

PAPER • OPEN ACCESS

Characterization and Evaluation of Physical and Mechanical Properties of Un hulled Arabica Coffee Bean

To cite this article: S I Kuala *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **251** 012040

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Characterization and Evaluation of Physical and Mechanical Properties of Un hulled Arabica Coffee Bean

S I Kuala, D D Hidayat, C E W Anggara and R Saparita

Development Center for Appropriate Technology, Indonesian Institute of Sciences, KS Tubun Street 5 Subang 41213, West Java, Indonesia

Email: seri.kuala.sk@gmail.com

Abstract. This work was carried out to characterize the physical and mechanical properties of unhulled arabica coffee bean. The results of this work found that at moisture content of 18.76 ± 0.19 % wb, the average length, width, thickness, geometric diameter and surface area of unhulled coffee bean ranged from 12.04 ± 1.06 mm, 8.24 ± 0.45 mm, 4.99 ± 0.34 mm, 7.90 ± 0.38 mm and 196.44 ± 19.09 mm² respectively. The average mass and volume ranged from 0.21 ± 0.06 g and 0.21 ± 0.06 cm³ respectively. The average particle density, bulk density and sphericity ranged from 1.00 ± 0.02 g/cm³, 0.40 ± 0.01 g/cm³ and 0.66 ± 0.04 respectively. The average porosity, aspect ratio, and shell content ranged from 60.16 ± 1.09 %, 68.88 ± 6.38 % and 16.55 ± 5.70 % respectively. The average hardness and fracturability ranged from 12.34 ± 1.28 gf and 2.45 ± 0.08 gf respectively. Regarding the angle of repose on the surface of stainless steel, aluminum, acrylic, and plywood results showed that the average emptying angle of repose ranged from $26.88 \pm 3.67^\circ$, $29.44 \pm 3.35^\circ$, $30.01 \pm 4.83^\circ$ and $40.0^\circ \pm 7.00^\circ$ respectively, and the average filling angle of repose ranged from $32.02 \pm 2.880^\circ$. Concerning friction, results of measurement indicated that average static friction of stainless steel, aluminum, acrylic, and plywood ranged from 0.36 ± 0.02 , 0.40 ± 0.03 , 0.38 ± 0.04 and 0.45 ± 0.03 respectively. The highest emptying angle of repose occurred on the surface of plywood inversely of that was occurring on the surface of stainless steel. There was a positive relationship between the angle of repose and the static friction.

Keywords: Un hulled coffee bean, physical properties, mechanical properties, texture profile, angle of repose

1. Introduction

Among the ASEAN countries, Indonesia has known as a producer and second largest coffee exporter after Vietnam [1]. In the world, Indonesia was the fourth largest coffee producer after Brazil, Vietnam, and Colombia [2]. In the case of coffee exports, Indonesia was the fourth largest coffee exporter in the world after Brazil, Vietnam, and Colombia [2]. In the world, Indonesia has known as specialty coffee through coffee variants. With its unique taste and aroma, Indonesia has an excellent opportunity to increase trade coffee in the world.

In Indonesia, coffee is one of the commodities that play an essential role in supporting efforts to increase non-oil exports. Foreign exchange earnings from commodity coffee in 2014 generated export value of 10.1 percent of the entire export value of agricultural commodities, or 0.5 percent of non-oil exports, or 0.4 percent of the total export value [3]. In recent years, the amount of coffee exports has



declined. The decline in the value of commodities, aside from the decrease in prices of coffee in the international market and has also suspected due to the declining quality of Indonesian coffee.

As much as 66% of world coffee production was an arabica coffee, and another 34% was robusta coffee [4]. It mentioned before that in Indonesia the production of coffee was 73.57 % robusta and 26.43 % Arabicas. To increase involvement in the world coffee market related to the increase of export value, Indonesia had to be able to increase the production of Arabica coffee with quality that meets the world coffee standards.

