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Size properties of legume seeds of different varieties using image analysis

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ABSTRACT

Image analysis system was used to provide geometric parameters of legume seeds, which are important for designing of engineering processes such as drying, milling, germination etc. Measured features of bean and lentil seeds were projected area, equivalent diameter, MaxFeret, MinFeret and thickness. Three approximation models (an oblate spheroid, two sphere segments and a triaxial ellipsoid) were used to evaluate volume and surface area of lentil and bean seeds of various varieties. The best approximation model was found as the triaxial ellipsoid and the oblate spheroid for bean varieties and two sphere segments for lentil varieties. From the model data estimated specific surface area were ranged from 5.1–5.8 cm^2/g for bean varieties and 11.57–11.95 cm^2/g for lentil varieties. Image analysis system provided fast and accurate values of important technological properties of legume such as geometric parameters, volume and surface area.

1. Introduction

In general, legume is a source of complex carbohydrates, proteins and dietary fiber, having significant amounts of vitamins and minerals (Costa et al., 2006). In addition consumption of dry beans and lentils has been linked to reduced risk of heart disease (Anton et al., 2008).

Surface area and volume of legume seeds is an important physical characteristic in processes such as harvesting, cleaning, separation, handling, aeration, drying, storing, milling, cooking and germination (Igathinathane and Chattopadhyay, 1998; Hsieh et al., 1998). The size and shape are important in electrostatic separation from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1970). Geometric parameters of legume seeds are important for germination process as well, bigger bean seeds germinate faster than smaller and medium ones (Kelli, 2007). Large seeded cultivars of azuki beans exhibit slower water absorption than smaller ones. Cultivars of faba beans and chickpeas require longer cooking times than small seeded cultivars (Hsieh et al., 1998).

Owing to the irregularities and variation in shapes, surface profiles, and dimensions of specific food materials, it is very difficult to evaluate their actual surface areas. For food materials, such as seeds, grains, fruits or vegetables that are irregular in shape, a complete specification of shape requires an infinite number of measurements. The shapes of most natural food materials generally resemble some of the regular geometrical objects, and this feature is utilized in the theoretical estimation of the surface area utilizing certain numerical techniques. Often three measurements along the mutually perpendicular axes, namely, length, width, and thickness are used to specify the shape of the food material. The length, thickness and width of particles are generally measured using a calliper.

Digital image analysis enables size measurements faster and more accurately. Computer vision includes the capturing, processing and analyzing images, facilitating the objective and nondestructive assessment of visual quality characteristics in food products (Brosnan and Sun, 2004). Koc (2007) used image analysis system to estimate the volume of watermelon. Tahir et al. (2007) evaluated the variability in the colour, morphology and textural features of cereal grain due to the change in moisture content of the kernels by using image analysis. Yan et al. (2008) investigated the change of shape factor by image analysis system with moisture content changing during drying. Wang and Nguang (2007) aimed to design a low cost automatic sensor system for estimating the volume and surface area of axi-symmetric agricultural products. Tanska et al. (2005) tested the determination of the geometrical features of rapeseed, surface colour of seeds, and also identification impurities that are difficult to separate during the cleaning process. Kadlec et al. (2006) dealt with shape characterization of pea seeds using image analysis to determine the specific surface area of 0.60 m^2/kg for micro-wave drying.

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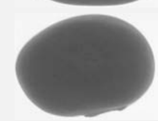
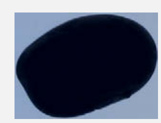
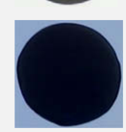
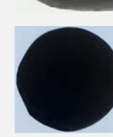
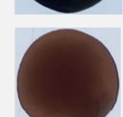
The objective of our research was to compare the seed sizes (projected area, equivalent diameter, length, width etc.) of bean and lentil varieties obtained from the Czech Republic and Turkey by using image analysis. To achieve this objective, by means of 2D visualization technique, completing height, the shape of a seed was practically as 3-D models. Geometrical shape was simulated as an oblate spheroid, two sphere segments, and a general ellipsoid for bean and lentil. According to these simulations, surface areas and volumes of the seeds of lentil and bean were calculated and verified with the volumes of seeds achieved by pycnometric measurements.

