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SOME ENGINEERING PROPERTIES OF SHELLED AND KERNEL TEA (*Camellia sinensis*) SEEDS

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Abstract

Background: *Camellia sinensis* is the source of tea leaves and it is an economic crop now grown around the World. Tea seed oil has been used for cooking in China and other Asian countries for more than a thousand years. Tea is the most widely consumed beverages after water in the world. It is mainly produced in Asia, central Africa, and exported throughout the World. Some engineering properties (size dimensions, sphericity, volume, bulk and true densities, friction coefficient, colour characteristics and mechanical behaviour as rupture force of shelled and kernel tea (*Camellia sinensis*) seeds were determined in this study.
Materials and Methods: This research was carried out for shelled and kernel tea seeds. The shelled tea seeds used in this study were obtained from East-Black Sea Tea Cooperative Institution in Rize city of Turkey. Shelled and kernel tea seeds were characterized as large and small sizes.
Results: The average geometric mean diameter and seed mass of the shelled tea seeds were 15.8 mm, 10.7 mm (large size); 1.47 g, 0.49 g (small size); while the average geometric mean diameter and seed mass of the kernel tea seeds were 11.8 mm, 8 mm for large size; 0.97 g, 0.31 g for small size, respectively. The sphericity, surface area and volume values were found to be higher in a larger size than small size for the shelled and kernel tea samples. The shelled tea seed's colour intensity (Chroma) were found between 59.31 and 64.22 for large size, while the kernel tea seed's chroma values were found between 56.04 68.34 for large size, respectively. The rupture force values of kernel tea seeds were higher than shelled tea seeds for the large size along X axis; whereas, the rupture force values of along X axis were higher than Y axis for large size of shelled tea seeds. The static coefficients of friction of shelled and kernel tea seeds for the large and small sizes higher values for rubber than the other friction surfaces.
Conclusion: Some engineering properties, such as geometric mean diameter, sphericity, volume, bulk and true densities, the coefficient of friction, *L*, a*, b** colour characteristics and rupture force of shelled and kernel tea (*Camellia sinensis*) seeds will serve to design the equipment used in postharvest treatments.

Keywords: *Camellia sinensis*, geometric, gravimetric, friction, colour characteristics

Introduction

The tea family (Theaceae Mirbel) is a family of angiosperms with near global distribution. The largest genus in Theaceae is *Camellia* L. and consists of at least 250 accepted names, with *Camellia japonica* L. and *Camellia sinensis* L. two of the best- known species. *Camellia sinensis* is the source of tea leaves and now an economic crop is grown around the world (Darfler, 2014).

Camellia sinensis L. is well known and extensively planted in order to make popular commercial tea drinks in the genus *Camellia,* while *Camellia oleifera* is the most important and widely distributed of the 18 species used for producing tea seed oil. Tea seed oil has been used for cooking in China and other Asian countries for more than a thousand years (Hui-Chen, 2007). Tea is the most widely consumed beverages after water in the world. It is mainly produced in Asia, central Africa, and exported throughout the world (Chen, 2006). Tea production in the world increased steadily and reached 4.8 million tonnes in recent years. On an average, during the last two decade in the production foremost, China, which contributed 35% to the world tea production, is closely followed by India (21%), Kenya (8%) and Sri Lanka (7%). Turkey (5 %) is the fifth biggest tea producer country with a black tea production of 225.000 tonnes/year, which made it one of the largest tea markets in the world, and its 120.000 tonnes are being consumed in Turkey.

Tea plants cultivated from seeds generally give lower yields, require less fertilization and produce a heterogeneous stand and product compared to plants propagated by vegetative cutting. Seed propagation also results with an extensive support that helps protect soils, prevent erosion and enhance fertility. Historically, tea plantation was created through seed and same producers, and consumers prefer the heterogeneous product yielded by this method (Preedy, 2013). Tea is produced on the eastern Black Sea coast in Turkey, which has the mild climate with a high amount of precipitation and fertile soil**.** Tea is grown mostly in Rize Province (Wikipedia, 2015). At the beginning of tea cultivation in Turkey, the primary goal was to meet the domestic demand only. Today, Turkey holds a significant place among the world's largest tea producers. But still, a great percentage of products are marketed in our domestic market (FAO, 2015).