The physical and mechanical properties of coffee beans, the same as other grains and seeds are indispensable in processing, designing, and manufacturing of equipment. Many researchers carried out research on the physical and mechanical properties of agricultural products among others were: [4] carried research on physical, mechanical and chemical properties of *Jatropha curcas*; [5] carried out research on physical properties of sugar beet seed, [6], [7], [8], [9], [10] and [11] carried out research on physical and mechanical properties of onion, [12] carried out research on physical and mechanical properties of wild medlar. Many other researched done on physical and mechanical properties of agricultural products were: sweet cherry [13], kiwifruit [14], jujube fruit [15], Simarouba fruit and kernel [16], date fruit [17], goldenberry [18], kumquat [19], cocoa bean were [20] and [21], [22], and [23]. Relevant parameters to be known to increase the quality of coffee bean among others are physical and mechanical properties of the coffee bean. The data of physical and mechanical properties of unhulled coffee bean has not been covering yet on those studies mentioned above. Therefore this study focused on assessing the physical and mechanical properties of unhulled arabica coffee bean

2. Materials and methods

Unhulled arabica coffee bean samples collected from Cipunagara village (6°46'57.71 "S 107°41'37.15" E, 1153 MAMSL), Cislak district, Subang regency, Indonesia.

2.1. Measurement of physical properties

Moisture content determined by using indirect moisture methods indirect moisture methods. The instrument used was Moisture Bulk Density Tester AMTAST JV-010S (P 30) with the specification of test range: 0 – 40 %, repeat error $\leq 0.2\%$, test error $\leq 0.5\%$, environment temperature 0-40 °C, relative humidity $\leq 80\%$, amount of sample 150 - 200 grams.

Size and dimension of the 50 samples of the unhulled arabica coffee bean measured by digital vernier caliper with the accuracy of 0.01 mm. Mass (M) of samples measured by using an analytical balance. Volume (V) of samples measured by using a graduated cylinder. The volume quantity determined by counting the number of displaced water. The geometric diameter (D_{gm}), sphericity (ψ), surface area (S_a), particle density (ρ_p), bulk density (ρ_b), porosity (ϵ), aspect ratio (R_a) and shell /silverskin (Cs) content calculated from equation (1), equation (2), equation (3), equation (4), equation (5), equation (6), equation (7), and equation (8) respectively.

$$D_{gm} = \sqrt[3]{w \times l \times t} \quad (1)$$

$$\psi = \frac{D_{gm}}{l} \quad (2)$$

$$A_s = \pi(D_{gm})^2 \quad (3)$$

$$\rho_p = \frac{M}{V} \text{ gr/cm}^3 \quad (4)$$

$$\rho_b = \frac{M_{\text{psob}}}{V_{\text{psob}}} \text{ gr/cm}^3 \quad (5)$$

$$\epsilon (\%) = \frac{(\rho_p - \rho_b)}{\rho_p} \times 100\% \quad (6)$$

$$R_a = \frac{W}{L} \times 100 \% \quad (7)$$

$$C_s = \frac{W_{LUS} - W_s}{W_{LUS}} \times 100 \% \quad (8)$$

The determination of geometric diameter (Dgm), sphericity (ψ), particle density (ρ_p), bulk density (ρ_b) referred to [24], [25], [26] and [27]. Sphericity and aspect ratio were calculated regarding [28]. Surface area calculated regarding [29], [30], [31] and [32]. Porosity and shell content calculated regarding [21].

2.2 Measurement of mechanical properties

Hardness and fracturability were measured using TA X plus Texture Analyser Stable Micro System. The operative condition of the TA was: test mode of compression, the test speed of 0.1 mm/sec, distance of 2.5 mm, data acquisition of 200 pps and probe of P/2. Samples randomly chose and positioned horizontally on the platform of the Texture Analyser instrument.

Samples randomly chose and positioned horizontally on the platform of the Instron testing machine (Instron, 5566, USA). Berries placed with its front side facing upward while the beans placed with their flat sides facing upward. Uniaxial compression conducted at a rate of 0.83 cm/s. The maximum force recorded during the test before the sample fracture taken as the fracture force of the sample. Deformation determined from the fracture force. Ten samples were recorded for their values [33]. There are two types of the angle of repose, i.e., emptying and filling angle of repose. The emptying angle of repose (θ_e) measured by an apparatus consisting of a sloping platform with adjustable angles. The individual of coffee bean sample was dropped from the distance of 10 cm above the device of the plane board to get a natural position; then the plane board was raised gradually until the coffee bean just started to slide down. The angle of repose determined by measuring the height of the seeds at two points on the sloping platform and the horizontal distance between the points as in equation (9) [34], [10]. There were four types of materials used in determining the angle of repose, i.e., stainless steel 1 mm, aluminum 1 mm, acrylic 3 mm and plywood 18 mm.