2. Materials and methods

2.1. Seed samples

The varieties of bean and lentil samples used in the study are given in Table 1. Tigar bean, white bean (Krajova), and white bean (ST513) were obtained from AGRITEC s.r.o. Šumperk, Gene Bank, and green lentil (Moench) was obtained from Crop Research Institute (CRI) Praha-Ruzyně, Gene Bank. The other seed cultivars were obtained from local market of Turkey and the Czech Republic.

Table 1
Bean and lentil samples used in this study.

Sample	Variety	Captured image
Czech Republic		
White bean (Krajova)	*Phaseolus vulgaris* L. cv. Krajova 477	
White bean (ST513)	*Phaseolus vulgaris* L. cv. ST513	
Tigar bean	*Phaseolus vulgaris* L. cv. Tigar	
White speckled red bean	*Phaseolus vulgaris* L. cv. Pinto	
Kidney bean	*Phaseolus vulgaris* L. cv. Kidney	
Green lentil (Moench)	*Lens esculenta* L. cv. Moench	
Green lentil (Medik)	*Lens culinaris* Medik	
Turkey		
White bean	*Phaseolus vulgaris* L. cv. Dermason	
White speckled red bean	*Phaseolus vulgaris* L. cv. Barbunia	
Green lentil	*Lens culinaris* Medik	
Red lentil	*Lens culinaris* Medik	

3. Methods

3.1. Image analysis

The measurements of geometrical parameters were performed using a customized personal computer-based digital image analysis system LUCIA (Laboratory Universal Computer Image Analysis) version 3.52 software (Laboratory Imaging Co., Czech Republic) using low-noise CCD Cohu 2252 camera connected with object-lenses with magnification of 2.5 and 0.5 in series. In order to observe 3-D model, the five times replicated thickness (height) h of the seed was measured by digital calliper.

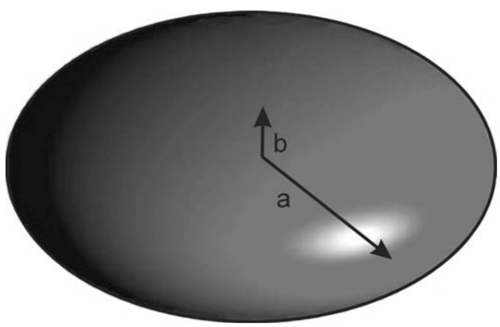


Fig. 1. Oblate spheroid.

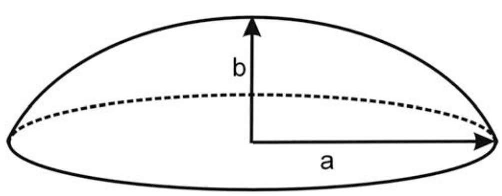


Fig. 2. Sphere segment.

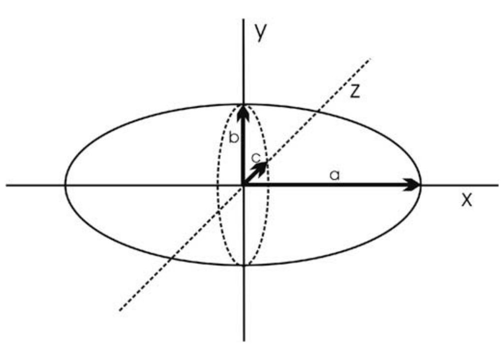


Fig. 3. General ellipsoid.

3.2. Volume and surface area evaluation

A seed was considered as oblate spheroid (Fig. 1), two sphere segments (Fig. 2), and general ellipsoid (Fig. 3). The volume and surface area could be calculated using equations in Table 2.

