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Research Article

Important Physical and Mechanical Properties of Dominant Potato Variety Widely Grown in Ethiopia

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ABSTRACT

The physical attributes of agricultural product are utmost essential in developing technologies for different unit operations. Pertinent potato tuber attributes were studied. 100 samples of dominant and popular potato tuber varieties grown in Ethiopia which are free from any injuries from each variety were obtained from Holeta Agricultural Research Center. In this study, the physical attributes of potato tubers were determined at a moisture content of 70.75, 69.99, 71.75, 69.70 and 72.38% (wet basis) for Belete, Jalenie, Gera, Gudene and Chala varieties, respectively. Except specific gravity of potato tuber, other physical properties studied were significantly different at 5% of level of significance. Analysis of variance showed that there is also a significant difference in coefficient of static friction and angle of repose of all potato tuber varieties under four different materials and dynamic coefficient of friction under mild steel sheet metal and galvanized sheet.

RESEARCH ARTICLE

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INTRODUCTION

Potato is the first in terms of production from tuber and root crops grown in more than 125 countries (Alemu *et al.*, 2021). It is used for daily consumption for a billion people (Gebru *et al.*, 2017). It plays a significant role in improving food security and Ethiopian smallholder potato grower's income due to its high yield potential per hectare (Ayalew, 2014; CSA, 2015; Alemu *et al.*, 2021). It is widely grown in eastern, southern, central and northwestern region of Ethiopia, which is around 83% of potato growers (CSA, 2009). Around 1,288,146 households are dependent on potato production and about 67,361.87 ha of land is under potato production which has 31.13% area coverage among root crops (CSA, 2015; Alemu *et al.*, 2021). It can be used for cooking, processing, feed, seed tubers, starch and alcohol production (Alemu *et al.*, 2021). Within 30 years, the average potato crop productivity in Africa, Asia and Latin America has increased by 44, 25 and 71 percent, respectively (FAO, 2009).

Physical attributes of agricultural products are important in many grains/seeds and vegetables, and food materials handling and processing operation. Physical characteristics of agricultural products plays a significant role during development of equipment used for different operation (Malcolm *et al.*, 1986; Razavi *et al.*, 2007; Joshi and Raisoni, 2016). In addition to physical attributes, mechanical properties have to be taken into account during development of machines. Therefore, the objective of this study was to determine pertinent physical and mechanical attributes of potato tuber variety widely grown in Ethiopia.

MATERIALS AND METHODS

Source of experimental material

The study was conducted at Melkassa Agricultural Research Center (MARC); which is found in Oromia National Regional State, Ethiopia. It is located at an altitude of 1550 meters above sea level (masl) and lies between 8° 24' 0" to 8° 30' 12" N, 39° 21' 0" to 39° 35' 14" E latitude and longitude, respectively. Agro-ecologically, the area is characterized as arid and semi-arid.

100 samples free from any injuries of dominant and popular potato varieties (Belete, Jalenie, Gera, Gudene and Chala) grown in Ethiopia were used from Holeta Agricultural Research Centers as shown in Figure 1. The samples were kept in a refrigerator at a temperature of 4°C and relative humidity of 95% for 24 hours as recommended by Hurst *et al.* (1993) to offset the effect of the environment.

Figure 1. Potato variety used during physical and mechanical attributes measurements.

Determination of Physical Attributes

Shape and size

To measure potato tuber mass digital balance with accuracy of 0.10 g was used. As shown in Figure 2, major, minor and intermediate diameters of each tuber were measured using digital caliper with an accuracy of 0.01 mm and measuring range of 0-150 mm.

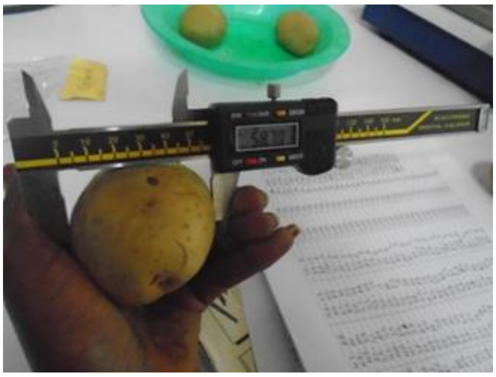

Figure 2. Measurement of principal dimensions of potato tuber.