In determining the coefficient of friction, the sample filled into a PVC cylinder (diameter 10 cm, height 5 cm) which placed on the friction surface. The PVC cylinder was then lifted 3 mm from the friction surface so that the barrel did not touch the friction surface. The friction surface was elevated gradually until the barrel started to slide down. The angle (θ) between the lifted friction surface and the horizontal surface is known as the static angle of friction between the sample and the friction surface. The coefficient of static friction obtained from equation (10) [21] and [35]. There were four types of material surfaces used to determine the static friction, i.e., stainless steel 1 mm, aluminum 1 mm, acrylic 3 mm and plywood 18 mm.

$$\theta_e = \frac{\tan^{-1}(h_2 - h_1)}{x_2 - x_1} \quad (9)$$

$$\mu_s = \tan \theta \quad (10)$$

The filling angle of repose (θ_f) measured by PVC cylinder (10 cm x 10 cm) in which this cylinder filled with the sample, then the barrel was lifted gradually until the example formed a cone. The diameter and height of the cone were measured, and the angle of repose was calculated using the equation as follows [36] and [35] :

$$\theta_f = \tan^{-1} \left[\frac{2h}{D} \right] \quad (11)$$

3. Results and discussion

All the properties assessed at an average moisture content of $18.76 \pm 0.19 \% \text{ wb}$.

3.1. Physical properties

Table 1 showed the value of the sample size, minimum, maximum, mean and standard deviation of the measured physical properties. The measured physical properties comprised of length (L), width (W), thickness (T), mass (M), volume (V), geometric diameter (Dgm), surface area (As), particle density

(pp), bulk density (ρ_b), sphericity (ψ), porosity (ϵ), aspect ratio (Ra), shell content (Cs) and moisture content (Mc).

Table 1. Descriptive statistics of coffee bean sample dimensions

	N	Minimum	Maximum	Mean	Std. Deviation
L (mm)	50	9.51	14.54	12.0406	1.0623
W (mm)	50	7.45	9.37	8.2386	0.4473
T (mm)	50	4.21	5.84	4.9906	0.3357
M (g)	50	0.08	0.44	0.2076	0.0566
V (cm ³)	50	0.08	0.45	0.2084	0.0574
D _{gm} (mm)	50	7.08	8.74	7.8998	0.3844
A _s (mm ²)	50	157.2	239.8	196.437	19.092
ρ_p (gr/cm ³)	50	0.96	1.04	0.9968	0.0168
ρ_b (gr/cm ³)	50	0.38	0.42	0.3968	0.0098
Ψ (%)	50	0.58	0.75	0.6588	0.0394
ϵ (%)	50	58.20	62.37	60.1612	1.0874
R _a (%)	50	57.26	82.12	68.8758	6.3824
C _s (%)	50	4.72	50.06	16.5474	5.7012
M _c (%)	50	18.10	19.10	18.7580	0.1939

Sahin and Sumnu [37] stated that dimension and size were essential parameters in the screening as well as grading and evaluating the quality of the products. In the hulling mechanism, the size of the coffee bean has also been significant to set the steel huller component clearance.