3.3. Volume measurement of wheat seeds by pycnometric method

The volumes determined by the geometrical approximations were compared with the volume measured by pycnometric method described by Firatligil-Durmuş et al. (2008).

3.4. Statistical analysis

The results of geometric features reported in this work are the average of 200 seeds, and the coefficient of variance, expressed as the percentage ratios between standard deviation (SD) and the mean values. Analysis of variance with a 95% confidence level ($P = 0.05$) and Tukey's multiple comparison test were done to determine the significant difference using MiniTab statistical programme version 12.2 (MiniTab Inc., USA).

4. Results and discussion

4.1. Geometric features

Table 3 shows the results obtained with samples of 200 seeds for each cultivar of bean. The mean value, standard deviation and coefficient of variation of each parameter are presented. The average projected area, equivalent diameter, perimeter, MaxFeret, MinFeret, and thickness of bean ranged from 46.63–131.54 mm^2, 7.44–12.83 mm, 24.27–43.78 mm, 8.72–17.00 mm, 6.34–9.72 mm, 4.71–7.00 mm, respectively for the bean varieties used in the tests. The bean varieties showed differences in projected area ($P < 0.05$). According to these differences in variety characteristics, it is possible to classify bean variety depending on size by image analysis like in the study of Shouche et al. (2001) for wheat and Sakai et al. (1996) for rice. The difference in projected area between Turkish and Czech white speckled red bean was 26.6%. Turkish white bean cultivar was bigger in projected area, perimeter and MaxFeret than the other cultivars. The bean varieties were significantly of the same thickness ($P > 0.05$).

According to Cetin (2007), Barbunia (white speckled white) bean are characterized by projected area in the range of 73.85–97.35 mm^2, length in 16.68 mm, width in 9.36 mm and thickness 7.51 mm. These data corresponds with the data obtained from Turkish white speckled bean, but the Czech seeds were of smaller values than these data. Altuntas and Yildiz (2007) found that faba bean length ranged from 18.40–19.77 mm, width from 12.54–13.66 mm and thickness from 7.00–8.02 mm. For locust bean cultivar, length, width and thickness were found as 8.0–12.0 mm, 6.0–8.5 mm and 4.5–6.0 mm, respectively (Ogunjimi et al., 2002). According to Haciseferogullari et al. (2003), sakiz faba bean are characterized by length in 20.39 mm, width in 14.54 mm and

Table 2
Equations for volume and sphere calculations.

Geometrical object	Volume	Surface area	Nomenclature
Oblate spheroid	$V = \frac{4}{3}\pi a^2 b$	$S = 2\pi\left(a^2 + \frac{b^2}{2\varepsilon}\ln\left(\frac{1+\varepsilon}{1-\varepsilon}\right)\right)$	a-the half of equivalent diameter (mm)
		$\varepsilon = \frac{\sqrt{a^2-b^2}}{a}$	b-the half of thickness (mm) ε-an eccentricity of the ellipse
Sphere segment	$V = \frac{1}{6}\pi b(3a^2 + b^2)$	$S = \pi(a^2 + b^2)$	
General ellipsoid	$V = \frac{4}{3}\pi abc$	$S = \frac{\pi^2}{4} a(b + c + \sqrt{2(b^2 + c^2)})$	a-the half of MaxFeret (mm) b-the half of MinFeret (mm) c-the half of the thickness (mm)

Table 3
Geometric features of bean varieties.

