https://doi.org/10.48196/017.01.2021.03

Submitted: November 26, 2020
Accepted: May 30, 2021

Determination of the Physical and Mechanical Properties of Turmeric (*Curcuma longa* L.)

Jose D. de Ramos[1], Marife R. Santiago[2], Roselle P. Barreto[3], Niña Mae G. Talaro[3], and Jessica R. Cullat[4]

[1]University Extension Specialist III, Center for Agri-fisheries and Biosystems Mechanzation, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, 4031 College, Laguna, Philippines (Author for correspondence email: jdderamos@up.edu.ph)

[2]University Extension Specialist II, Center for Agri-fisheries and Biosystems Mechanzation, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, 4031 College, Laguna, Philippines

[3]University Research Associate II, [4]Project Staff, Center for Agri-fisheries and Biosystems Mechanzation, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, 4031 College, Laguna, Philippines

ABSTRACT

*Turmeric is a medicinal crop widely popular due to its curcumin content. While other countries have established the physical properties of this crop, literatures specific for turmeric found in the Philippines have yet been documented. Freshly harvested turmeric rhizomes were randomly selected and their physical and mechanical properties were measured. Test results showed that the rhizomes have an average moisture content of 84.7 %. The samples have mean dimensions of 77.2 mm (length), 23.0 mm (width) and 19.7 mm (thickness). Computations showed that the rhizomes have a geometric mean diameter, sphericity, aspect ratio, surface area, and volume of 32.4 mm, 0.436, 31.6, 3371.2 mm^2, and 19044.8 mm^3, respectively. The gravimetric properties were also determined, and measurements showed that the fresh rhizomes have true density, bulk density, and porosity of 1.002 g/mL, 0.51 g/mL, and 48.8 %, respectively. Frictional properties against plywood (across the grain), plywood (along the grain) and stainless steel revealed that the rhizomes have a coefficient of friction of 0.41, 0.30 and 0.20 against these materials, respectively. The average angle of repose on a flat level surface is 18.6°. The maximum puncture and shear force that mother rhizomes can withstand were determined to be 0.1761 and 0.1708 kN, respectively. For the finger rhizomes, a maximum puncture force of 0.1029 kN and shear force of 0.0899 kN were recorded. Fresh rhizomes were sliced and dried until the final moisture content reached 8 to 9%, in which they were then pulverized. Optical properties were characterized using the CIE L*a*b* color scale and were converted to H-S-B. Preliminary findings showed that hue values for the three classifications were almost the same and were identified to fall between the orange and yellow hue. The dried rhizomes recorded the lowest saturation and brightness values, however, these values increased after pulverization indicating that only the surface color was affected and the interior of the rhizomes retained its vividness.*

Keywords: *turmeric, physical properties, mechanical properties, rhizomes*

INTRODUCTION

Turmeric or 'Luyang Dilaw', in the Philippines is a rhizomatous plant belonging to the ginger family (Zingiberaceae). It is commonly utilized as spice for various food products and as a source of curcumin for medicinal purposes. The origin of the plant is unknown but at present, it is extensively grown in various parts of Asia such as the Philippines, Indonesia, Thailand, and India. Among these countries, India is considered to be the largest producer and exporter of turmeric and turmeric-based products since it is an important component of various Indian dishes and traditional remedies (Plotto, 2004).

In the Philippines, turmeric is marketed as pure powder or tea, blended with other herbal plants. It is not popular as a food additive because of its stringent smell and strong taste. Since the plant is not considered a high-value crop, standards regarding their physical and engineering properties are not readily available. The Philippine National Standard (PNS)/BAFS120:2013 ICS 67.080.20: Turmeric Classification and Grading, is the only available standard reference for turmeric grading but without quantitative values of their physical and engineering properties.

Turmeric plant commonly reaches one meter long and bears yellow-white flowers that are sterile, hence reproduction and cultivation can be done through the rhizomes only. Turmeric is a tropical crop and grows best in areas with temperature of 20°C to 35°C and annual rainfall ranging from 1500 to 2250 mm. It grows best in partly shaded areas and in areas fully exposed to sunlight. It can be grown up to an altitude of 1500 meters above sea level, and thrives best in well-drained sandy or clay-loam soil rich in organic matter with pH of 4.5 to 7.5 (ICAR, 2015; Sharma et al, 2016).

