Image Vision Technology for the Characterisation of Shape and Geometrical Properties of Two Varieties of Lentil Grown in Turkey

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Abstract

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Geometrical features of lentil seeds (*Lens culinaris* Medik) were analysed using the image analysis LUCIA system Ver. 3.52. The values of the weight of 1000 kernels, kernel density, specific volume, specific surface area, and surface area of 1000 kernels of red and green lentils were determined as 66.61 and 138.56 g, 1504.5 and 1376.4 kg/m^3, 0.6647 and 0.7265 cm^3/g, 0.594 and 0.579 m^2/kg, 395.4 and 801.9 cm^2, respectively. The lentil volume was simulated by an oblate spheroid and two sphere segments and the volumes obtained with both models were compared with that obtained by pycnometric method. Percentage differences of the two sphere segment approximation for red and green lentils were 4.4% and 4.2%, respectively. The height (thickness) of lentils was constant and practically the same with both varieties (2.6 mm) and therefore it was possible to simplify the geometrical models. Thus, 2D image analysis is suitable for a quick evaluation of the specific volume and surface area of grains on the basis of the projected area (equivalent diameter) without the measurement of the height. Image processing provides a simple, rapid, and non-invasive methodology to estimate lentil geometric features and engineering parameters.

Keywords: image analysis; lentil; legumes; size parameters; geometrical model

Lentil, is botanically classified as *Lens culinaris,* is an important crop in many developing countries. It has been the basis of diet for many people living in the Turkey, Middle East, and Asia. Turkey has about 439 900 ha of lentil harvesting area and 622 684 tons of lentil production per annual. Lentil contains high contents of proteins, lipids, carbohydrates, potassium, and phosphorus. In addition, lentil is also a good source of certain amino acids, such as lysine and arginine, which is important for its use in balancing the deficiency of these essential amino acids in cereal-based diets (Lee *et al*. 2007). There are, however, also antinutrient compounds in legumes (flatulence-causing oligosaccharides such as verbascose and stachyose, lectins, protease inhibitors, and others) whose contents can be minimised by washing, heat processing, and/or by germination (Kadlec *et al*. 2006a; Nikolopoulou *et al*. 2007).

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Physical properties of legume seeds are the key parameters for the design of engineering processes and machines, storage structures, and process control. The engineering processes include the heat treatment, air transport, drying, milling, germination. For example, bigger bean seeds germinate faster than smaller and medium ones. The size and shape are important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery. The shape of the material is significant for the analytical prediction of its drying behaviour (Isik & Unal 2007; Altuntas & Yildiz 2007).

This basic information is important to engineers but also to food scientists, processors, and other scientists who may exploit these properties and find new uses.

Factory laboratories and some researchers as well determine simplythe weight of 1000 seeds or the apparent density (density of lentil bulks), while the data on real density are rare. Bhatty (1988) found the weight of a lentil sample of the Canadian cultivar Laird to be 71.43–76.92 g/1000 seeds, and of the cultivar Eston 37–40 g/1000 seeds. Bhattacharya *et al.* (2005) determined the same characteristic with the cultivar *Lens esculenta* as 30.8 g/1000 seeds. According to Altuntas and Yildiz (2007), faba bean are characterised by kernel density of 1150–1210 kg/m^3. Isik and Unal (2007) characterised kidney beans by the kernel density of 1230–1390 kg/m^3.

Owing to the irregularities and variations in shapes, surface profiles, and dimensions of specific food materials, it is difficult to evaluate the actual surface areas and volumes. BET method used for the determination of the surface area of powdered materials is not applicable because of very small values of the specific surface area and because of partial porosity of the grain cover for gases.

A detailed specification of the shape requires a high number of measurements of individual objects of food materials, such as seeds, grains, fruits or vegetables whose snapes are irregular. The shapes of most natural food materials generally resemble some of the regular geometrical objects, and this feature is utilised in the theoretical estimation of the surface area. Three measurements along the mutually perpendicular axes, namely the length, width, and thickness, are used to specify the shape of the food material. Two dimensions are required to represent oblate spheroids for which an analytical mathematical formula for the surface area determination is available (Kumar & Mathew 2003). However, manual size measurement using a digital calliper, subject to human error, may not be an efficient and practical approach to estimate the dimensions and subsequently the volume. Nowadays, the commonly used method for many applications is the so-called image analysis. Machine vision is a non-destructive method that involves image analyses and image processing operations (Koc 2007).