Features		Czech Rebublic					Turkey	
		White speckled red bean	Kidney bean	Tigar bean	White bean (Krajova)	White bean (ST513)	White speckled red bean	White bean
Projected area (mm^2)	Mean value	82.31a	118.19b	102.78c	107.91d	43.63e	104.18d	131.54f
	Range	56.46–118.30	71.57–155.03	63.44–150.91	75.81–142.66	30.53–63.81	77.33–137.19	103–51-167.23
	SD	10.10	13.14	15.87	12.77	5.41	10.70	11.36
	CV%	12.27	11.12	15.44	11.83	12.40	10.27	8.63
Equivalent diameter (mm)	Mean value	10.22a	12.25a	11.41a	11.70a	7.44b	11.50a	12.93a
	Range	8.48–12.27	9.55–14.05	8.99–13.86	9.82–13.48	6.23–9.01	9.92–13.22	11.48–14.59
	SD	0.62	0.69	0.88	0.70	0.45	0.59	0.56
	CV%	6.09	5.62	7.74	5.94	6.12	5.11	4.30
Perimeter (mm)	Mean value	33.79a	42.67b	41.58bc	39.22 cd	24.27d	37.64e	43.78bc
	Range	27.42–40.76	31.77–49.24	32.03–51.90	32.11–99.43	20.49–29.66	32.33–43.58	38.22–48.94
	SD	2.06	2.62	3.39	5.13	1.54	1.95	1.90
	CV%	6.10	6.14	8.15	13.07	6.35	5.18	4.33
MaxFeret (mm)	Mean value	12.57a	16.69b	16.87b	14.33ab	8.72c	13.71a	17.00b
	Range	9.80–15.3	12.02–19.43	12.67–21.12	11.35–17.51	7.42–10.76	11.59–16.25	14.59–19.00
	SD	0.82	1.07	1.51	1.02	0.59	0.80	0.79
	CV%	6.53	6.40	8.96	7.14	6.73	5.82	4.62
MinFeret (mm)	Mean value	8.13a	8.78a	7.53b	9.30c	6.34d	9.72c	9.67c
	Range	6.59–9.68	7.40–10.50	6.19–9.21	8.04–10.94	5.07–7.60	8.27–11.76	8.71–11.14
	SD	0.54	0.57	0.56	0.54	0.40	0.62	0.45
	CV%	6.65	6.46	7.50	5.81	6.34	6.36	4.70
Circularity	Mean value	0.90a	0.81a	0.74a	0.89a	0.93a	0.92a	0.86a
	Range	0.85–0.95	0.75–0.89	0.70–0.81	0.17–0.95	0.83–0.96	0.88–0.96	0.82–0.89
	SD	0.02	0.02	0.02	0.07	0.02	0.02	0.01
	CV%	1.86	2.97	2.56	7.65	1.64	1.70	1.52
Elongation	Mean value	1.55a	1.91b	2.24c	1.54a	1.38d	1.41d	1.76ab
	Range	1.32–1.78	1.59–2.19	1.95–2.59	1.24–1.84	1.24–1.68	1.20–1.76	1.56–1.90
	SD	0.08	0.11	0.16	0.09	0.07	0.09	0.07
	CV%	5.13	5.75	7.04	5.92	4.76	6.12	3.71
Thickness (mm)	Mean value	5.39a	5.61a	4.71a	6.15a	4.60a	7.03a	5.50a
	Range	4.07–6.54	4.31–7.05	3.53–6.03	4.46–7.70	3.06–5.66	5.10–9.11	4.13–6.86
	SD	0.48	0.52	0.53	0.54	0.45	0.70	0.46
	CV%	8.90	9.33	11.32	8.75	9.86	9.98	8.44

Values in the same row with different letters are significantly different ($P < 0.05$).
Range: minimum – maximum value; SD – standard deviation; CV – coefficient of variance on the basis of measurements of 200 seeds.

thickness in 7.86 mm, projected area in 279 mm^2. A comparison between these results and those obtained in the present study indicates that seeds of locust bean were same in size but, faba bean seeds were bigger.