Geometric mean diameter

Geometric mean diameter (GMD) was determined using the three measured perpendicular diameters as shown in Equation 1 (Kamat *et al.*, 2020).

$$GMD = \sqrt[3]{abc} \quad (1)$$

Where: -

GMD = geometric mean diameter, mm

a, b and *c* = major, intermediate and minor diameter respectively, mm

Surface area

Surface area (*S*, mm^2) of the potato tuber was determined using Equation 2 (Mohsenin, 1986).

$$S = \pi(GMD)^2 \quad (2)$$

Volume

As shown in Figure 3 the volume of a potato tuber was determined based on the water displacement method (Mohsenin, 1986).

Figure 3. Measurement of volume of potato tuber by using water displacement method.

Sphericity

The sphericity *(φ)* of potato tubers was determined with presumption that the volume of solid can be approximating to the volume of a triaxial ellipsoid with a diameter equal to the minor, intermediate and major diameters using Equation 3 (Mohsenin, 1986).

$$\varphi = \sqrt[3]{\frac{abc}{a}} \tag{3}$$

Moisture content

Potato tuber moisture content was determined using hot air oven method and Equation 4 (Asoegwu, 1995). The weight of the potato tuber was measured before and after oven-drying at 105°C until constant weight was obtained using a digital balance with an accuracy of 0.01 g.

$$M_C = \frac{W_1 - W_2}{W_2} \tag{4}$$

Where:-

M_c= moisture content (% wb),

W_1= mass of potato tuber before oven-drying (g) and

W_2= mass of potato tuber after oven-drying (g).

Tuber density (ρ_p)

Tuber density is described as mass of a tuber divided to its actual volume (Equation 5). Internal pores are included (Mohsenin, 1986).

$$\rho_P = \frac{M_t}{V_C} \tag{5}$$

Where:

ρ_p = particle density (g cm^{-3}),

M_t = mass of a tuber (g) and

V_c = volume of a tuber (cm^3).

Bulk density (ρ_{bulk})

Bulk density (ρ_{bulk}) was determined from mass and volume of potato tuber using Equation 6. (Rahman, 2014).

$$\rho_{bulk} = \frac{Mass\ (g)}{Volume\ (m^3)} \quad (6)$$

Specific gravity (G_s)

The specific gravity of potato tuber was determined based on the water displaced method and Equation 7.

$$G_s = \frac{Weight\ in\ air\ (N)}{Weight\ in\ air\ (N) - Weight\ in\ water (N)} \quad (7)$$

Where N=Newton

Frictional properties of potato tuber

Static coefficient of friction

The static coefficients of friction between potato tuber and four different surfaces (Mild steel sheet metal, galvanized sheet, wood and rubber) were determined by using Equation 8 (Almaiman and Ahmad, 2002).

$$\mu_s = tan\alpha \quad (8)$$

Where:

μ_s = static coefficient of friction,
α = angle of inclination at which potato tuber start to slide down.

Dynamic coefficient of friction

The dynamic coefficient of friction was determined using a topless and bottomless plywood box with dimensions of 250 × 250 × 90 mm^3. The box was placed on a test surface and filled with a known quantity of potato tubers; then force was applied to bottomless plywood box until it moved uniformly with a horizontal pull. The friction test was replicated three times for the surfaces under investigation. For each replication, the box was refilled with a different sample. The dynamic coefficient of friction was determined using Equation 9 (Puchalski *et al.*, 2003; Amin *et al.*, 2004).

$$\mu_d = \frac{F}{mg} \quad (9)$$

Where:
μ_d = dynamic coefficient of friction,
F = friction force that will be measured using pull force gauge (N),
m = mass tuber (kg) and
g = gravitational acceleration ($m\ s^{-2}$).

Angle of repose

Angle of repose for potato tuber was determined with a bottomless cylinder. The cylinder was placed over a smooth surface and filled with potato tuber. The cylinder was then raised slowly allowing the tuber to flow down and form a natural slope. The height and diameter of the heap formed were measured and angle of repose was estimated using Equation 10.

$$\alpha = \tan^{-1} \frac{Height\ of\ potato\ tuber\ pile}{base\ of\ potato\ tuber\ pile/2} \quad (10)$$

Where α is expressed in degree.