The majority of the applications of computer vision in the food industry focuse on food quality and grading (Fernandez *et al.* 2005; Yang *et al.* 2005; Mendoza *et al.* 2007), the evaluation of mixing (Tukiendorf *et al.* 2003), crystallisation (Bubník *et al.* 2000), separation and aggregation processes (Šárka *et al.* 2006a, b), and the evaluation of the food texture and microstructure (Mezreb *et al.* 2003; Švec & Hrušková 2004; Soral-Smietana & Krupa 2005).

Numerous studies are currently conducted on the possibility of using this technique for the grain quality estimation. They are aimed at determining the geometry and colour of kernels for the purpose of the identification of species and varieties, types of microbiological contamination, and mechanical and/or thermal damage (Tanska *et al.* 2005). The size features are usually obtained using the measurements of the area, perimeter, length, and width (Zheng *et al.* 2006).

Tahir *et al.* (2007) evaluated the variability in the colour, morphology and textural features of wheat and barley due to the change in the moisture content of grain kernels. Sakai *et al.* (1996) analysed the effects of rice varieties and polishing methods on the shape of brown rice and polished rice. Shouche *et al.* (2001) measured the size parameters of Indian wheat varieties. The variation coefficients of the basic geometric parameters for most of Indian wheat varieties were 2–3%. Yadav and Jindal (2007a, b) modelled the changes of the milled rice kernel dimensions during cooking and soaking. Tanska *et al.* (2005) tested the possibility of applying digital image analysis to rapeseed quality estimation, including the determination of the geometrical features and colour of the seed surface. The coefficient of variation of the basic geometric parameters was 2–7% with rapeseed grain. Dalen (2004) determined the size distribution and percentage of broken kernels of rice.

Kadlec *et al.* (2006b) dealt with shape characterisation of pea seeds using image analysis to determine the specific surface area of 0.60 m^2/kg for micro-wave drying.

Venora *et al.* (2007) identified Sicilian landraces and Canadian cultivars of lentil. They are characterised by equivalent diameters of 4.47–6.97 mm and surface areas of 11.13–35.87 mm^2. According to Bhattacharya *et al.* (2005) the lentil seed diameter (*Lens esculenta*) is 4.45 mm and its thickness is 2.55 mm.

The aim of this study was to test the possibility of applying digital image analysis to determine the geometrical features of two different varieties (red and green type) of lentil grown in Turkey.

MATERIAL AND METHODS

Two varieties (red and green) of lentil (*Lens culinaris* Medik) were purchased from a local market in Turkey.

Image analysis. The measurements of the seed geometrical features were performed using a customised personal computer-based digital image analysis system. The digital image analysis was performed with a single seed. The images were acquired by means of a high resolution, low-noise CCD Cohu 2252 camera connected with object-lenses with a magnification of 2.5 and 0.5 in series. The image obtained was analysed using the LUCIA (Laboratory Universal Computer Image Analysis) ver. 3.52 software (Laboratory Imaging Co., Czech Republic). Before the analyses, calibration with a special calibration glass grid was done. For lighting, we used a lighting table.

Images captured in the computer system (Figure 1) are stored, processed, and displayed in the form of matrices (the elements are called pixels for the image processing purpose) in which the information stored is obtained as image features. Seven geometrical features were measured: projected area, equivalent diameter, perimeter, MinFeret, MaxFeret, circularity, and elongation.

Equivalent diameter (d_e) of every scanned object was calculated by means of the LUCIA software using the following formula:

$$d_e = \sqrt{\frac{4A}{\pi}} \quad (1)$$

where:

A – projected area of the measured object (mm^2)

The equivalent diameter (d_e) specifies the characteristic size of a lentil seed. Minferet or MaxFeret is the smallest or largest Feret diameter (minimum or maximum bounding diameter of a rectangular box fitting the object, found after checking angles round 10°). Elongation is defined as ratio MaxFeret/MinFeret. Circularity is calculated according to Eq. (2):

$$\text{circularity} = \frac{4\pi A}{o^2} \quad (2)$$

where:

A – projected area of the measured object (mm^2)

o – perimeter of the object (mm)

The values of these features were calculated automatically by the LUCIA software. For each variety, 200 seeds were measured by digital image analysis system. In order to observe 3D model, the five times replicated thickness (height) h of the seed was measured by digital calliper.