Table 2. Correlation coefficients among measures of unhulled coffee bean samples

		L	W	T	M	V	Dgm	Sa	Dp	Db	Sph	E	Ra	Cs
L	Pearson Correlation	1												
	Sig. (2-tailed)													
W	Pearson Correlation	.213	1											
	Sig. (2-tailed)	.137												
T	Pearson Correlation	.202	.249	1										
	Sig. (2-tailed)	.159	.081											
M	Pearson Correlation	.050	.108	.162	1									
	Sig. (2-tailed)	.728	.457	.262										
V	Pearson Correlation	.053	.099	.178	.998**	1								
	Sig. (2-tailed)	.714	.494	.216	.000									
Dgm	Pearson Correlation	.773**	.606**	.677**	.146	.152	1							
	Sig. (2-tailed)	.000	.000	.000	.312	.293								
Sa	Pearson Correlation	.772**	.603**	.680**	.150	.156	.999**	1						
	Sig. (2-tailed)	.000	.000	.000	.299	.279	.000							
Dp	Pearson Correlation	-.197	.146	-.095	-.047	-.092	-.108	-.111	1					
	Sig. (2-tailed)	.171	.311	.513	.747	.525	.455	.444						
Db	Pearson Correlation	.189	.072	-.265	.152	.143	.013	.008	.073	1				
	Sig. (2-tailed)	.188	.618	.063	.292	.321	.929	.955	.615					
Sph	Pearson Correlation	-	.171	.244	.015	.019	-.340*	-.337*	.194	-.275	1			
	Sig. (2-tailed)	.853**	.236	.087	.917	.896	.016	.017	.176	.053				
E	Pearson Correlation	-.272	.071	.192	-.122	-.145	-.045	-.043	.560**	-	.366**	1		
	Sig. (2-tailed)	.056	.625	.182	.401	.314	.759	.765	.000	.749**	.009			
Ra	Pearson Correlation	-	.375**	-.026	.000	-.005	-	-	.266	-.152	.921**	.306*	1	
	Sig. (2-tailed)	.820**	.007	.858	1.000	.975	.371**	.371**	.061	.293	.000	.031		
Cs	Pearson Correlation	.109	-.080	.015	-	-	.043	.040	-.064	-.184	-.121	.075	-	1
	Sig. (2-tailed)	.452	.582	.920	.587**	.581**	.768	.784	.659	.202	.403	.604	.146	.313

Lang and Sokhansanj [38] reported that mass was an essential parameter in the calculation of densities and it could determine the quality of materials. Since coffee was processed using the dry method, the volume of coffee bean was essential to consider in drying simulation models where the changed of the amount will lead to a significant error in the modeling. The volume quantity also played a necessary role in the roasting process where roasting made the beans expanded [39].

Surface area and geometric diameter related to length, width and thickness played a significant role in the drying process and were also essential for the determination of terminal velocity, the coefficient of drag and Reynolds number [24].

Mohsenin NN. [24] stated that in a separation process such as hulling and in quality evaluation particle density played a significant role and bulk density data required in handling and packing process. It can observe in Table 1 that the sphericity of coffee bean was $0.66 \pm 0.04\%$; it meant that most of the coffee bean samples had a nonspherical shape. The result of the observation found that only 12% of the coffee bean samples had a spherical shape. The coffee bean can be defined as a spherical if the sphericity value ≥ 0.70 [40].

Porosity is one of the most critical indicators of food microstructure and texture. Accurate prediction of porosity changes during drying had great importance for the optimization of the drying process and control of food quality [41].

Table 2 showed that volume had a relationship with mass. Geometric diameter had a relationship with length feature, width, and thickness feature. The surface area had a relationship with length, width, thickness, and geometric diameter. Sphericity had contact with length, geometric diameter, and surface area. Porosity had a relationship with particle density, bulk density, and sphericity.

Aspect ratio had a relationship with length feature, width, geometric diameter, surface area, and sphericity. Moreover, shell content had a relationship with mass and volume. To obtain the best statistical model for predicting the relationship between the measures of the sample the stepwise multiple regression analysis was applied. The results of stepwise multiple regression analysis among the standards of the example presented in Table 3.

Table 3. Regression equation among the physical measures of the unhulled coffee bean sample

Equation	R ²	SEE
$V = 1.013 M - 0.002$	0.995	0.0039
$D_{gm} = 0.218 L + 0.522 T + 0.311 W + 0.058$	0.999	0.0116
$S_a = 49.64 D_{gm} - 195.74$	0.999	0.6544
$\Psi = 0.002 S_a - 0.054 L + 0.991$	0.984	0.0051
$\varepsilon = 39.93 \rho_p - 88.27 \rho_b + 55.39$	0.941	0.2700
$R_a = 107.38 \Psi + 7.92 W - 8.02 D_{gm} - 3.76$	0.998	0.3091

3.2. Mechanical properties

Table 4. Descriptive statistics of hardness and fracturability

	N	Minimum (g-force)	Maximum (g-force)	Mean (g-force)	Std. Deviation (g-force)
Hardness, H	15	10.53	15.13	12.3419	1.27725
Fracturability, F_r	15	2.26	2.50	2.4517	0.07635

Table 4 shows the value of the samples size, minimum, maximum, mean and standard deviation of hardness and fracturability. The fracturability is the typical characteristic of the high degree of hardness with a low degree of cohesion materials [42]. Therefore the unhulled coffee bean can be defined as the product that had high hardness and low cohesiveness.