Turmeric rhizome is surrounded by rings of old leaves which thicken and become black over time. One distinct characteristic of turmeric rhizome is its bright yellow color used for food coloring and dyeing. According to Balakrishnan (2007), these bright yellow pigments are caused by a group of compounds called curcuminoids consisting of curcumin, demethoxycurcumin (DMC) and bisdemethoxycurcumin (BDMC). These compounds are responsible for the health benefits that can be derived from turmeric, which includes its anti-microbial, anti-angiogenic, and anti-inflammatory properties (Amalraj *et al*., 2017). On the other hand, the strong but distinct aroma of the rhizome is because of sesquiterpenes present in its essential oil.

The determination of physical and engineering properties of agricultural produce is important for the design of agricultural machinery and the improvement of processes for harvesting, handling, postharvest operations, and storage (Kumar and Kumar, 2016). Food products like turmeric are often characterized based on their physical dimension (length, width, thickness) and density since these properties are utilized for sorting and grading (Keramat-Jahromi *et al*., 2008). On the other hand, the color of the produce is an important determinant of consumer's behavior and is regarded as one of the most significant parameters in terms of quality (Ercisli *et al*., 2007).

This study is limited only to the characterization of turmeric rhizomes harvested at the Municipality of Dumingag, Zamboanga del Sur without regard to the production practices employed by the farmers in the area or the characteristics of the soil and the condition of the farms where the turmeric was grown. The output of this study is intended as inputs to the design and development of location-specific mechanization technology for the production of turmeric powder at the project site.

OBJECTIVES

The main objective of the study was to determine some physical and mechanical properties (i.e. physical dimensions, geometric mean diameter, sphericity, aspect ratio, surface area and volume, radius of curvature, bulk density, true density, porosity, angle of repose, angle of friction, coefficient of static friction, moisture content, color, and puncture and shear force) of fresh turmeric rhizomes. It also aimed to characterize some important properties of turmeric after drying and pulverization processes.

METHODOLOGY

Materials

Batch of thirty (30) kilograms of fresh turmeric rhizomes were procured from a farmer supplying the processing center in Dumingag, Zamboanga del Sur, Philippines. All the rhizomes were harvested from his farm and was raised based on the farmer's traditional cultural practices. No characterization as to the type of soil, fertilization, irrigation and other factors affecting plant growth was done.

The rhizomes were brushed and cleaned manually to remove soil particles and dried leaves. After air drying, the physical and mechanical properties of the turmeric rhizomes were determined. These include the physical dimensions (length, width, and height), geometric mean diameter, sphericity, aspect ratio, surface area, volume, radius of curvature, bulk density, true density, porosity, angle of repose, angle of friction, color, moisture content, puncture force, and shear force.

Physical Dimensions

Mean values of the length (L), width (W) and thickness (T) of 100 pieces randomly selected turmeric rhizomes were determined using a Vernier caliper (Mitutoyo digimatic caliper, 0.01 mm resolution).

Geometric Mean Diameter (GMD)

Using the physical dimensions obtained from the samples, the geometric mean diameter was computed using Equation 1. (Mohsenin, 1986)

$$GMD = (L \ x \ W \ x \ T)^{\frac{1}{3}}$$ *Equation 1*

Sphericity (S)

The shape of agricultural products and food materials are characterized in terms of their sphericity. It is defined as the ratio of the surface area of a sphere having the same volume as the turmeric rhizome to the surface area of the rhizome (Obomeghei and Ebabhamiegbebho, 2020; Ahangarnezhad, *et al.*, 2019; Kumar and Kumar, 2016). Sphericity is important since it is used in heat and mass transfer calculations (Kumar and Kumar, 2016; Ajav and Ogunlade, 2014). Using the values of the geometric mean diameter (GMD), sphericity was calculated using the equation:

$$Sphericity = \frac{GMD}{L}$$ *Equation 2*

Aspect Ratio (AR)

Together with sphericity, aspect ratio is also an important parameter in determining the shape of a produce.

$$Aspect \ Ratio = \frac{Width}{Length} x100$$ *Equation 3*

Surface Area (SA) and Volume (V)

Using the geometric mean diameter, the approximate surface area and volume of turmeric rhizomes were computed using the following equations.