RESULTS AND DISCUSSION

Physical properties

The physical properties of potato tubers were determined at a moisture content of 70.75, 69.99, 71.75, 69.70 and 72.38% (w.b) for Belete, Jalenie, Gera, Gudene and Chala varieties, respectively. The temperature recorded in the laboratory during the experiments was 20-28°C.

The weight measurement of each potato tubers showed that Belete variety had the maximum weight of 102.24 g while the minimum value was recorded for Chala Variety 59.66 g.

The mean major diameters of 66.96, 56.28, 55.43, 63.45 and 54.09 mm were observed for Belete, Giera, Jalenie, Gudene and Chala varieties, respectively. The maximum and minimum tubers major diameters of 106.82 mm and 76.90 mm were obtained for Belete and Jalenie varieties, respectively.

The intermediate diameters ranged between 38.72 and 73.63, 30.18 and 71.31, 32.95 and 65.49, 33.17 and 58.67, and 34.15 and 58.19 mm for Belete, Gera, Gudene, Jalenie and Chala varieties, respectively. The maximum tuber intermediate diameter was observed with Belete variety (73.63 mm) and the minimum was observed was Chala (58.19 mm).

The minor diameter ranged between 31.97 and 57.39, 25.56 and 57.05, 30.47 and 52.04, 26.83 and 46.82 and 29.09 and 50.23 mm for Belete, Gera, Gudene, Jalenie and Chala varieties respectively. The maximum tuber intermediate diameter was observed with Belete variety (57.39 mm) and the minimum was observed in Jalenie variety (46.82 mm).

As shown in Table 1, multiple regression equations were determined to describe the relationship between the weight of tubers and its main dimensions for each variety. The equations show that the dimensions of each tuber's varieties were directly proportional with its weight.

Table 1. Multiple regression model of weight of potato tuber and main dimension of potato tuber varieties.

Variety	*Regression Model*	*R Square*
Belete	Weight = 1.61a +2.48b +1.67c -204.54	R^2 = 0.91
Jalene	Weight = 1.21 a +1.39b +0.70c -95.29	R^2 = 0.97
Chala	Weight = 1.32 a +1.53b +1.77c -148.27	R^2 = 0.95
Gera	Weight = 1.06 a +1.76b +1.64c -139.83	R^2 = 0.88
Gudene	Weight = 1.32 a +1.53b +1.77c -148.27	R^2 = 0.95

Where: a, b and c = major, intermediate and minor diameter respectively, mm

The geometric mean diameters of the selected potato tubers were 52.68, 45.28, 49.87, 47.88 and 44.52 mm for Beleta, Jalenie, Giera, Gudene and Chala varieties, respectively. The maximum geometric mean diameter was observed with Belete variety (75.60 mm) followed by Gudenie variety (67.13 mm) and the minimum was obtained with Giera variety (30.39 mm). The measured surface areas were 8959.30, 6545.70, 7924.10, 7333.10 and 6311.70 mm^2 for Beleta, Jalenie, Gera, Gudene and Chala varieties, respectively.

The measured volumes were 83924.00, 83924.00, 68979, 60943 and 48697 mm^3 for Beleta, Jalenie, Giera, Gudene and Chala varieties respectively. The calculated volumes were 83089, 50994, 67696, 60750 and 48152 mm^3 for Beleta, Jalene, Gera, Gudene and Chala varieties, respectively. The sphericity of the selected potato varieties was found to be 0.80, 0.82, 0.87, 0.76 and 0.82 for Beleta, Jalene, Gera, Gudene and Chala, respectively.

Tuber densities of selected varieties of potato were determined to be 1.23, 1.22, 1.19, 1.20 and 1.25 g cm^{-3} for Beleta, Jalene, Gera, Gudene and Chala, respectively. The maximum and minimum tuber densities were recorded for Chala and Gera varieties, respectively. Bulk densities of 525.94, 529, 523.60, 519.10 and 518.03 kg m^{-3} were recorded for Belete, Gera, Jalene,Gudene and Chala varieties, respectively.