Volume and surface area evaluation using oblate spheroid and two sphere segments approximations. Each seed was considered as an oblate spheroid (Figure 2) or two sphere segments (Figure 3). The volume and surface area of the oblate spheroid or the sphere segment could be calculated using equations Eqs. 3–6 that are commonly found in mathematical handbooks:

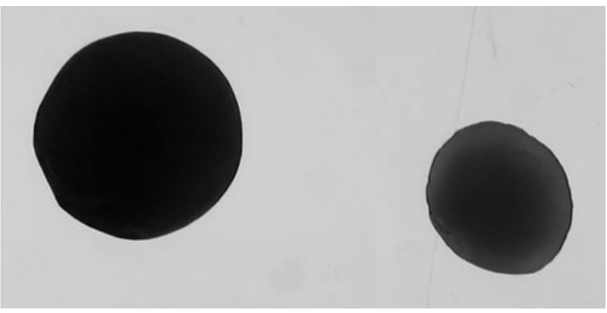

Figure 1. Example of captured lentils (left – green lentil, right – red lentil)

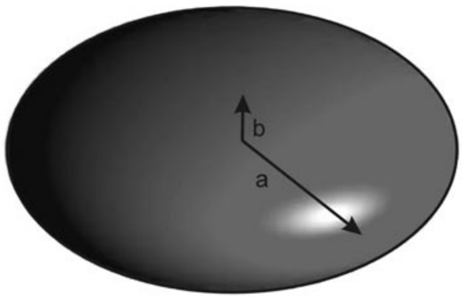

Figure 2. Oblate spheroid

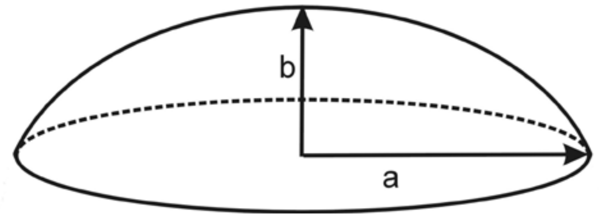

Figure 3. Sphere segment

$$V_{\text{oblate spheroid}} = \frac{4}{3}\pi a^2 b \tag{3}$$

$$S_{\text{oblate spheroid}} = 2\pi\left(a^2 + \frac{b^2}{2\varepsilon}\ln\left(\frac{1+\varepsilon}{1-\varepsilon}\right)\right) \qquad \varepsilon = \frac{\sqrt{a^2-b^2}}{a} \tag{4}$$

$$V_{\text{sphere segment}} = \frac{1}{6}\pi b\,(3a^2 + b^2) \tag{5}$$

$$S_{\text{sphere segment}} = \pi\,(a^2 + b^2) \tag{6}$$

where:
a – half of equivalent diameter ($d_e/2$) (mm)
b – half of thickness (height; $h/2$) (mm)
ε – eccentricity of the ellipse

Volume measurement of lentil seeds by pycnometric method. The density measurement was performed using 85% glycerine at 30°C. The first step was the determination of glycerine density:

$$\rho = \frac{Z_2 - Z_0}{Z_1 - Z_0}(\rho_k - \rho_v) + \rho_v \tag{7}$$

where:
ρ_k – density of water at 30°C = 997.6 kg/m^3
ρ_v – air density ρ_v = 1.2 kg/m^3
Z_0 – weight of the empty pycnometer
Z_1 – weight of the pycnometer filled with water
Z_3 – weight of the pycnometer filled with glycerine and 1 ml wetting agent Fotonal (Foma Bohemia Ltd., Czech Republic) containing surface active substances (oil, polyoxyethylenealcohol ether, and polyoxyethylenenonylophenol ether)

After the determination of the glycerine density, the grain density and volume were determined this way: The weight of 25 grains (m) was measured carefully. The grains were put into the pycnometer and 1 ml of wetting agent was added. Then the pycnometer was filled up with glycerine, kept at constant temperature, the outside of the pycnometer was dried and the pycnometer was weighed again (Z_3). The volume of 25 grains was calculated using Eq. (8).

$$V = V_0 - \frac{(Z_3 - Z_0) - m}{r} \qquad V_0 = \frac{(Z_1 - Z_0)}{r_k} \tag{8}$$

where:
V_0 – volume of the pycnometer
Z_3 – weight of the pycnometer filled with glycerine and lentils

If the surfactant agent were not used, small bubbles would originate on the surface of seeds and the measurement would be misrepresented.

