (*Glycine max (*L.*) Merrill*) seeds exhibit different protein profiles as revealed by proteomic analysis. *Journal of Agricultural and Food Chemistry*, 62, 1283-1293.

Gupta RK, and Das SK (1997). Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research*, 66 (1), 1-8.

Izli N, Unal H, and Sincik M (2009). Physical and mechanical properties of rapeseed at different moisture content. *Internatioanl Agrophysics*, 23, 137-145.

Jaliliantabar F, Lorestani AN, and Gholami R (2013). Physical properties of kumquat fruit. *Internatioanl Agrophysics*, 27, 107-109.

Kibar H, and Ozturk T (2008). Physical and mechanical properties of soybean. *Internatioanl Agrophysics*, 22, 239-244.

Kuźniar P, Szpunar-Krok E, Findura P, Buczek J, and Bobrecka-Jamro D (2016). Physical and chemical properties of soybean seeds determine their susceptibility to mechanical damage. Zemdirbyste-Agriculture, 103, 183-192.

Liu J, Qin WT, Wu HJ, Yang CQ, Deng JC, Iqbal N, Liu WG, Du J, Shu K, Yang F, Wang XC, Yong TW, and Yang WY (2017). Metabolism variation and better storability of dark-versus light-coloured soybean (*Glycine max L. Merr.*) seeds. *Food Chemistry*, 223, 104-113.

Mohsenin NN (1986). Physical properties of plant and animals materials. New York, USA: Gordon Breach Science Press.

Poljuha D, Sladonja B, Setic E, Milotic A, Bandelj D, Jakse J, and Javornik B (2008). DNA fingerprinting of olive varieties in Istria (Croatia) by microsatellite markers. *Scientia Horticulturae,* 115, 223-230.

Razavi SAM, Yeganehzad S, and Sadeghi A (2009). Moisture dependent physical properties of canola seeds. *Journal of Agricultural Science and Technology*, 1, 309-322.

Shirkole SS, Kenghe RN, and Nimkar PM (2011). Moisture dependent physical properties of soybean. *International Journal of Engineering Science And Technology*, 3, 3807-3815.

Tarighi J, Mahmoudi A, and Rad MK (2011). Moisture-depend some postharvest properties of two cultivar of safflower (Darab and Goldasht). *Modern Applied Science*, 5, 139-148.

Tavakoli H, Rajabipour A, and Mohtasebi SS (2009). Moisture-dependent some engineering properties of soybean grains. *Agricultural Engineering International: the CIGR Ejournal*, vol. XI. Manuscript 1110.

Unal H, Isik E, and Alpsoy HC (2006). Some physical and mechnical properties of black-eyed pea (*Vigna unguiculata L.*) grains. *Pakistan Journal of Biological Sciences*, 9, 1799-1806.

Unal H, Sincik M, and Izli N (2009). Comparison of some engineering properties of rapeseed cultivars. *Industrial Crops and Products*, 30, 131-136.

Zhou S, Sekizaki H, Yang Z, Sawa S, and Pan J (2010). Phenolics in the seed coat of wild soybean (*Glycine soja*) and their significance for seed hardness and seed germination. *Journal of Agricultural and Food Chemistry,* 58(20), 10972-10978.