The tea industry is still dependent on seeds for replanting and crop improvement, despite the availability of a number of good clones for vegetative propagation. Crop improvement and conservation programmes are greatly hindered by the recalcitrant nature of tea seeds. For long-term storage of tea seeds, one strategy would require identification of the maturity index for the collection of seeds in order to avoid collection of immature or non-viable seeds at the proper developmental stage (Bhattacharya et al. 2002).

The information on some engineering properties (size dimensions, sphericity, porosity, volume, bulk and true densities, the coefficient of friction, colour characteristics) is important to design equipment, improve relevant machines and facilities used in the plantation, harvesting, transportation, processing and storing of shelled and kernel tea seeds. The coefficient of friction of the shelled and kernel tea seeds against the various surfaces is also important to design the conveying, transporting and storing equipment. Bulk density and porosity of shelled and kernel tea seeds have an important effect to the designing of transporting and storing structures.

In recent years, several researchers have investigated the geometric, volumetric, colour, mechanical and frictional properties of hazelnuts, (Ercisli et al., 2011a), shea nuts, (Aviara et al., 2005), pine nuts, (Ozguven and Vursavuş 2005), African nutmegs, (Burubai et al. 2007), olive fruits, (Kılıçkan and Güner 2008), peanut and kernel, (Dilmac and Altuntas, 2012), walnut cultivars (Altuntas and Erkol, 2010; Altuntas and Erkol, 2011; Ercisli et al., 2011b), respectively.

Both interspecific and intraspecific variation in seed size plays significant roles in seed dispersal, seed germination and seedling recruitment. Seed size and number are related with the intrinsic constraint in seed packaging and the seed size-number trade-offs in plants. Seed size and number vary greatly both within and among plant individuals, populations or species (Xiao et al. 2015). Under the same operating conditions, tea seed size may play a significant role in processing. Therefore, both the shelled and kernel tea seeds samples and kernel were classified into two categories as large and small sizes. There is a paucity of technical information and data in the scientific literature with regards to the physical properties (geometric, volumetric, colour and frictional) of shelled and kernel tea (Camellia sinensis) seed walnuts. Therefore, the objective of this study was to investigate the engineering properties of shelled and kernel tea seeds classified into two categories as large and small sizes.

Materıals and Methods

This research was carried out for shelled and kernel tea seeds. The shelled tea seeds used in this study were obtained from East-Black Sea Tea Cooperative Institution in Rize city of Turkey. The samples were cleaned manually to remove all foreign matter, dust, dirt, broken and immature seeds. The shelled and kernel tea seeds samples and kernel were classified into two categories as large and small sizes. The initial moisture content of shelled tea and its kernel was determined by using a standard method. The available moisture content of the samples was determined by oven drying at 105°± 1°C for 24h (Altuntas, 2008). The available moisture content of shelled tea seeds for large and small sizes were 8.66 and 8.15% d.b., whereas the moisture content of kernel tea seeds for large and small sizes was 4.78 and 4.79% d.b., respectively.

The size dimensions (length, width and thickness) and seed mass of shelled and kernel tea seeds were measured using a dial micrometer (0.01 mm accuracy), and a digital electronic balance (0.01 g resolution), respectively. The geometric mean diameter (D_g), sphericity (Φ), seed volume, true and bulk densities of tea seed were determined methods presented by Altuntas (2008). The shelled and kernel tea seeds colour characteristics in terms of L^*, a^*, b^* values was determined using a Minolta colorimeter (CR-3000 Model). L^* (lightness or darkness); a^* (green or red); b^* (blue or yellow) colour characteristics of tea seeds were measured at three points of each sample as the means of three replication values (Jha et al., 2005).

