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Image analysis of the shapes and dimensions of Teff seeds (*Eragrostis tef*)

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Abstract. With aid of the image analysis using trio ocular microscope the dimensions, circumferences and areas in two perpendicular planes of Teff seeds were measured and based on this information the new ellipsoid model of the seed's shape was derived and compared with measured values. From statistical analysis implies that this model on probability 0.95 is significantly identical with measured values of the Teff seeds. Determined model can help more accurately set up and developed accurate mathematical model for describing mechanical behaviour of individual seeds as well as bulk seeds.

Key words: model, ellipsoid, ball, cereals, grain, dimension.

INTRODUCTION

Teff (*Eragostis tef)* has been widely cultivated and used in Ethiopia and neighbourhood countries, it accounts for about a quarter of total cereal production in Ethiopia and it is main product used in local cuisine (Stallknecht, 1993; Bultosa & Taylor, 2004; Arendt & Zannini, 2013; Bultosa, 2016). However the physical and mechanical properties of Teff seeds are not very well described in professional literature yet (Zewdu & Solomon, 2007) which is given by very small dimensions of Teff seeds (less than 1 mm) (Gebremariam et al., 2014). Nowadays they are only few already published studies focused on the processing of Teff seeds (Stewart & Getachew, 1962; Stojceska et al., 2010; D'Silva et al., 2011). Understanding to the dimensions and shape of the seeds is important factor for creating mathematical models required for modelling of the seed's mechanical behaviour. For accurate mathematical model of the seed's shape that are used in modern simulation processes, for example finite element model (Petrů et al., 2012; Petrů et al., 2014), they are inappropriately ball models of the seeds based on the geometric mean diameter or arithmetic mean diameter (Lizhang et al., 2013; Zhan et al., 2013). From already published studies follows that mathematical model should be based on the ellipsoid model with respect to the true cross section areas and circumferences of the modelled seeds (Petrů et al., 2012; Petrů et al., 2014). The aim of this study is to determinate the dimensions of Teff seeds and with their utilization to derivate accurate ellipsoid mathematical model for the Teff seed shape.

MATERIALS AND METHODS

Sample

Teff (*Eragrostis tef*) seeds (Fig. 1) obtained from Hawassa region, Ethiopia, were used for the experiment. The moisture content $M_c = (11.4 \pm 0.8)\%$ d.b. of the samples was determined by the conventional method ASAE using a standard hot air oven with a temperature setting of 105 °C and a drying time of 17 h (ASAE S410, 1998). Samples having 100 g of weight were randomly selected from a batch of Teff seeds for determining moisture content. The mass of each sample was determined using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany). Three samples were tested for each experiment and the results averaged.

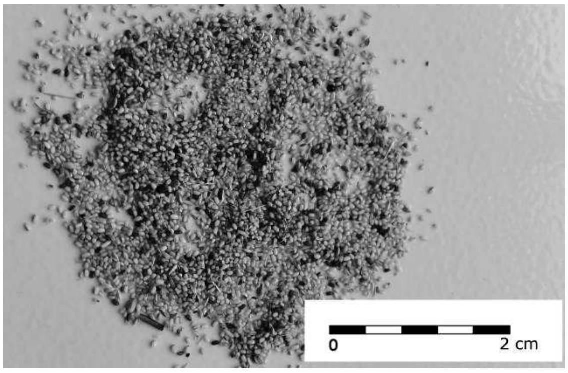

Figure 1. Teff seeds.

Seeds dimensions

For determination of dimensions 20 pieces of Teff seeds were used. Dimensions of the each seeds, length L^* (mm), width W^* (mm), thickness T^* (mm), areas S_I^* (mm^2), S_{II}^* (mm^2) and circumferences O_I^* (mm), O_{II}^* (mm) were determined by digital image analyses using ImageJ software from pictures which were taken with aid of trio ocular microscope (Bresser BioScience Trino, Besser GmbH, Rhede, Germany) in two perpendicular planes as shown in Fig. 2.

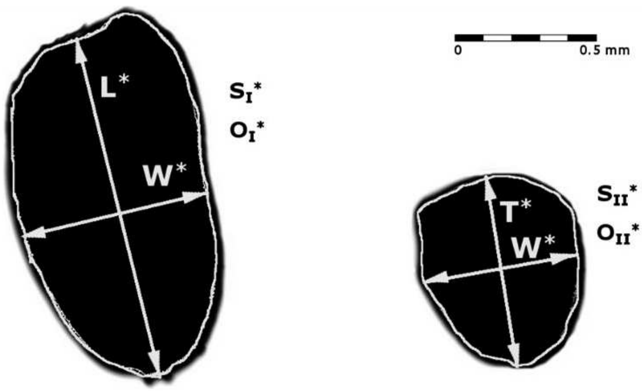

Figure 2. Image analysis of Teff seed.