Fracture force was necessary for equipment design such as the crusher. The fracture force will determine the maximum strength which applied to a material without damaging the processed product.

Table 5 shows the value of emptying angle of repose on various surface materials and filling angle of repose. Results show that from 50 samples the emptying angle of repose on surface of stainless steel, aluminum, acrylic and plywood ranged from 26.88 ± 3.670 , 29.44 ± 3.350 , 30.01 ± 4.830 and 40.00 ± 7.000 , with minimum value of 15.260, 19.200, 16.040 and 20.010 and with the maximum amount of 32.650, 35.380, 43.170 and 57.360. The average filling angle of reposed ranged from 32.02 ± 2.880 with a minimum value of 20.320 and with the maximum amount of 37.450.

Table 5. Descriptive statistics of emptying and filling angle of repose

	N	Minimum (°)	Maximum (°)	Mean (°)	Std. Deviation (°)
$EAOR_{ss}$	50	15.26	32.65	26.8838	3.6691
$EAOR_{al}$	50	19.20	35.38	29.4442	3.3508
$EAOR_{acry}$	50	16.04	43.17	30.0092	4.8323
$EAOR_{plyw}$	50	20.01	57.36	40.0024	6.9950
$FAoR$	50	20.32	37.45	32.0158	2.8793

The highest emptying angle of repose occurred on the surface of plywood inversely of that was happening on the surface of stainless steel. In general, both emptying and filling angle of repose can determine the behavior of materials flow [43]. Therefore, the angle of repose has also used in equipment design and storage structures [24].

Table 6 shows that average static friction of stainless steel, aluminum, acrylic and plywood ranged from 0.36 ± 0.02 , 0.40 ± 0.03 , 0.38 ± 0.04 and 0.45 ± 0.03 with minimum value of 0.32, 0.35, 0.33 and 0.40 and with the maximum value of 0.40, 0.45, 0.52 and 0.52 respectively.

The highest static friction occurred on the surface of plywood; the opposite happened on that of stainless steel. Static friction showed a positive correlation with the emptying angle of repose. The higher emptying angle of repose the higher static friction will occur. The coefficient of friction used in designing agricultural equipment, bins, silos, and other storage and handling structures [24].

Table 6. Descriptive statistics of static friction on various surfaces

	N	Minimum	Maximum	Mean	Std. Deviation
$\mu_{staticSS}$	20	0.32	0.40	0.3565	0.0211
$\mu_{staticAL}$	20	0.35	0.45	0.3990	0.0255
$\mu_{staticACRY}$	20	0.33	0.52	0.3765	0.0404
$\mu_{staticPLYW}$	20	0.40	0.52	0.4505	0.0347

3.3. Correlation between physical and mechanical properties

Best relationship between them obtained by using the stepwise multiple regression analysis. In general emptying and filling angle of repose, tangentially were dependent much on the length, width and aspect ratio. In more detail, the relationship between the emptying and filling angle of repose was presented in Table 7.

Table 7. The regression equation of the relationship between an emptying angle of repose and the physical measures

Equation	R ²	SEE
$\theta_f = (3.14 L - 0.175 W + 0.005 R_a - 0.409 \varepsilon + 0.10 T) \operatorname{tg} \theta_f + 16.707$	0.995	0.2124
$\theta_{e-ss} = (3.919 L - 0.045 W + 0.002 R_a - 0.008 S_a + 0.253 T) \operatorname{tg} \theta_{e-ss} + 2.268$	0.988	0.4207
$\theta_{e-Al} = (3.605 L - 0.117 W + 0.003 R_a - 0.163 \varepsilon + 17.685 \psi) \operatorname{tg} \theta_{e-al} + 4.785$	0.991	0.3426
$\theta_{e-Acry} = (3.413 L - 0.134 W + 0.003 R_a) \operatorname{tg} \theta_{e-Acry} + 8.562$	0.991	0.4765
$\theta_{e-Plyw} = (2.567 L - 0.135 W + 0.003 R_a) \operatorname{tg} \theta_{e-Plyw} + 12.919$	0.962	1.4052

Regarding the correlation between the physical properties and mechanical properties which consisted of hardness and fracturability, results of multiple regression analysis showed that there was not found the relationship between both of them.