The coefficient of friction of shelled and kernel tea seeds is defined as a tangent value of the angle of slope between sliding surface and vertical and horizontal planes (Celik et al., 2007). The experiment was conducted using laminate, plywood, chipboard and galvanized metal friction surfaces.

To rupture force measurements, a biological material test device, Instruction Manual for Materials Testing Machines (Sundoo, SH–2, 500 N, China), was used. Biological material test device has three main component, which are moving platform, a driving unit and a data acquisition, dynamometer, PC card and software, system (Altuntas and Yildiz, 2007). The shelled and kernel tea seeds were placed on the moving platform considering the variation of loading position (X and Y axes) and pressed with a plate fixed on the dynamometer until the shelled and kernel tea seeds ruptured. Force and time curves of shelled and kernel tea seeds were recorded The X-axis (length) is the longitudinal axis, while the Y-axis (width) is transverse axis containing the minor dimension (width) at right angles to the X-axis (Kılıçkan and Güner, 2008; Altuntas and Ozkan, 2008). Three replication were made for each test, and for each test 10 samples were used. For the shelled and kernel tea seeds, compression test measurements of seed samples were measured using by 73 mm diameter plate with biological materials test device. For the rupture force of seed samples for shelled and kernel tea along two axial (F_x and F_y) forces were measured (Altuntas and Yildiz, 2007).

Experimental results were analyzed using t-test of SPSS 13.0 software statistical package programme (SPSS, 2000).

Results and Dıscussıon

Geometric and gravimetric properties

Some engineering properties such as size dimensions, sphericity, porosity, volume, bulk and true densities of shelled and kernel tea seeds for large and small sizes were given in Table 1 and Table 2, respectively.

Table 1: Some descriptive statistics for the geometric and gravimetric properties of shelled tea seeds.

Geometric and gravimetric properties	Large size				Small size				*t-test*	
	Mean	SEM*	max.	min.	Mean	SEM*	max.	min.	*Sig.*	*t-test value*
Length, *L* (mm)	16.90	0.097	19.75	14.85	11.34	0.083	13.30	9.15	**	*27.066*
Width, *W* (mm)	15.87	0.108	19.39	13.58	10.88	0.110	13.09	7.90	**	*18.546*
Thickness, *T* (mm)	15.90	0.100	19.06	13.31	10.55	0.094	12.41	7.16	**	*20.962*
Geometric mean diameter, D_g (mm)	15.76	0.081	18.36	14.41	10.65	0.082	12.36	8.49	**	*20.830*
Sphericity, Φ	0.944	0.102	0.999	0.790	0.931	0.006	0.999	0.630	*ns*	*1.700*
Seed mass, *M* (g)	1.467	0.030	2.395	0.732	0.488	0.015	0.830	0.140	**	*53.863*
Bulk density, ρ_b (kg/m^3)	440.54	3.045	416,47	386.37	449.79	0.55	451.22	449.08	**	*-5.082*
True density, ρ_t (kg/m^3)	611.93	61.94	982.61	496.67	716.13	20.56	884.62	664.29	*ns*	*-1.503*
Surface area, *S* (cm^2)	8.100	0.102	11.413	5.566	3.522	0.061	4.838	1.611	**	*20.348*
Volume, *V* (cm^3)	2.129	0.041	3.625	1.235	0.629	0.016	1.001	0.192	**	*18.611*
Sheel thickness, S_t (mm)	1.422	2.010	0.972	0.180	1.343	1.830	0.852	0.169	*ns*	*0.478*
Moisture content (% d.b)	8.656	0.369	9.161	7.910	8.150	0.272	8.652	7.714	*ns*	*0.992*

SEM: Standard error of mean; **: P<0.01; ns: P>0.05 (non significant)

The geometric mean diameter of shelled tea seed for large and small sizes ranged between 14.41 to 18.36 mm and 8.49 to 12.36 mm, while, the geometric mean diameter of kernel tea seed increased from 7.92 to 14.00 mm and 5.48 to 9.54 mm for large and small sizes, respectively (Table 1, 2). The seed mass of shelled and kernel tea seeds for large sizes ranged between 0.73 to 2.40 g and 0.57 to 1.35 g, while, the seed mass of shelled and kernel tea seeds for small sizes ranged between 0.14 to 0.83 g and 0.05 to 0.51 g, respectively. The geometric mean diameter and seed mass values were found to be a higher increase in the larger size than small size for the shelled and kernel tea samples (Table 1, 2).