$$Surface \ Area = \pi \ x \ (GMD)^2$$ *Equation 4*

$$Volume = \frac{\pi}{6} x(GMD)^3$$ *Equation 5*

Radius of Curvature

Radius of curvature is a significant property needed when designing chutes and conveyors (Kumar and Kumar, 2016) since it determines the rollability of the produce. In the experiment, the minimum radius of curvature (Rmin) and the maximum radius of curvature (Rmax) of the rhizomes were obtained using Equations 6 and 7, respectively.

$$R_{min} = \frac{H}{2}$$ *Equation 6*

$$R_{max} = \frac{H^2 + \frac{Length^2}{4}}{2}$$ Equation 7

where: H = average of length and thickness (mm)

Bulk Density (ρ_b)

Bulk density is defined as the mass of materials per unit volume. Unlike particle or true density, it considers both the solids and the free and pore spaces between materials in a given volume. It is a measure of the amount of materials that can fill a given volume, and is important in the design of chutes, conveyors, and hoppers. The bulk density of turmeric rhizomes was determined using a cylindrical container with a height of 20 cm and a diameter of 25 cm. Using these dimensions, the volume of the cylinder was calculated. The weight of the rhizomes placed inside the container was obtained. Using the weight and the volume, the bulk density of was computed using the following equation.

$$\rho_b = \frac{Weight\ of\ turmeric}{Volume\ of\ container}$$ Equation 8

True density (ρ_t)

True density is the ratio of the mass of an object and its true volume. The true density of turmeric rhizomes was obtained using the water displacement method (Kumar and Kumar, 2016). Using the volume of the displaced water and the mass of single turmeric, the true density is calculated using Equation 9.

$$\rho_t = \frac{Weight\ of\ single\ turmeric}{Volume\ of displaced\ water}$$ Equation 9

Porosity (P)

Porosity is a physical property that determines the percentage of voids or pore spaces in a sample bulk. According to Kumar and Kumar (2016), this property is important in creating models of various heat and mass transfer process. The porosity of fresh turmeric rhizomes was calculated using the equation below (Mohsenin, 1986).

$$P(\%) = \frac{\rho_t - \rho_b}{\rho_t} x100$$ Equation 10

Angle of Repose (Θ_r)

An important parameter used to characterize the inter-particle resistance of bulk solids is the angle of repose. It is the measure of the steepest angle formed by the pile of solids to the horizontal. For free-flowing objects, the angle of repose is smaller compared to objects that are fine and sticky. The angle of repose of turmeric rhizomes was determined using a bottomless cylinder with a diameter of 15 cm and height of 20 cm. The cylinder was placed on a flat, smooth surface and was filled with turmeric rhizomes. It was raised slowly until the rhizomes fall down the slope. The height (H) and diameter (D) created by the pile were measured. Using these values, the angle of repose was calculated using Equation 11.

$$\theta_r = tan^{-1}\frac{2H}{D}$$ Equation 11

Angle of Friction (Θ_f)

Angle of friction is commonly used in designing hoppers, conveyors, and chutes for agricultural machinery. It measures the angle by which a product begins to slide or move down on a particular surface. The angle of friction of turmeric rhizomes was determined against the surface of the following materials: stainless steel, wood (across grain), and wood (parallel grain). A tilting platform, with one end pivoted and the other end raised up or down with a screw mechanism was used in the measurement (Wandkar *et al*, 2012). The angle at which the rhizome starts to slide when the platform was inclined gradually was measured using a Vernier bevel protractor.

Coefficient of Static Friction (μ)

The coefficient of static friction is defined as the ratio of force needed to start sliding the sample over a surface by the weight of the sample. From the values of angle of friction, the coefficient of static friction for each material was calculated as:

$$\mu = \tan(\boldsymbol{\theta}_f)$$

Equation 12

Moisture Content (MC)

The moisture content of fresh turmeric rhizomes was determined using the standard oven drying method. Three replicates were prepared, each comprising at least 25 grams of sliced turmeric. The samples were placed in an oven for 72 hours and the weights were measured. The moisture contend in wet basis was calculated using Equation 13.

$$MC_{wb}\,(\%) = \frac{Initial\ Weight - Final\ Weight}{Initial\ Weight}\, x\ 100$$