Geometric mean diameter D_g (mm) and arithmetic mean diameter D_a (mm) were calculated using the following equations (Eq. 1; Eq. 2), (Mohsenin, 1970)

$$D_g = \sqrt[3]{W^* \cdot T^* \cdot L^*} \tag{1}$$

$$D_a = \frac{W^* + T^* + L^*}{3} \tag{2}$$

Sphericity was calculated by Eq. 3 (Mohsenin, 1970).

$$\phi = \frac{D_g}{L^*} \tag{3}$$

Area based on arithmetic diameter S_a (mm^2) and area based on geometric diameter S_g (mm^2) were calculated by Eq. 4 and Eq. 5.

$$S_a = \frac{1}{4} \cdot \pi \cdot D_a^2 \tag{4}$$

$$S_g = \frac{1}{4} \cdot \pi \cdot D_g^2 \tag{5}$$

Theory and modelling

Model of the Teff seeds shape was based on the similarities with ellipsoid (Fig. 3) and on that principle the basic assumptions were determined.

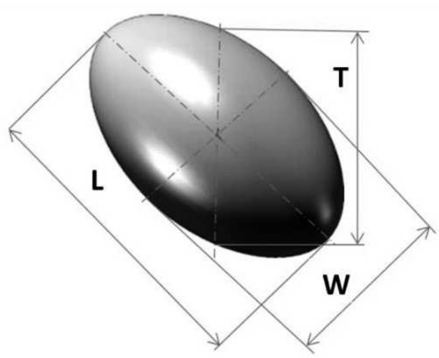

Figure 3. 3D ellipsoid model of Teff seed.

Areas of the seed in two perpendicular planes S_I, S_{II} (mm^2) is calculated as area of ellipse (Eq. 6; Eq. 7)

$$S_I = \frac{\pi}{4} \cdot W \cdot L \tag{6}$$

$$S_{II} = \frac{\pi}{4} \cdot W \cdot T \tag{7}$$

where: L – axis length (mm); W – axis width (mm); T – axis thickness (mm).

Circumference of ellipse O_I (mm) is given by Eq. 8 (Zill et al., 2011)

$$O_I = \frac{\pi}{2} \cdot \left[\frac{3}{2} \cdot (W + L) - \sqrt{W \cdot L} \right] \tag{8}$$

Ratios of axis length φ (–), χ (–) are described by Eq. 8; Eq. 9.

$$\varphi = \frac{W}{L} \tag{9}$$

$$\chi = \frac{S_I}{S_{II}} = \frac{L}{T} \tag{10}$$

Using Eq. 8, Eq. 6 and Eq. 9 the formula for axis length calculation (Eq .11) were derived.

$$L = \frac{\frac{4}{3} \cdot \frac{O_I}{\pi} + \frac{2}{3} \cdot \sqrt{4 \cdot \frac{S_I}{\pi}}}{1 + \varphi} \tag{11}$$

And then using Eq.10 formula for axis thickness calculation (Eq. 12) was determined.

$$T = \frac{L}{\chi} \tag{12}$$

And then using Eq. 9 formula for axis width calculation (Eq. 13) was determined.

$$W = \varphi \cdot L \tag{13}$$

Volume of the ellipsoid was calculated by Eq. 14.

$$V_m = \frac{4}{3} \cdot \pi \cdot W \cdot T \cdot L \tag{14}$$

RESULTS AND DISCUSSION

Measured dimensions, areas and circumferences of Teff seeds with their standard deviations are presented in Table 1 and histogram of Teff seed geometric diameters for seven groups of dimensions is shown in Fig. 4.

Table 1. Measured dimensions, areas and circumferences of Teff seed

	L^* (mm)	W^* (mm)	T^* (mm)	S_I^* (mm^2)	S_{II}^* (mm^2)	O_I^* (mm)	O_{II}^* (mm)
Amount	1.191	0.632	0.608	0.663	0.360	3.227	2.025
Standard deviation	0.109	0.064	0.099	0.164	0.128	0.224	0.232

It is evident that Teff seeds have very small dimensions in comparison to the commonly used food grains (Bultosa & Taylor, 2004; Arendt & Zannini, 2013; Bultosa, 2016; Wrigley et al., 2016) which also correspond to the already published studies (Zewdu & Solomon, 2007; D'Silva et al., 2011; Gebremariam et al., 2014). From the sphericity (Table 2) it is also clear that the shape of the seeds are very similar to the shape of hempseeds (Sacilik et al., 2003) or flaxseeds (Coşkuner & Karababa, 2007) and linseeds (Selvi et al., 2006). From conducted experiments (Table 1) implies that when the seeds are compared dimensionally they are not similar seeds commonly used for food or industrial purposes (Arendt & Zannini, 2013; Bultosa, 2016).