Table 2: Some descriptive statistics for the geometric and gravimetric properties of kernel tea seeds.

Geometric and gravimetric properties	Large size				Small size				*t-test*	
	Mean	SEM*	max.	min.	Mean	SEM*	max.	min.	*Sig.*	*t-test value*
Length, *L* (mm)	12.04	0.103	14.01	7.91	8.09	0.087	9.70	5.21	**	*16.471*
Width, *W* (mm)	13.77	0.105	19.39	13.58	9.17	0.093	11.14	6.94	**	*14.960*
Thickness, *T* (mm)	15.90	0.100	16.27	9.24	6.91	0.092	8.85	4.50	**	*13.252*
Geometric mean diameter, D_g (mm)	11.78	0.086	14.00	7.92	7.97	0.079	9.54	5.48	**	*16.768*
Sphericity, Φ	0.833	0.010	0.988	0.507	0.867	0.009	0.993	0.609	*ns*	*-1.542*
Seed mass, *M* (g)	0.969	0.019	1.352	0.573	0.305	0.011	0.506	0.053	**	*14.614*
Bulk density, ρ_b (kg/m^3)	637.70	2.85	652.78	626.71	643.22	2.04	655.59	637.14	*ns*	*-0.863*
True density, ρt (kg/m^3)	1018.62	13.34	1082.62	974.42	1048.46	63.62	1193.89	974.42	*ns*	*-1.013*
Surface area, *S* (cm^2)	3.195	0.078	4.607	1.142	1.528	0.039	2.401	0.636	**	*0.720*
Volume, *V* (cm^3)	0.549	0.019	0.930	0.115	0.182	0.007	0.363	0.048	**	*0.202*
Moisture content (% d.b)	4.784	0.170	5.117	4.567	4.794	0.052	4.854	4.688	*ns*	*-0.065*

SEM: Standard error of mean; **: P<0.01; ns: P>0.05 (non significant)

The sphericity, surface area and volume of shelled tea seed for large size ranged from 0.79 to 1.00; 5.57 to 11.41 cm^2, and 1.24 to 3.63 cm^3, while, the sphericity, surface area and volume of kernel tea seed increased from 0.63 to 1.00, 1.61 to 4.84 cm^2, 0.19 to 1.00 cm^3 for small size, respectively (Table 1, 2). The sphericity, surface area and volume values were found to be the higher increase in a larger size than small size for the shelled and kernel tea samples (Table 1, 2). The effect of the seed size on the length, width and thickness for shelled and kernel tea seeds was statistically found significant (P<0.01) (Table 1, 2).

The geometric mean diameter, seed mass, volume and sphericity of African nutmeg was reported as 12.43 mm, 0.90 g, 1.00 cm^3 and 0.74 at 4.93% (d.b) by Burubai et al. (2007), respectively. In this study, the geometric mean diameter, seed mass, and sphericity values of small size shelled tea seeds were found lower decrease in according to African nutmeg seed values, while the geometric mean diameter, seed mass, volume and sphericity values of large size shelled tea seeds were found higher in according to African nutmeg seed values, In this study, the geometric mean diameter, seed mass, volume and sphericity values of kernel tea seeds for both large and small sizes were found lower than African nutmeg seed values. The effect of the seed size on the geometric mean diameter, seed mass, surface area, and seed volume for shelled and kernel tea seeds was statistically found significant (P<0.01) (Table 1, 2).