The mean value, standard deviation and coefficient of variation of lentil geometric parameters are presented in Table 4. The results were obtained with samples of 200 seeds. The projected area, equivalent diameter, perimeter, MaxFeret, MinFeret, and thickness of lentil ranged from 14.41–37.28 mm^2, 4.28–6.28 mm, 13.67–21.86 mm, 4.45–7.14 mm, 4.17–6.65 mm, 2.39–2.61 mm, respectively for the lentil varieties used in the tests. Red lentil seeds were smaller in size than all seeds of the green lentil varieties. The green lentil varieties used in this study showed similarity in geometric related parameters ($P > 0.05$). The analysis showed that the coefficient of variation was around 3–6% for most of the basic geometric parameters such as equivalent diameter, MaxFeret, MinFeret and thickness. These variances correspond with the data of Shouche et al. (2001) for wheat seeds and the digital image data of Tanska et al. (2005) for rape seeds. The comparison of the results of Venora et al. (2007) and Bhattacharya et al. (2005) with our results (Table 4) indicates that Turkish and Czech varieties are the same in size as Sicilian landraces and Canadian cultivar.

4.2. Comparison of approximation methods with the pycnometric method

In order to calculate the surface area and volume with different approximation methods, the MaxFeret, MinFeret, equivalent diameter and thickness of the seed were firstly obtained using image analysis system. From the measured three dimensions, the surface area and volume of sample were estimated using equations in Table 2. The volumes determined by different approximation methods were compared with the volumes measured by the pycnometric method and are shown in Table 5 for bean varieties and Table 6 for lentil varieties.

Triaxial ellipsoid approximation method was suitable for most of the bean varieties except white speckled red bean from Turkey. The percentage difference between volume estimated by the pycnometric method and triaxial ellipsoid approximation method ranged from 0.49% to 6.14%. For white speckled red bean from Turkey, the sphere segment approximation method was the best suitable model. The percentage difference between volume estimated by the pycnometric method and ellipsoidal approximation method for Tigar bean, white speckled red bean from the Czech Republic and white bean (Dermason) were smaller than 1%. This may be explained based on the fact that these varieties were closer to the ellipsoidal geometry than the other bean varieties. The shape of white speckled red bean from Turkey and the Czech Republic were different from each other. The variety from the Czech Republic was close to ellipsoidal geometry, the variety from Turkey was close to two sphere segments geometry. The paired samples *t*-test results showed that the bean variety (except white speckled red bean from Turkey) volume measured with the pycnometric method was significantly same with the volume estimated with ellipsoid approximation ($P > 0.05$).

Two sphere segments approximation was more suitable in the computation of the volume with both red and green lentils than oblate sphere approximation. The percentage difference between volumes estimated by the pycnometric method and two sphere segments approximation method ranged from 4.22% to 5.14%.

Table 4
Geometric features of lentil varieties.