The specific gravity of potato tubers of selected varieties ranged from 1.05 to 1.09. As shown in Table 2, the maximum specific gravity was recorded for Belete variety and the minimum one is recorded for Gera variety. All potato tuber varieties in this study, except Chala and Gera with specific gravity of 1.06 and 1.05, respectively, had a specific gravity greater than 1.07. Except specific gravity of potato tuber, all other physical properties of each variety of potato tuber are significantly different at 5% of level of significance. There was no significant difference among varieties of potato tuber in their specific gravity. The summarized value of important physical and engineering properties of potato tuber variety is shown in Table 2.

Table 2. Physical and engineering attributes of potato tuber varieties.

Variety	Variable	Mean	SD	C.V.	Minimum	Maximum
Belete	Weight(g)	102.42	54.80	53.51	38.00	363.60
	Geometric mean diameter (mm)	52.68	8.81	16.72	39.17	75.76
	Calculated volume (mm^3)	82699	43093	52.11	31477	227654
	Particle density ($g\ cm^{-3}$)	1.24	0.12	9.97	1.08	2.19
	Specific gravity	1.09	0.13	11.74	1.01	2.10
	Shape index	1.42	0.18	12.51	1.09	1.84
Jalenie	Weight(g)	61.55	21.81	35.66	27.20	134.30
	Geometric mean diameter (mm)	45.28	5.81	12.82	32.91	58.27
	Calculated volume(mm^3)	50681	19149	37.78	18668	103612
	Particle density ($g\ cm^{-3}$)	1.22	0.14	11.49	1.03	1.84
	Specific gravity	1.07	0.09	8.06	0.99	1.90
	Shape index	1.35	0.13	9.45	1.07	1.66
Gera	Weight(g)	80.24	28.34	35.32	18	166.80
	Geometric mean diameter (mm)	49.87	5.99	12.	30.39	64.67
	Calculated volume(mm^3)	67263	23958	35.62	14698	141623
	Particle density ($g\ cm^{-3}$)	1.19	0.11	9.43	0.83	1.56
	Specific gravity	1.05	0.09	8.27	0.58	1.49
	Shape index	1.20	0.10	8.01	1.05	1.87
Gudene	Weight(g)	72.50	31.15	42.96	34.6	201.10
	Geometric mean diameter (mm)	47.88	6.52	13.63	37.74	67.13
	Calculated volume(mm^3)	60750	27093	44.60	28137	158396
	Particle density ($g\ cm^{-3}$)	1.20	0.07	5.95	1.04	1.48
	Specific gravity	1.07	0.21	19.38	0.49	2.32
	Shape index	1.52	0.17	11.51	1.14	1.94
Chala	Weight(g)	59.66	21.49	36.01	32.9	141.30
	Geometric mean diameter (mm)	44.52	5.20	11.68	36.61	61.33
	Calculated volume(mm^3)	48152	18362	38.13	25701	120812
	Particle density ($g\ cm^{-3}$)	1.25	0.06	5.21	1.02	1.43
	Specific gravity	1.06	0.02	2.22	1.00	1.21
	Shape index	1.34	0.14	10.50	1.09	1.89

Where, SD = standard deviation and CV = coefficient of variation.

Mechanical properties of potato tubers

As shown in Table 3, the mean angle of repose of potato tubers ranged from 23.12 to 31.74° on mild steel sheet metal, 23.01 to 41.14° on Galvanized sheet, 22.61 to 38.39° on wood and 25.68 to 36.61° on rubber surface. The maximum and minimum angle of repose was recorded as 41.14 and 22.61° for Belete and Chala varieties on Galvanized sheet and wood surface, respectively.

The static coefficients of friction of the different variety's potato tubers ranged from 0.22 to 0.27 on mild steel sheet metal, from 0.18 to 0.30 on galvanized sheet, from 0.29 to 0.43 on wood and from 0.27 to 0.47 on rubber. The minimum and maximum static coefficients of friction were recorded as 0.18 and 0.47 for Gera and Belete variety on Galvanized sheet and rubber, respectively.