Kenghe et al. (2013a) reported that the surface area of Lathyrus varieties was increased from 73.31 to 84.88 mm^2, 70.38 to 79.45 mm^2 and 54.78 to 62.29 mm^2, whereas, grain volume increased from 12.22 to 14.15 mm^3, 11.73 to 13.24 mm^3 and 9.13 to 10.38 mm^3, respectively with the corresponding increase in moisture content, for Pratik, Ratan and NLK-40 varieties, respectively. In this study, the surface area and volume values of shelled and kernel tea seeds for both large and small sizes were found higher than of Lathyrus varieties (Pratik, Ratan and NLK-40).

Ercisli et al. (2011a) reported that the geometric and gravimetric properties of hazelnut cultivars such as geometric mean diameter, mass, sphericity and surface area increased from 17.52 to 22.41 mm, 1.80 to 4.15 g, 68.88 to 97.35% and 8.21 to 15.82 cm^2 for nuts, 13.05 to 16.64 mm, 0.99 to 1.82 g, 63.55 to 97.26% and 5.36 to 8.74 cm^2 for kernel, respectively. Ercisli et al (2011 b) reported that the mass, geometric mean diameter, sphericity and surface area of Yalova-1 and Maraş 18 walnut cultivars were found to be 12.44 and 12.70 g, 36.33 and 36.83 mm, 87.41 and 81.08%, 41.48 and 42.66 cm^2 for nuts, whereas, the mass, geometric mean diameter, sphericity and surface area of kernel walnut of Yalova-1 and Maraş 18 cultivars were found to be 7.38 and 7.40 g, 27.98 and 28.86 mm, 84.86 and 81.21%, 24.64 and 26.19 cm^2, respectively. In this study, shelled and kernel tea seed values such as geometric mean diameter, sphericity and seed mass were lower than shelled hazelnut and its kernel and shelled and kernel walnut by reported Ercisli et al. (2011 a, b).

The true density and bulk density of shelled tea seed for large size ranged from 496.7 to 884.6 kg/m^3; 386.4 to 416.5 kg/m^3, while, the true and bulk densities of kernel tea seed increased from 664.3 to 952.6 kg/m^3; 449.1 to 451.2 kg/m^3 for small size, respectively (Table 1, 2). The effect of the seed size on the bulk density of shelled tea seeds was statistically found significant (P<0.01), whereas, the effect of the seed size on the true density for shelled tea seeds was not statistically found significant (P>0.05). In this study, the true density and bulk density values were found to be higher in small sized than large sized for the shelled and kernel tea seeds (Table 1, 2). The effect of the seed size on the true density and bulk density for kernel tea seeds was not statistically found significant (P> 0.05) (Table 1, 2).

Ozguven and Vursavus (2005) reported that the true density and bulk density values for pine nut were 983.59 kg/m^3 and 619.85 kg/m^3, respectively. Dilmac and Altuntas (2012) reported that the bulk density and true densities were increased from 181.31 to 211.51 kg/m^3, 837.55 to 944.85 kg/m^3 for peanut, 535.09 to 547.84 kg/m^3 and 937.11 to 954.60 kg/m^3 for peanut kernel, respectively. In this study, the bulk and true densities values of shelled tea seeds for small sizes were found lower than that of peanut kernel values reported by Dilmac and Altuntas (2012). Kenghe et al. (2013 b) reported that the grain sizes of bulk densities of the Ratan (for 7.90% d.b.), Pratik (for 6.75%) and NLK-40 (for 7.33%) Lathyrus cultivar samples were 5.08 mm, 4.96 mm and 4.33 mm, and 810 kg/m^3, 825 kg/m^3 and 830 kg/m^3, respectively for small medium and large sized grains. In this study, the bulk density values of shelled and kernel tea seeds for small size and large size were found lower than that of Lathyrus grain values reported by Kenghe et al. (2013 b).