Features[a]		Czech Republic		Turkey	
		Green lentil (Medik)	Green lentil (Moench)	Red lentil	Green lentil
Projected area (mm^2)	Mean value	32.11a	37.28a	14.41b	34.64a
	Range	23.28–40.74	27.37–48.01	10.80–18.49	28.92–41.09
	SD	2.68	4.21	1.40	2.41
	CV%	8.34	11.30	9.68	6.96
Equivalent diameter (mm)	Mean value	6.39a	6.88a	4.28b	6.64a
	Range	5.44–7.20	5.90–7.82	3.71–4.85	6.07–7.23
	SD	0.27	0.39	0.21	0.23
	CV%	4.21	5.66	4.83	3.49
Perimeter (mm)	Mean value	20.21a	21.86a	13.67b	20.98a
	Range	17.27–22.76	18.77–24.83	11.92–15.43	19.14–22.80
	SD	0.84	1.23	0.66	0.74
	CV%	4.17	5.61	4.84	3.51
MaxFeret (mm)	Mean value	6.59a	7.14a	4.45b	6.83a
	Range	5.65–7.50	6.01–8.19	3.91–5.07	6.24–7.45
	SD	0.28	0.44	0.21	0.23
	CV%	4.32	6.13	4.82	3.40
MinFeret (mm)	Mean value	6.23a	6.65a	4.17b	6.48a
	Range	5.33–7.09	5.84–7.62	3.57–4.70	5.86–7.08
	SD	0.28	0.35	0.22	0.25
	CV%	4.46	5.28	5.25	3.89
Circularity	Mean value	0.99a	0.98a	0.97a	0.99a
	Range	0.97–1.00	0.93–0.99	0.93–0.99	0.96–1.00
	SD	0.01	0.01	0.01	0.01
	CV%	0.63	0.90	1.19	0.61
Elongation	Mean value	1.06a	1.07a	1.07a	1.05a
	Range	1.02–1.19	1.02–1.19	1.02–1.17	1.01–1.16
	SD	0.03	0.03	0.03	0.02
	CV%	2.47	2.92	2.84	2.15
Thickness (mm)	Mean value	2.39a	2.54a	2.61a	2.63a
	Range	1.98–2.73	2.16–2.95	2.22–3.03	2.30–3.18
	SD	0.12	0.16	0.15	0.12
	CV%	5.03	6.40	5.60	4.65

Values in the same row with different letters are significantly different ($P < 0.05$).
Range: minimum – maximum value; SD – standard deviation; CV – coefficient of variance on the basis of measurements of 200 seeds.

Table 5
Comparison of surface area and volume of bean varieties estimated using different approximation models with pycnometric method.

		Czech Republic					Turkey	
		White bean (ST513) (105 seeds)	White bean (Krajova) (52 seeds)	Tigar bean (50 seeds)	Kidney bean (50 seeds)	White speckled red bean (50 seeds)	White bean (Dermason) (51 seeds)	White speckled red bean (48 seeds)
Manual method								
Pycnometric method	V (mm^3)	13,310	21,307	16,010	19,000	15,346	23,558	20,288
Oblate spheroid	V (mm^3)	13,971	23,244	16,444	20,543	15,544	23,794	24,878
	E (%)	4.97	9.09	2.71	8.12	1.29	1.00	22.62
	S (mm^2)	13,760	15,879	13,267	14,963	11,920	17,139	15,809
Two sphere segments	V (mm^3)	11,865	19,050	13,067	16,500	12,780	18,909	21,079
	E (%)	10.86	10.59	18.38	13.16	16.72	19.73	3.90
	S (mm^2)	12,572	14,400	12,072	13,575	10,809	15,595	14,431
Triaxial ellipsoid	V (mm^3)	13,978	22,616	15,931	19,990	15,220	23,443	25,227
	E (%)	5.02	6.14	0.49	5.21	0.82	0.49	24.34
	S (mm^2)	12,367	14,453	12,961	14,217	10,902	16,285	14,330

V = volume, S = surface area, E = difference between approximation method and the pycnometric method.

The paired t-test results showed that the lentil volume measured with the pycnometric method were not significantly different than the volume estimated with sphere segment approximation ($P > 0.05$). The difference between the volumes estimated by oblate sphere approximation and the pycnometric method was statistically significant ($P < 0.05$). As it shown in Table 6, the volumes determined using two sphere segments approximation are less than the volumes measured with the pycnometric method. When two sphere segments approximation method was chosen for lentil volume estimation, it was assumed that a perfect sphere segment such as in Fig. 2 would be the standard shape to describe lentils. In reality, their shapes were not perfect sphere segments; therefore the volume estimated by sphere segment approximation was less than the volume measured with the pycnometric method. The accuracy of the approximation methods depends highly on the uniformity of the seed having the presumed shape. In summary, the percentage difference between the image processing method and the traditional method, which is lower than 5.14%, demonstrates that this image processing results largely agree with the values obtained by the traditional measurement.