4. Conclusion

The results of this work found that the analyzed unhulled coffee bean, physically had an average length, width, thickness, geometric diameter, and surface area ranged from 12.04 ± 1.06 mm, 8.24 ± 0.45 mm, 4.99 ± 0.34 mm, 7.90 ± 0.38 mm and 196.44 ± 19.09 mm² respectively. The average mass and volume ranged from 0.21 ± 0.06 grams and 0.21 ± 0.06 cm³ respectively. The average particle density, bulk density and sphericity ranged from 1.00 ± 0.02 gr/cm³, 0.40 ± 0.01 gr/cm³ and $0.66 \pm 0.04\%$ respectively. The average porosity, aspect ratio, and shell content ranged from $60.16 \pm 1.09\%$, $68.88 \pm 6.38\%$ and $16.55 \pm 5.70\%$ respectively.

Concerning the relationship between the physical properties of unhulled coffee bean analyzed, stepwise multiple regression analysis indicated that the volume was dependent on mass. The geometric diameter was dependent on length, thickness and width, the surface area, was dependent on geometric diameter, sphericity was dependent on surface area and length, porosity was dependent on the particle, and bulk densities and aspect ratio was dependent on sphericity, width, and geometric diameter.

Results of mechanical properties measurement indicated that the average hardness and fracturability ranged from 12.34 ± 1.28 g-force and 2.45 ± 0.08 g-force respectively. Based on the value of hardness and fracturability, the unhulled coffee bean samples defined as a product that had high hardness and low cohesiveness. Regarding the angle of repose on the surface of stainless steel, aluminum, acrylic, and plywood results showed that the average emptying angle of repose ranged from $26.88 \pm 3.670^\circ$, $29.44 \pm 3.350^\circ$, $30.01 \pm 4.830^\circ$ and $40.00 \pm 7.000^\circ$ respectively, and the average filling angle of repose ranged from 32.02 ± 2.880 . Concerning friction, results of measurement indicated that average static friction of stainless steel, aluminum, acrylic, and plywood ranged from 0.36 ± 0.02 , 0.40 ± 0.03 , 0.38 ± 0.04 and 0.45 ± 0.03 respectively. The highest emptying angle of repose occurred on the surface of plywood inversely of that happened on the surface of stainless steel. There was a positive association between the quantity of repose angle and the static friction. The bigger the angle of repose was the higher static friction occurred. There was not found any relationship between the physical properties and hardness and fracturability of the unhulled coffee bean.

5. Acknowledgment

This work is part of community empowerment concerning improving the quality of community coffee processing in Alor district, National Priority Program conducted at the Center for Appropriate Technology Development - Indonesian Institute of Sciences - Indonesian Institute of Sciences. We thank the members of the team responsible for this activity on their cooperation. We would like to extend my most profound appreciation to all who gave us the possibility to complete this report. And we would also like to thank Teguh Santoso, Maulana Furqon, Taufik Yudhi, and S. Khudaifanny for their help in carrying out this work.

Appendices

D_p	: Polar diameter, mm	Ra	: Aspect ratio, %
D_e	: Equatorial diameter, mm	w	: Width, mm
D_{gm}	: Geometric diameter, mm	l	: Length, mm
As	: Surface area, mm ²	t	: Tick, mm
Π	: 3,14	θ_e	: Emptying angle of repose (°)
M	: Mass, gr	θ_f	: Filling angle of repose (°)
V	: Volume, ml	h_1	: High 2, mm
ρ_p	: Particle density, gr, ml	h_2	: High 2, mm
ρ_b	: Bulk density, gr/ml	x_1	: Length 1, mm
ε	: Porosity, %	x_2	: Length 2, mm
ψ	: Sphericity, %	μ_s	: Coefficient static friction