Colour characteristics

Colour characteristics of shelled and kernel tea seeds for large and small sizes were given in Table 3. The $L*$ values of shelled and kernel tea seeds for large size observed from 35.8 to 44.0 and 45.4 to 53.6, while, $L*$ values of shelled and kernel tea seeds for small size increased from 34.18 to 40.28; 40.2 to 46.6, respectively. The effect of the seed size on $L*$ values for shelled tea seeds was not statistically found significant (P>0.05), whereas, the effect of the seed size $L*$ values for kernel tea seeds was statistically found significant (P<0.01) (Table 3).

Table 3: Some descriptive statistics for the colour characteristics of shelled and kernel tea seeds.

Colour properties	**Large size**				**Small size**				***t-test***	
Shelled tea seed	Mean	SEM*	max.	min.	Mean	SEM*	max.	min.	*Sig.*	*t-test value*
*L**	37.76	0.692	39.99	35.77	37.42	1.049	40.28	34.18	*ns*	*0.406*
*a**	7.87	0.418	9.40	6.83	8.64	0.891	10.61	5.69	*ns*	*-1.170*

*b**	14.70	0.510	16.00	13.61	15.07	1.041	18.08	11.97	*ns*	*-0.486*
Chroma	16.67	0.660	18.42	15.38	17.38	20.50	13.25	1.13	*ns*	*-0.748*
Hue angle (°)	61.86	0.660	64.22	59.31	60.44	1.370	64.57	56.95	*ns*	*1.216*
Kernel tea seed										
*L**	49.94	1.606	53.59	45.44	44.54	1.139	46.58	40.24	**	*4.593*
*a**	10.83	0.759	13.54	8.83	13.99	0.659	16.22	12.12	**	*-5.265*
*b**	20.35	0.501	22.23	19.44	18.49	1.537	22.72	13.71	*ns*	*1.917*
Chroma	23.05	0.909	24.23	22.14	23.19	1.672	27.91	19.72	*ns*	*-0.162*
Hue angle (°)	61.98	0.909	68.34	56.04	52.54	1.672	56.28	44.03	**	*0.796*

SEM: Standard error of mean; **: P<0.01; ns: P>0.05 (non significant)

The mean *a** and *b** values of shelled tea seeds for large and small sizes were as 7.9 and 14.7; 8.6 and 15.1; while average *a** and *b** values of kernel tea seeds for large and small sizes were as 10.8 and 20.4; 14.0 and 18.5, respectively (Table 3). The effect of the seed size on *a** colour characteristics values for shelled tea seeds was not statistically found significant (P>0.05), whereas, the effect of the seed size on *a** values for kernel tea seeds was statistically found significant (P<0.01). The shelled tea seed's colour intensity (Chroma) were found between 59.31 and 64.22 for large size, while the kernel tea seed's chroma values were found between 56.04 68.34 for large size, respectively. For the small size, the average colour intensity (Chroma) and hue angle were observed as 60.44 and 17.38 for shelled tea seed, 52.54 and 23.19 for kernel tea seeds, respectively. The effect of the seed size on the Chroma and *b** colour characteristics values for shelled and kernel tea seeds was not statistically found significant (P>0.05) (Table 3). *L**, *a** colour characteristics values were found to be higher in large tea seeds than the small size tea seeds for both shelled and kernel tea seeds, whereas, *b** value was found to be higher in small size than large size for both shelled and kernel tea seeds (Table 3).

Ercisli et al. (2011) reported that *a** and *b** values increased from 8.67 to 14.33 and 13.23 to 23.82, while, *a** and *b** values for kernels increased from 9.44 to 12.63 and 18.08 to 24.01, among hazelnut cultivars, respectively. And also, chroma (colour intensity) of hazelnut varieties were found between 15.90 and 27.84, while chroma of hazelnut kernels was found between 20.44 and 26.91 among hazelnut cultivars. In this study, *a** values of shelled tea seeds both large and small sizes were found lower than that of shelled hazelnut cultivars values reported by Ercisli et al. (2011).