Gaston et al. (2002) reported 11.31% of percentage difference between volume of Argentina wheat cultivar estimated by ellipsoidal approach and the pycnometric method. Koc (2007) found that the percentage difference between volume estimation

Table 6
Comparison of surface area and volume of lentil varieties estimated using different approximation methods with the pycnometric method.

		Czech Republic		Turkey	
		Green lentil (Medik) (200 seeds)	Green lentil (Moench) (200 seeds)	Red lentil (200 seeds)	Green lentil (200 seeds)
Manual method					
Pycnometric method	V (mm^3)	8480	10,340	4440	10,081
Approximation method	V (mm^3)	10,246	12,628	5021	12,155
Oblate spheroid	E (%)	20.82	22.13	13.07	20.58
	S (mm^2)	16,012	18,508	8672	17,587
Two sphere segments	V (mm^3)	8044	9904	4235	9597
	E (%)	5.14	4.22	4.63	4.80
	S (mm^2)	14,636	16,934	7904	16,030

V = volume, S = surface area, E = difference between approximation method and pycnometric method.

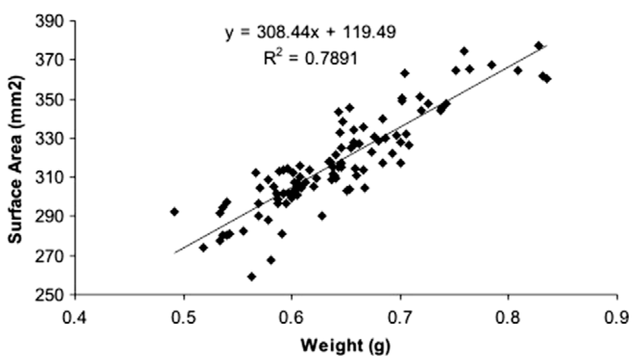


Fig. 4. Bivariate fit of surface area by weight for white bean (Dermason).

of watermelon with ellipsoid approximation and the water displacement method was 7.8%. Du and Sun (2006) calculated the volume of ham with derived and partitioned methods. The difference between approximation methods and the water displacement method was 4.96% for derived method and 1.79% for partitioned method. Wang and Nguang (2007) concluded that the percentage difference between volume of egg, lemon, lime and tamarillos estimated by sum of conical frustum approximation method and the water displacement method 3.23%, 4.18%, 6.68%, and 4.39%, respectively. These all results correspond with our data obtained in this study.

4.3. Relationships of surface area and weight

The good performance of the approximation method to estimate the volume of samples tested here, evidenced that the method can approximate the actual surface area of foodstuffs with high accuracy. Thus, to generalize the obtained results for tested object, the estimated values of the surface area were correlated with the weight of samples. The fitting performance of correlations of the calculated surface area to experimental values of weight is shown in Fig. 4 for white bean (Dermason) from Turkey.

This observed relationship between weight and surface area of seeds was verified. The weight of 1000 seeds was measured as 613.214 g (Table 7) (it corresponds 0.6132 g per one seed). The surface area of one seed was calculated from the equation in the Fig. 4, it equalled to 308.63 mm^2. The surface area from Table 5 was calculated as 319.31 mm^2. Thus, values calculated from sample weight and observed values from approximation method were in good agreement.

Prediction equations for surface area of foodstuffs (apple and meat) were reported by Goni et al. (2007). Values of R^2 of relationship between weight and surface area were 0.93, 0.98, and 0.95 for granny smith apple, red delicious apple and meat

Table 7
Main characteristics of bean varieties.

Sample	Specific volume (cm^3/g)	Specific surface area (cm^2/g)	Weight of 1000 seeds (g)	Density (kg/m^3)
CZ				
White speckled red bean	0.82a	5.82a	374.44a	1220.0a
Tigar bean	0.72a	5.82a	445.04b	1389.9b
Kidney bean	0.78a	5.84a	487.25c	1282.2c
White bean (ST513)	0.74a	7.63b	171.72d	1354.6d
White bean (Krajova)	0.75a	5.10c	545.45e	1331.2e
TR				
White bean	0.75a	5.21c	613.21f	1327.5f
White speckled red bean	0.78a	5.52c	544.73e	1288.8g

Values in the same column with different letters are significantly different ($P < 0.05$).