Volume verification. The volumes determined by the oblate spheroid and sphere segments approximations were compared with the volume measured by pycnometric method. The percentage error between the approximation and the pycnometric value was determined using the following formula:

$$\text{Percentage difference} = \frac{|\text{measured}_1 - \text{measured}_2|}{\text{measured}_1} \times 100 \tag{9}$$

Statistical analysis. The experimental results were analysed statistically using the MINITAB software. The calculations were performed at the significance level P = 0.05.

RESULTS AND DISCUSSION

Table 1 shows the results obtained with replicated samples of 200 grains of each cultivar of lentils. The mean value, standard error and coefficient of variation of each parameter are presented. This analysis showed that the coefficient of variation was around 2–6% and 1–5% with red lentil and green lentil, respectively, for most of the basic geometric parameters. These data 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 two replicates showed comparable values of all the parameters with both red and green lentils. This demonstrates the accuracy of the scanner for digital inputs of the image attributes.

The comparison of the results of Venora *et al.* (2007) and Bhattacharya *et al.* (2005) with our results (Table 1) indicates that Turkish varie-

Table 1. Geometrical features of lentils

Geometrical feature		Lentil cultivar	
		red lentil	green lentil
Equivalent diameter (mm)	mean value	4.28	6.64
	range	3.71–4.85	6.07–7.23
	SD	0.21	0.23
	CV	4.83	3.49
Perimeter (mm)	mean value	13.67	20.98
	range	11.92–15.43	19.14–22.80
	SD	0.66	0.74
	CV	4.84	3.51
MaxFeret (mm)	mean value	4.45	6.83
	range	3.91–5.07	6.24–7.45
	SD	0.21	0.23
	CV	4.82	3.40
MinFeret (mm)	mean value	4.17	6.48
	range	3.57–4.70	5.86–7.08
	SD	0.22	0.25
	CV	5.25	3.89
Circularity	mean value	0.97	0.99
	range	0.93–1.00	0.96–1.00
	SD	0.01	0.01
	CV	1.19	0.61
Elongation	mean value	1.07	1.05
	range	1.02–1.17	1.01–1.16
	SD	0.03	0.02
	CV	2.84	2.15
Thickness (height) (mm)	mean value	2.60	2.63
	range	2.22–3.03	2.30–3.18
	SD	0.15	0.12
	CV	5.60	4.65
Projected area (mm^2)	mean value	14.41	34.64
	range	10.80–18.49	28.92–41.09
	SD	1.40	2.41
	CV	9.68	6.96

Range: minimum – maximum value; SD – standard deviation; *CV*– coefficient of variance

ties are the same in size as Sicilian landraces and Canadian cultivar.

The main characteristics of the lentil samples used in the study are given in Table 2. The green lentil measured is of a greater weight (139 per 1000 seeds) than the other cultivars. As to the sample weight, our data for red lentil (66.6 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 Bhatta-

Table 2. Main characteristics of the lentils

Characteristic	Lentil cultivar	
	red lentil	green lentil
The weight of 1000 kernels (g)	66.61	138.56
Density (kg/m^3)	1504.5	1376.4
Specific volume (cm^3/g)	0.6647	0.7265
Specific surface area (m^2/kg)	0.594	0.579
Surface area of 1000 kernels (cm^2)	395.4	801.9

charya *et al.* (2005) determined for the cultivar *Lens esculenta*. On the other side, the sample weight of bean is much greater than of lentil. Altuntas and Yildiz (2007) determined the weight of 1000 kernels for faba bean as 1140 to 1332 g, Isik and Unal (2007) the weight of 1000 kernels of kidney bean as 522–560 g. The measured kernel density of our cultivars was higher than those given in the data of Altuntas and Yildiz (2007) and Isik and Unal (2007).

The results obtained with the two lentil cultivars from both the approximation approach and the traditional approach are shown in Table 3.

The calculated specific surface area agrees with the above-mentioned data of Kadlec *et al.* (2006b) for pea seeds.