Altuntas and Erkol (2009) reported that *L** colour characteristics of shelled walnuts decreased from initial to last moisture content with values from 55.09 to 50.85 for Bilecik cultivar (from 10.0% to 15.8% dry basis), from 56.50 to 39.38 for Yalova-1 cultivar (from 11.5 to 23.2% dry basis), and from 53.21 to 46.84 for Yalova-3 cultivars (from 11.3 to 19.5% dry basis), respectively. In this study, *L** values of shelled tea seeds for small sizes were found lower than that of shelled walnut cultivars (Bilecik, Yalova-1 and Yalova-3) values reported by Altuntas and Erkol (2009).

Frictional properties

The frictional properties of shelled and kernel tea seeds for large and small sizes were given in Table 4. The static coefficients of friction values of shelled and kernel tea seed for large and small sizes were higher for rubber than the other friction surfaces. This is a result of the increasing adhesion on rubber friction surface between the product. The lower static coefficients of friction for large and small sized shelled and kernel tea seeds were found for laminate than the other friction surfaces (Table 4).

Table 4: Some descriptive statistics for the frictional properties of shelled and kernel tea seeds.

Friction properties	***Large size***				***Small size***				***t-test***	
Shelled tea seed	Mean	SEM*	max.	min.	Mean	SEM*	max.	min.	*Sig.*	*t-test value*
Friction surface										
Laminate	0.364	0.011	0.384	0.344	0.445	0.012	0.466	0.424	**	*-7.735*
Plywood	0.488	0.012	0.510	0.466	0.510	0.013	0.532	0.488	*ns*	*-1.937*
Galvanized metal	0.473	0.071	0.488	0.466	0.452	0.019	0.488	0.424	*ns*	*1.663*
Chipboard	0.539	0.015	0.554	0.510	0.473	0.007	0.488	0.466	**	*6.300*
Rubber	0.617	0.008	0.625	0.601	0.634	0.029	0.675	0.577	*ns*	*-0.884*
Kernel tea seed										
Friction surface										
Laminate	0.411	0.466	0.364	0.030	0.411	0.445	0.384	0.018	*ns*	*1.289*
Plywood	0.772	0.810	0.754	0.019	0.488	0.510	0.445	0.021	**	*27.696*
Galvanized metal	0.650	0.675	0.625	0.014	0.633	0.675	0.601	0.022	**	*3.873*
Chipboard	0.675	0.700	0.649	0.015	0.728	0.781	0.649	0.040	*	*-2.846*
Rubber	0.666	0.675	0.649	0.008	0.602	0.675	0.554	0.037	**	*3.883*

SEM: Standard error of mean; **: P<0.01; *: P<0.05; ns: P>0.05 (non significant)

The effect of the seed size on the coefficient of frictions of the shelled tea seeds for plywood, galvanized metal and rubber surfaces was not statistically found significant (P>0.05); whereas, the effect of the seed size on the coefficient of friction of the kernel tea seeds for plywood, galvanized metal and rubber surfaces was statistically found significant (P<0.01) (Table 4). Owolarafe et al (2007) reported that the coefficient of static friction was as 0.58, 0.53, 0.56 and 0.56, for plywood, aluminium, mild steel sheet and galvanised steel sheet respectively variety of fresh palm fruit (cv. Dura).

Shirkole et al. (2013) reported that the static coefficient of friction values of soybean varieties (TAMS-38 and JS-335) were found in the range of 0.390 to 1.428 and the greatest value was found the rubber surface than the other friction surfaces in the moisture contents specified. In this study, the similar results the static coefficient of friction values for shelled and kernel tea seeds were reported by Shirkole et al (2013).

Mechanical behaviour

The mechanical properties (rupture force) of shelled and kernel tea seeds for large and small sizes along X and Y axes were shown in Table 5. The rupture force of shelled and kernel tea seeds for large size along X axis observed from 38.1 to 183.8 N; 100.7 to 308.7 N, while, the rupture force of shelled and kernel tea seeds for large size along Y axis increased from 37.9 to 111.7 N; 124.2 to 393.1 N, respectively. The effect of the seed size on the rupture force (X-axis) values for shelled and kernel tea seeds was statistically found significant (P<0.01) (Table 5).