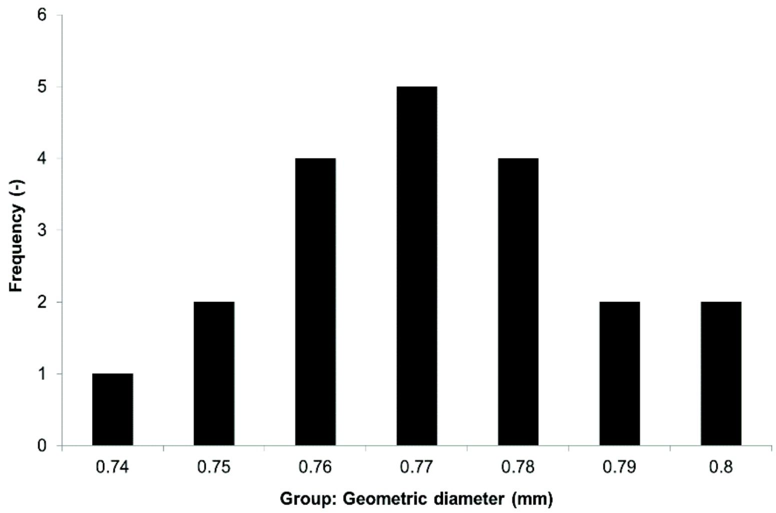

Figure 4. Histogram of Teff seed geometric diameters for seven groups of dimensions.

From measured amounts (Table 1) dimensions, sphericity, volumes of Teff seed's ball model were calculated and they are shown in Table 2.

Table 2. Calculated amounts of Teff seed's ball model

D_a (mm)	D_g (mm)	ϕ (-)	S_a (mm^2)	S_g (mm^2)
0.810	0.771	0.647	0.515	0.605

With aid of measured amounts (Table 1) dimensions, volumes, areas and circumferences of Teff seed's ellipsoid model were also determined and they are shown in Table 3.

Table 3. Calculated amounts of Teff seed's ellipsoid model

L (mm)	W (mm)	T (mm)	V_m (mm^3)	S_I (mm^2)	S_{II} (mm^2)	O_I (mm)	O_{II} (mm)
1.295	0.687	0.703	2.621	0.697	0.302	3.181	1.948

From statistical analysis (Table 4) which was done by Student t test for level of significance 0.05 (*t-test*, $n = 20$, $P > 0.05$) it follows that values for ellipsoid model are statistically significant with measured amounts and that values of ball's model based on arithmetic diameter is statistically different from measured values. The area of ball model based on the geometric mean is statistically significant with measured area in plane I but, it is statistically different from the measured area in plane II. It is clear that the most suitable model is ellipsoid's model that dimensions, areas and circumferences adequately correspond to the true dimensions and shape of the Teff seeds.

Table 4. Statistical analysis measured values with models' values

Compared amount	S_a	S_g	S_I	S_{II}	O_I	O_{II}
T-test value	3.93	1.54	0.94	1.96	0.89	1.44
Critical value	2.09	2.09	2.09	2.09	2.09	2.09

The necessity of using ellipsoid model instead ball model for mathematical descriptions of mechanical behaviour have been already published by studies focused on the virtual modelling of the cereals such are Jatropha seeds (Petrů et al., 2012; 2014), rice kernel (Lizhang et al., 2013) or rice seeds (Zhan et al., 2013) and they confirm determined results of this study. It implies that the development of mathematical models based on ellipsoid's shape could be integral part of mathematical models, described behaviour of seeds or bulk seeds. From already conducted experiments (Mohsenin, 1970; Zewdu & Solomon, 2007) follow that dimensions of this model must be depended on the moisture content and temperature and this factor must be taken into account when a complex model will be created.

Determined, described and verified ellipsoid model can be used not only for description of Teff seeds but also for description of other cereals. It is evident that the ellipsoid model depends on the ratio of cereal dimensions and that this model in case of a certain ratio of axis length can be transform into ball's model.

CONCLUSIONS

The dimensions, circumferences and areas in two perpendicular planes of Teff seeds (*Eragostis tef)* were measured.

The shape of the Teff seed was discussed and on this base new ellipsoid model for the seeds shape was derived.

Ellipsoid model was compared with measured values and also with determined values of commonly used ball model.

From statistically analysis implies that this model on significance level 0.05 is significantly identical with measured values of the Teff seeds and that it describe the shape of the seeds more precisely than ball model.

This determined model can help more accurately set up and developed accurate mathematical model for describing mechanical behaviour of individual seeds as well as bulk seeds.

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