6. References

- [1] United States Department of Agriculture 2016 *Indonesia: Coffee Annual*

- [2] Food and Agriculture Organization 2016 *United Nations*
- [3] Association of Indonesian Coffee Exporters 2005 *Statistik Kopi 1980-2005*
- [4] Karaj S, Huaitalla R M and Müller J 2008 Physical, mechanical and chemical properties of *Jatropha curcas* L. seeds and kernels *Proceedings of the Conference on International Agricultural Research for Development. Stuttgart, Germany* 7-9
- [5] Dursun I, Tugrul K M, and Dursun E 2007 Some physical properties of sugarbeet seed *J. Stored Prod. Res.* **43** 2 149–155
- [6] Yalcin H and Kavuncuoglu H 2014 Physical, chemical and bioactive properties of onion (*Allium cepa* L.) seed and seed oil *J. Appl. Bot. Food Qual.* **87** 87–92
- [7] Ghaffari H, Marghoub N, Sheikhdarabadi M S, Hakimi A, and Abbasi F 2013 Physical properties of three Iranian onion varieties *Int. Res. J. Appl. Basic Sci.* **7** 9 pp. 587–593
- [8] Eissa A H and Gamea G R 2003 Physical and mechanical properties of bulb onions. *Miser Journal of Agricultural Engineering* **20** (3) 661-676
- [9] Rathinakumari A C and Jesudas D M 2015 Physical and mechanical properties of onion sets (*Allium cepa*, L.) *Int. J. Trop. Agric.* **33** 2 817–823
- [10] Sunitha B, Sujatha G, Girish B, Kiran B R, and Ramana MV 2016 Determination of physical properties of onions (Arka kirthiman) *Internat. J. Proc. Post Harvest Technol* **7** 1 36–41
- [11] Shoba H, Rajeshwari N, and Nagaraja G 2017 A Study on Physico-Mechanical Properties of Onion Varieties Under Koppal District, (Karnataka) Article History *Curr. Agric. Res. J.* **5** 381–386
- [12] Haciseferoğullari H, Özcan M, Sonmete M H, and Özbek O 2005 Some physical and chemical parameters of wild medlar (*Mespilus germanica* L.) fruit grown in Turkey *J. Food Eng.*, **69** 1–7
- [13] Vursavuş K, Kelebek H, and Selli S 2006 A study on some chemical and physical-mechanic properties of three sweet cherry varieties (*Prunus avium* L.) in Turkey *J. Food Eng.* **74** 568–575
- [14] Celik A, Ercisli S, and Turgut N 2007 Some physical, pomological and nutritional properties of kiwifruit cv. Hayward *Int. J. Food Sci. Nutr.* **58** 6 411–418
- [15] Akbolat D, Ertekin C, Menges H O, Ekinci K, and Erdal I 2008 Physical and nutritional properties of jujube (*Zizyphus jujuba* Mill.) growing in Turkey *Asian J. Chem.* **20** 1 757–766
- [16] Dash A K, Pradhan R C, Das L M, and Naik S N 2008 Some physical properties of simarouba fruit and kernel Pressurized liquid extraction of bioactives from green tea and seabuckthorn for food applications View project Utilization of gaseous fuels in IC engines View project,” *Int. Agrophysics* **22** 111–116
- [17] Jahromi M K, Rafiee S, Jafari A, Bousejin M R G, Mirasheh R, and Mohtasebi S S 2008 Some physical properties of date fruit (cv. Dairi),” *J. Agrophysics* **22** 221–224
- [18] Ersoy N and Bagci Y 2011 Altın Çilek (*Physalis peruviana* L.), Pepino (*Solanum muricatum* Ait.) ve Passiflora (*Passiflora edulis* Sims) Tropikal Meyvelerinin Bazı Fizikokimyasal Özellikleri ve Antioksidan Aktiviteleri *J. Agric. Food Sci.* **25** 3 67–72
- [19] aliliantabar F J, Lorestani A N, and Gholami R 2013 Physical properties of kumquat fruit *Int. Agrophysics*
- [20] Niemenak N, Eyamo J A, Onomo P E, and Youmbi E 2014 Physical and chemical assessment quality of cocoa beans in south and center regions of Cameroon *Agric. Food Sci.* **5** 27–33,
- [21] Bart-Plange A and Baryeh E A 2003 The physical properties of Category B cocoa beans *J. Food Eng.* **60** 219–227
- [22] Bart-Plange A, Dzisi A K, Addo A, Teye E, and Kumi F 2012 A Comparative Study of Some Physical Properties of Large and Medium Size Cocoa Beans from Ghana *ARPN J. Sci. Technol.* **2** 3 135–141
- [23] Ha L T V, Bangun N, Philip R A, Anh P H, Messens K, and Dewettinck K 2016 Physico-chemical properties of fourteen popular cocoa bean varieties in Dongnai – highland Vietnam *Can Tho Univ. J. Sci.* **4** 81–86