The dynamic coefficients of friction ranged from 0.48 to 0.67 on mild steel sheet metal, from 0.52 to 0.65 on galvanized sheet, from 0.62 to 0.68 on wood and from 0.61 to 0.68 on rubber surfaces. The minimum and maximum dynamic coefficients of friction were recorded as 0.48 and 0.68 for Belete and Chala varieties on mild steel sheet metal and rubber surfaces, respectively.

Table 3. Mechanical attributes of dominant and popular potato varieties.

Property	Material	Varieties					
		Belete	Jalenie	Giera	Gudenie	Chala	Average
Coefficient of static friction	Mild steel sheet metal	0.23	0.274	0.2309	0.2614	0.2187	0.2430
	Galvanized sheet metal	0.3	0.243	0.1824	0.2248	0.1885	0.277
	Wood	0.43	0.332	0.3122	0.3512	0.2937	0.3438
	Rubber	0.47	0.365	0.2742	0.3252	0.2805	0.3430
	Average	0.3575	0.3035	0.2499	0.2906	0.2453	0.2894
Coefficient of dynamic friction	Mild steel sheet metal	0.4762	0.6556	0.6664	0.6455	0.6698	0.6227
	Galvanized sheet metal	0.5203	0.5981	0.6477	0.5497	0.5524	0.5736
	Wood	0.6716	0.623	0.6803	0.6505	0.6664	0.6584
	Rubber	0.6147	0.6805	0.6786	0.6435	0.6846	0.6604
	Average	0.5707	0.6393	0.6683	0.6223	0.6433	0.6288
Angle of repose	Mild steel sheet metal	31.6033	26.7033	31.74	35.4967	23.12	29.7327
	Galvanized sheet metal	41.1433	23.01	36.2	28.9667	24.14	30.692
	Wood	38.3867	27.4433	38	37.9733	22.61	32.8827
	Rubber	36.6133	29.9167	31.56	33.6967	25.68	31.4933
	Average	36.9367	26.7683	34.36	34.0333	23.8875	31.2002

As shown in Table 4, the result of analysis of variance showed that static coefficient of friction and angle of repose of all potato tuber varieties under four different materials and dynamic coefficient of friction under mild steel sheet metal and galvanized sheet is significantly different. There is no significant difference in dynamic coefficient of friction of all varieties of potato tuber between wood and rubber surface.

Table 4. Analysis of variance on mechanical properties of potato tuber (source of variation: between varieties).

Property	Material	SS	df	MS	F	P-value
Static Coefficient of friction	Mild steel sheet metal	0.0077	4	0.0019	8.0600	0.0036
	Galvanized sheet metal	0.0300	4	0.0067	19.3900	0.0001
	Wood	0.0340	4	0.0085	4.9300	0.0200
	Rubber	0.0700	4	0.0200	10.1200	0.0015
Dynamic coefficient of friction	Mild steel sheet metal	0.0800	4	0.0200	53.6400	0.0000
	Galvanized sheet metal	0.0300	4	0.0073	7.0000	0.0000
	Wood	0.0066	4	0.0017	1.1780	0.3800
	Rubber	0.0100	4	0.0027	1.6100	0.2500
Angle of repose	Mild steel sheet metal	280.9700	4	70.2400	22.8100	0.0001
	Galvanized sheet metal	733.3300	4	183.3300	21.5800	0.0001
	Wood	652.5300	4	163.1300	13.2200	0.0005
	Rubber	202.0600	4	50.5200	9.3800	0.0020

Where, SS: sum of square, MS: mean square, df: degree of freedom, F: F ratio and P: significance level at 5%

CONCLUSION

Pertinent physical and mechanical attributes of the potato tuber relevant to develop equipment for potato production were studied. The study revealed that for five different varieties of potato tubers; the mean major, intermediate and minor diameters were 66.00, 50.94 and 42.27 mm, respectively. The mean geometric diameters, surface area, percent and Sphericity of the potato tubers were found to be 48.06 mm, 7414.77 mm^2 and 81.92%, respectively. For tubers of five different varieties, tuber density, bulk density and specific gravity were found to be 1.22 g cm^{-3}, 518.03 kg m^{-3} and 1.07 respectively.

DECLARATION OF COMPETING INTEREST

The author declares that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author confirms sole responsibility for the following: investigation, methodology, conceptualization, formal analysis, data curation, validation, writing - original draft, review, editing and visualization etc.

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