The percentage differences for the volume estimation with oblate spheroid approximation and two sphere segments approximation were 11.8% and 4.4%, respectively, for red lentil. For green lentil, the differences were 17.2% and 4.2%, respectively. Two sphere segments approximation was more suitable in the computation of the volume with both red and green lentils. In summary, the percentage difference between the image processing method and the traditional method, which is lower than 4.4%, demonstrates that this image processing results largely agree with the values obtained by the traditional measurement.

The height (thickness) of lentils, which is a very important parameter, is constant in both varieties (2.6 mm) (Figure 4). This value corresponds to the data of Bhattacharya *et al.* (2005) as well. In that case, it is possible to simplify the models from Eqs 3–6, thus 2D image analysis measurement being sufficient for quick calculations of the specific volume and surface area. The percentage difference for the constant height approximation is practically the same compared with the model using the height of lentils (Table 3). Therefore, 2D image processing provides a simple, rapid, and non-invasive methodology to estimate lentil geometric features and engineering parameters.

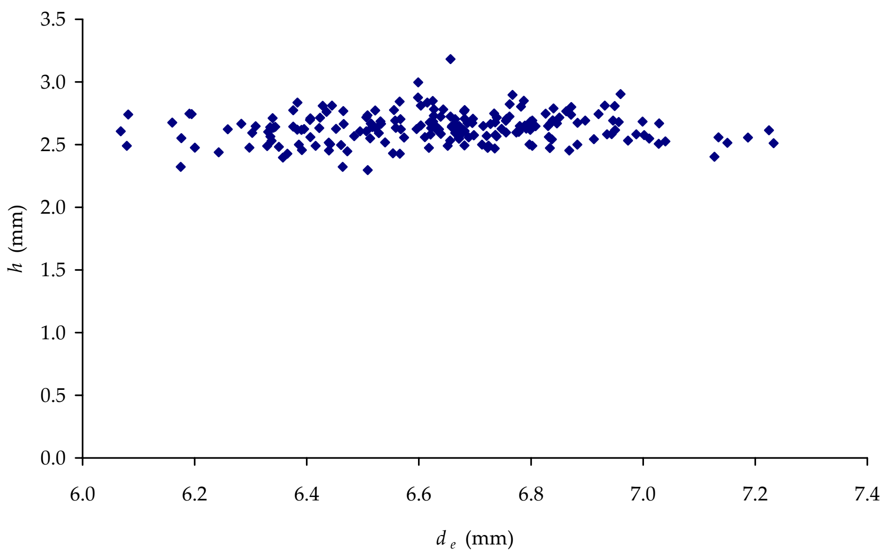

Figure 4. The dependence of lentil height h on equivalent diameter d_e

Table 3. Volume and surface area measurements for 200 lentil seeds

Lentil cultivar	PM	OSAM	SSAM	SSAMH
Volume (mm^3)				
Red lentil	4 432	5 023	4 237	4 224
Green lentil	10 076	12 162	9 602	9 597
Surface area (mm^2)				
Red lentil	–	8 676	7 908	7 902
Green lentil	–	17 595	16 038	16 033

PM – pycnometric method; OSAM – oblate spheroid approximation method; SSAM – sphere segment approximation method; SSAMH – sphere segment approximation method – constant height

Conclusions

The research work was aimed at the size distribution of green and red lentil grains coming from Turkey. The authors chose the image analysis using the LUCIA system for the determination of the geometrical features of seeds. First, it was necessary to develop the measurement methodology, which included the selection of a suitable magnification, the design of lighting, the preparation of a suitable subroutine in which the values of contrast and threshold are defined, etc.

Oblate spheroid and two sphere segments approximations were used to estimate the volume and surface area of lentil seeds. The results indicated that the performance of the sphere segments approximation method is better than that of the oblate spheroid method to estimate the surface area and volume of lentil seeds. Compared with the pycnometric measurement of the volume, the percentage difference of the two sphere segments approximation for red and green lentils were 4.4% and 4.2%, respectively.

The height (thickness) of lentils was constant and equal in both varieties and therefore it was possible to simplify the geometrical models. Thus, 2D image analysis is suitable for a quick computation of the specific volume and surface area of grains from the measured projected area (equivalent diameter) without the measurement of the seed height. Image processing provides a simple, rapid, and non-invasive methodology to estimate lentil geometric features and engineering parameters.

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