- [24] Mohsenin N N 1986 *Physical properties of plant and animal materials: Structure, Physical Characteristics, and Mechanical Properties* New York: Gordon and Breach Science Publishers
- [25] Bahnasawy A H, El-Haddad Z A, El-Ansary M Y, and Sorour H M 2004 Physical and mechanical properties of some Egyptian onion cultivars *J. Food Eng.* **62** 255–261
- [26] Ismail I, Anuar M S, and Shamsudin R 2014 Physical properties of liberica coffee (*Coffea liberica*) berries and beans *Pertanika J. Sci. Technol* **22** 1 65–79
- [27] Kaveri G and Thirupathi V 2015 Studies on geometrical and physical properties of CO 4 onion bulb (*Allium cepa* Lvar. *aggregatum* don.) *Int. J. Rec. Sci. Res* **6** 2897-2902.
- [28] Loghavi M, Souri S, and Khorsandi F 2011 Physical and Mechanical Properties of Almond (*Prunus dulcis*) in *Annual International Meeting ASABE*
- [29] McCabe W L, Smith J C, and Harriott P 1986 *Unit operations of chemical engineering*, 4th Edition (New York: McGraw-Hill)
- [30] Sacilik K, Öztürk R, and Keskin R 2003 Some Physical Properties of Hemp Seed *Biosyst. Eng.* **86** 2 191–198
- [31] Tunde-Akintunde T Y and Akintunde B O 2004 Some physical properties of sesame seed *Biosyst. Eng.* **88** 1 127–129
- [32] Altuntaş E, Özgöz E, and Taşer Ö F 2005 Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds *J. Food Eng.* **71** 1 37–43
- [33] Pittia P, Dalla Rosa M, and Lerici C R 2001 Textural Changes of Coffee Beans as Affected by Roasting Conditions *LWT - Food Sci. Technol.* **34** 168–175
- [34] Chandrasekar V and Viswanathan R 1999 Physical and Thermal Properties of Coffee *J. Agric. Eng. Res.* **73** 3 227–234
- [35] Pradhan R C, Naik S N, Bhatnagar N, and Vijay V K 2009 Moisture-dependent physical properties of jatropha fruit,” *Ind. Crops Prod.* **29** 341–347
- [36] Razavi S M A, Amini M A, Rafe A, and Emadzadeh B 2007 The physical properties of pistachio nut and its kernel as a function of moisture content and variety: Part III: Frictional properties *J. Food Eng.* **81** 1 226–235
- [37] Sahin S and Sumnu S G 2006 *Physical Properties of Foods* (New York: Springer Science+Business Media)
- [38] Lang W and Sokhansanj S 1993 Bulk volume shrinkage during drying of wheat and canola *J. Food Process Eng.* **16** 4 305–314
- [39] Franca A S, Mendonça J C F, and Oliveira S D 2005 Composition of green and roasted coffees of different cup qualities *LWT - Food Sci. Technol.* **38** 709–715
- [40] Eke C N U, Asoegwu S N, and Nwandikom G I 2007 Some Physical Properties of Jackbean Seed (*Canavalia ensiformis*) modeling the energy requirement for cutting selected fruits and vegetables View project Biogas Technology View project Some Physical Properties of Jackbean Seed (*Canavalia ensiformis*) *CIGR Ejournal Manuscr.* **9** 1–11
- [41] Wang D 2016 *Prediction of Texture Characteristics in Apple Drying Using Computer Vision* Dalhousie University (Doctoral dissertation)
- [42] Szczesniak A S 2002 Texture is a sensory property *Food Qual. Prefer.* **13** 215–225
- [43] Ileleji K E and Zhou B 2008 The angle of repose of bulk corn stover particles *Powder Technol.* **187** 110–118