Equation 13

Color

The color of agricultural produce is an important determinant of some properties such as maturity and quality. It is measured using either the R-G-B (Red-Green-Blue) scale or the L*-a*-b* (Luminosity- Red/Green Chromaticity- Yellow/ Blue Chromaticity) scale. The color of fresh turmeric rhizomes was determined using the CIE L*-a*-b* color meter. Ten color measurements were obtained, and the average of the values was calculated. From the three values, the chroma (C*) and hue angle (h*) were computed using the equations below.

$$c^* = (a^2 + b^2)^{\frac{1}{2}}$$

Equation 14

$$h^{\circ} = \arctan\left(\frac{b^*}{a^*}\right)$$

Equation 15

Puncture and Shear Force

The maximum puncture and shear force of fresh turmeric rhizomes (mother rhizomes and fingers were measured using an Instron model 4411 Universal Testing Machine (UTM). Mother rhizomes are the central bulbs to which the fingers or the lateral branches are attached. There is a need to test both the mother rhizomes and the fingers since both are used in peocessing and there is a notable difference in hardness between the two. Mother rhizomes are thicker and are more difficult to cut compared to the fingers. The values of maximum puncture and shear force of the two can serve as basis in determining the power requirement during the design of processing machines (e.g. slicer). ASAE (1979) recommended 20 specimens per test to ensure that the variations in mechanical properties due to shape, size, age and cellular structure, which are inherent in biological materials, are kept to a minimum. The same standard set the testing speed at 25 mm/min.

Drying and Pulverization

Remaining turmeric samples were dried in a cabinet dryer, with a temperature of 55°C, until its moisture content reached 5 to 7 %. Drying air temperature of 55 - 60°C produced the optimum drying conditions for turmeric to achieve high product quality and minimize loss of curcumin content (Plotto, 2004; Singh *et al*, 2010; Gan *et al*, 2017; Lokhande *et al*, 2013). Previous experiments conducted by the authors of this paper have shown that the optimum properties for pulverization can be achieved when turmeric is dried to moisture content of 5 to 7%. The dried samples were ground using a hammer-mill type pulverizer and the optical properties were determine using the CIE L*a*b color meter. For both dried and pulverized samples, the bulk density, and angle of repose were also measured.

RESULTS AND DISCUSSION

The results of the experiment regarding various physical and engineering properties of fresh turmeric rhizomes are summarized in Tables 1 to 3.

Geometric Properties

The linear dimensions of fresh turmeric samples taken at an average moisture content of 84.4 % were found to be 41.19-128.32, 15.45-62.40, and 13.09-30.15 mm for the length, width, and thickness, respectively. Their corresponding coefficient of variation (CV) was calculated to be 25.89, 25.15, and 15.69 %, respectively. Balasubramanian *et al*. (2012) also determined physical properties of turmeric found in India and they recorded a length, width and thickness ranging from 30.38 – 50.60, 9.77 – 10.64, and 5.18 – 6.44 mm, respectively, which are relatively lower than the samples obtained from the farm in Dumingag.

For the other geometric properties, the values of the geometric mean diameter, sphericity, aspect ratio, surface area, volume, and maximum and minimum radius of curvature were calculated to be 20.37-45.05 mm, 0.289-0.755, 16.08-78.49, 1303.08-6473.80 mm2, 4423.15-47860.08 mm3, 13.72-38.06 mm, and 594.29-4954.62 mm, respectively. From these values, the volume of the turmeric yielded the highest coefficient of variation with 46.89 % while the geometric mean diameter yielded the lowest with 15.40 %. Upon comparing these values to the properties obtained by Balasubramanian *et al*. (2012), it is once again confirmed that the samples obtained in the locality are bigger in terms of geometric mean diameter, sphericity, surface area and volume.

Gravimetric Properties

The gravimetric properties of fresh turmeric rhizomes are presented in Table 1. The results show that the average true density of turmeric was 1.002 g/mL with a CV of 4.29 %, while the average bulk density was found to be 0.512 g/mL with a CV of 1.76 %. From these values, the porosity was calculated to have an average value of 48.77 % with a CV of only 4.42 %.