Table 8
Main characteristics of lentil varieties.

Sample	Specific volume (cm^3/g)	Specific surface area (cm^2/g)	Weight of 1000 seeds (g)	Density (kg/m^3)
TR				
Red lentil	0.67a	11.87a	33.31a	1500.2a
Green lentil	0.73a	11.57b	69.28b	1374.6b
CZ				
Green lentil (Medik)	0.69a	11.95a	61.26c	1444.7c
Green lentil (Moench)	0.71a	11.70ab	72.40d	1400.4d

Values in the same column with different letters are significantly different ($P < 0.05$).

piece, respectively. Eifert et al. (2006) reported an equation to predict the surface area of apples, cantaloupe, strawberry and tomato from weight measurement. It was a linear equation, with R^2 equal to 0.47, 0.75, 0.96, and 0.87, respectively.

4.4. Main characteristics of legume seeds

The main characteristics of the bean and lentil samples used in the study are given in Tables 7 and 8, respectively. The values of specific volume, specific surface area, the weight of 1000 seeds, and seed density were ranged from 0.72–0.82 cm^3/g, 5.1–5.8 cm^2/g, 171.72–613.21 g, 1220.0–1389.9 kg/m^3, respectively for bean varieties. Cetin (2007) found similar results of density and weight of 1000 seeds 1126.15–1223.68 kg/m^3, 751.77–889.83 g, respectively for white speckled red bean. The specific volume of bean varieties were not significantly different ($P > 0.05$) but the density were significantly different ($P < 0.05$). The specific surface area of white bean (ST513) was significantly bigger than the other varieties. The main characteristics of some bean varieties were reported by some researchers. Altuntas and Yildiz (2007) found that faba bean density ranged from 1151.33 to 1206.21 kg/m^3 and the 1000 seeds weight from 1140.15 to 1333.67 g. For locust bean variety, 1000 seeds weight was found as 283 g and density was between 1098.0–1215.7 kg/m^3. According to Haciseferogullari et al. (2003), sakiz faba bean is characterized by density of 1248 kg/m^3 and 1000 seeds weight of 1349.34 g. A comparison between these results and those obtained in the present study indicates that the density of the seeds corresponds with these data but the weight of 1000 seeds was smaller.

The specific volume of lentil varieties was not significantly different ($P > 0.05$). The density and 1000 seeds weight were significantly different ($P < 0.05$). The 1000 seeds weight of red lentil variety was smaller than this one for other variety. As to the sample weight, our data for red lentil (69.28 g/1000 seeds) are close to the above-mentioned data of Bhatty (1988) for the Canadian cultivar Laird but they are very different when compared to the data of Bhattacharya et al. (2005) determined for the cultivar *Lens esculenta*.

5. Conclusion

In the present study, a digital image system was used for determining geometric features of bean and lentil seeds. Approximation of a 3-D model was used to calculate surface area and volume. Triaxial ellipsoid approximation method was suitable for most of the bean varieties except white speckled red bean from Turkey. The percentage difference between volume estimated by the pycnometric method and triaxial ellipsoid approximation method ranged from 0.49% to 6.14%. For red speckled red bean from Turkey, the two sphere segments approximation model gives the best fit to volumes measured pycnometrically. Also the two sphere segments approximation was more suitable in the volume computation of both red and green lentils than oblate sphere approximation. The percentage difference between volumes estimated by the pycnometric method and two sphere segments approximation method ranged from 4.22% to 5.14%. Digital image processing approach could potentially be a simple, rapid, and non-invasive alternative to the traditional measurement methods.

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