Table 5: Some descriptive statistics for the mechanical behaviour (rupture force) of shelled and kernel tea seeds by compression test.

Mechanical behaviour	**Large size**				**Small size**				***t-test***	
Shelled tea seed	Mean	SEM*	max.	min.	Mean	SEM*	max.	min.	*Sig.*	*t-test value*
Rupture force (X axis, N)	129.9	21.20	183.8	38.1	82.1	8.18	115.6	51.8	**	*3.360*
Rupture force (Y axis, N)	68.1	12.89	111.7	37.9	56.7	13.01	94.3	16.4	*ns*	*1.245*
Kernel tea seed										
Rupture force (X axis, N)	211.7	25.9	308.7	100.7	37.4	1.049	40.3	34.2	**	*6.694*
Rupture force (Y axis, N)	240.4	31.1	393.1	124.2	92.3	10.4	147.0	53.3	**	*4.798*

SEM: Standard error of mean; **: P<0.01; ns: P>0.05 (non significant)

The rupture force values of kernel tea seeds were higher than shelled tea seeds for the large size along X axis; whereas, the rupture force values of along X-axis were higher than Y axis for large size of shelled tea seeds (Table 5). The effect of the seed size on mechanical properties (rupture force, Y-axis) for shelled tea seeds was not statistically found significant (P>0.01), whereas, the effect of the seed size on rupture force along Y axis for kernel tea seeds was statistically found significant (P<0.01) (Table 5). Ercisli et al (2013b) reported that the rupture forces required cracking walnut along a longitudinal axis through the hilum (X) and right angles to the longitudinal axis (Y-axis) obtained as 184.8 N and for 227.6 N for Maraş -18 cultivar and 117.3 N and 184.9 N for Yalova-1, respectively. In this study, rupture force values of shelled tea seeds both large and small sizes were found lower values than that of shelled walnut cultivars (Yalova-1 and Maraş-18) values reported by Ercisli et al. (2013b).

The rupture force of shelled tea seeds for small size among X and Y axes increased from 51.8 to 115.6 N; 16.4 to 94.3 N, while, the rupture force of kernel tea seeds for small size along X and Y axes increased from 34.3 to 40.3 N; 53.3 to 147.0 N, respectively. In this study, the rupture force values of kernel tea seeds were higher increased than shelled tea seeds for small size along Y axis; whereas, the rupture force values of shelled tea seeds among X axis were higher increased than kernel tea seeds for the small size. Koyuncu et al, (2004) reported that the rupture forces required to crack walnuts at longitudinal axis through the hilum (X) obtained as 246.7 and 167.4 N for Bilecik and Sebin walnut cultivars, respectively.

Conclusıon

The measured some engineering properties such as geometric mean diameter, sphericity, volume, bulk and true densities, the coefficient of friction, *L**, *a**, *b** colour characteristics and rupture force of shelled and kernel tea (*Camellia sinensis*) seeds will serve to design the equipment used in postharvest treatments. The following conclusions are drawn from the investigation on some engineering properties of shelled and kernel tea seeds.

The geometric mean diameter and seed mass values were found to be higher in the larger size than small size for the shelled and kernel tea samples. The sphericity, surface area and volume values were found to be higher in the larger size than small size for the shelled and kernel tea samples. The true density and bulk density values were found to be higher in small size than the large size for the shelled and kernel tea seed samples.

*L**, *a** colour characteristics values were found to be higher values in a large tea seeds than the small size tea seeds, whereas, *b** value was found to be lower values in a large size than small size for both shelled and kernel tea seeds. The static coefficients of friction of shelled and kernel tea seeds for the large and small sizes were found higher values for rubber than the other friction surfaces. The rupture force values of kernel tea seeds were found the higher than shelled tea seeds for the large size along X axis; whereas, the rupture force values of along Y axis were lower values than X axis for large size of shelled tea seeds.

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