Frictional Properties

Quantitative values of the frictional properties of fresh turmeric rhizomes are presented in Table 2. From the table, it can be observed that the rhizomes have an average angle of repose of 18.65° with a CV of 17.00 %. The largest value of angle of friction was observed from plywood (across grain) with an average value of 22.09° while the lowest value was observed from stainless steel with an average value of 11.51°. Similarly, the highest value of coefficient of friction was observed from the plywood (across grain) with 0.408, while the lowest value was observed from the stainless steel with 0.204. Larger values obtained from the plywood was due to its rough surface compared to the smoother and more polished surface of stainless steel. Balasubramanian *et al*. (2012) recorded a higher angle of repose (i.e. 37.57 – 38.90°) as well as higher coefficient of friction from plywood (i.e. 0.80 – 0.96) and mild steel (0.84 – 0.94).

Table 1. Geometric and gravimetric properties of fresh turmeric

PARAMETER	DIMENSIONS			GEOMETRIC MEAN DIAMETER, mm
	Length, mm	Width, mm	Thickness, mm	
Range	41.19-128.32	15.45-62.40	13.09-30.15	20.37-45.05
Mean	77.257	23.001	19.752	32.38
SD	20.003	5.784	3.099	4.988
CV (%)	25.89	25.15	15.69	15.40

Table 1. ...continued

PARAMETER	SPHERICITY	ASPECT RATIO	SURFACE AREA, mm^2	VOLUME, mm^3	RADIUS OF CURVATURE, mm		TRUE DENSITY (g/mL)	BULK DENSITY (g/mL)	POROSITY (%)
					Rmin	Rmax			
Range	0.289-0.755	16.08-78.49	1303.08-6374.80	4423.15-47860.08	13.72-38.06	594.29-4954.62	0.946-1.074	0.489-0.519	28.00-52.04
Mean	0.436	31.63	3371.207	19044.765	24.252	2027.733	1.002	0.512	48.767
SD	0.083	10.932	1040.692	8929.321	5.309	941.822	0.043	0.009	2.155
CV (%)	19.04	34.56	30.87	46.89	21.89	46.45	4.29	1.76	4.42

Table 2. Frictional properties of fresh turmeric rhizomes

PARAMETER	Angle of Repose	ANGLE OF FRICTION (°)			COEFFICIENT OF STATIC FRICTION		
		Plywood (Across Grain)	Plywood (Along Grain)	Stainless Steel	Plywood (Across Grain)	Plywood (Along Grain)	Stainless Steel
Range	14.83-24.91	17.07-30.34	13.05-20.94	9.79-14.34	0.307-0.581	0.232-0.383	0.173-0.256
Mean	18.653	22.093	16.334	11.510	0.408	0.293	0.204
SD	3.171	3.325	1.743	1.054	0.069	0.033	0.019
CV (%)	17.00	15.05	10.67	9.16	16.96	11.30	9.43

Optical Properties

The optical properties of turmeric rhizomes were described using the L*-a*-b* color scale (Table 3). It can be observed that the values of luminosity, red/green chromaticity, and yellow/blue chromaticity are 34.50-59.00, 14.70-21.00, and 50.80-76.90, respectively. The average value of chroma was computed to be 74.156 with a CV of 7.78 % while the average value of hue angle was 75.08, with a CV of 1.64 %. Visually, the fresh turmeric rhizomes exhibited a vibrant golden yellow color. Since the hue angle (75.08°) is approaching 90°, this indicates that the fresh rhizomes is in the yellow and yellow orange hue.

Table 3. Optical properties of fresh turmeric rhizomes

PARAMETER	FRESH TURMERIC			CHROMA	HUE ANGLE
	L*	a*	b*	(C*)	(h*)
Range	34.50-59.00	14.70-21.00	50.80-76.90	53.60-79.23	71.40 – 78.12
Mean	55.076	19.014	71.662	74.156	75.08
SD	5.187	1.367	5.795	5.768	1.228
CV (%)	9.42	7.19	8.09	7.78	1.64

Table 4. Mechanical properties of fresh turmeric rhizomes

PARAMETER	MOTHER RHIZOMES		FINGER RHIZOMES	
	Puncture Force (kN)	Shear Force (kN)	Puncture Force (kN)	Shear Force (kN)
Range	0.1252-0.3988	0.1246-0.2430	0.0803-0.1499	0.0682-0.1232
Mean	0.1761	0.1708	0.1029	0.0899
SD	0.0620	0.0408	0.0172	0.0159
CV (%)	35.32	23.87	16.76	17.66

Mechanical Properties

Some of the mechanical properties of fresh turmeric rhizomes are summarized in Table 4. The maximum force needed to puncture a mother and finger rhizomes ranged from 0.1252-0.3988kN and 0.0803-0.1499kN, with an average of 0.1761 kN and 0.1029kN, respectively. The puncture force has a CV of 35.23 % for the mother rhizome and 16.76 % for the finger rhizomes. Meanwhile, the maximum shear force recorded for the mother and finger rhizomes has an average of 0.1708 kN and 0.0899 kN, with a CV of 23.87 % and 17.66 %, respectively. Since the recorded puncture and shear force are lower in the finger rhizome, it may be more susceptible to mechanical damage compared to the mother rhizome.

Dried and Powdered Turmeric

The physical properties of turmeric rhizomes dried at 55°C and powdered turmeric are summarized in Table 5 and 6, respectively. For the dried rhizomes, the average values of L*-a*-b* were calculated to be 27.24, 8.78, and 32.37, respectively. The mean value of chroma was 33.57 with a CV of 25.93 percent, and hue angle was 74.88 with a CV of 3.43 percent. Meanwhile, for the powdered turmeric, the average values of L*-a*-b* were calculated to be 43.09, 14.448, and 55.51, respectively. The mean value of chroma was 57.36 with a CV of 4.17 percent, and hue angle was 75.40 percent with a CV of 0.7.

To further understand the optical properties of turmeric, the L* a* b* values were converted to H-S-B values. Hue (H) is the color pigment or shade of an object, saturation (S) refers to the intensity or richness of the color while B refers to the brightness of the color. The hue can be visualized in the color wheel and may range from 0 to 360° (Figure 1). Certain hue values correspond to specific colors (e.g. 0 = red, 30 = orange, 60 = yellow, 120 = green, 240 = blue) (Pagliarini *et al.*, 2021). Saturation, on the other hand, may range from 0 to 100% where 100 indicates that the color is rich and intense while 0 appears gray. Brightness also ranges from 0 to 100% where 0 is black and 100 is white. Sites that readily convert L* a* b* values to H-S-B values were identified and used (e.g. colorizer.org). The equivalent HSB values of the samples are summarized in Table 7.

Since the hue values of all samples are `between 36 - 39°, this indicates that the turmeric samples are between the orange and yellow range. This color range corresponds to the visual observation of the actual samples. The dried rhizomes exhibited the lowest hue, saturation, and brightness among the three classifications indicating the darkening and dullness of the surface color of turmeric after drying. This is expected since qualitatively, the dried rhizomes appeared to be duller and more

Table 5. Optical properties of turmeric rhizomes dried at 55 °C

PARA-METER	DRIED TURMERIC			CHROMA	HUE ANGLE
	L*	a*	b*	(C*)	
Range	18.30-44.90	5.30-16.30	22.40-53.90	23.11-55.95	70.53-81.49
Mean	27.243	8.776	32.367	33.570	74.88
SD	7.805	2.931	8.345	8.706	2.565
CV (%)	28.65	33.40	25.78	25.93	3.43

Table 6. Optical properties of powdered turmeric rhizomes

PARAM-ETER	TURMERIC POWDER			CHROMA	HUE ANGLE
	L*	a*	b*	(C*)	(h*)
Range	40.10-45.50	13.50-15.30	52.60-57.60	54.59-59.33	74.49-76.56
Mean	43.090	14.448	55.510	57.361	75.40
SD	1.797	0.350	1.355	1.297	0.526
CV (%)	4.17	2.42	2.44	2.26	0.70

Table 7. Converted L* a* b* values of fresh rhizomes, dried rhizomes and powder to H-S-B values

CLASSIFICATION	HUE (°)	SATURATION (%)	BRIGHTNESS (%)
Fresh Rhizomes	37.95	100	73
Dried Rhizomes	36.62	87	35
Turmeric Powder	38.72	100	56

brownish after the drying process. Also, browning is associated with cell damage caused by the drying process which is commonly observed in fruits and other crops. It should also be noted that the hue, saturation, and brightness increased upon processing the dried rhizomes into turmeric powder. This may indicate that the dark color registered in the dried samples are only at the surface while the interior of the rhizomes retained its vibrant color. Since the color of the dried samples are difficult to measure using the color meter due to its irregular shape, it is possible that some readings are uneven and might have registered the color of the turmeric skin, causing the values to lean towards the darker shade.

Aside from value conversion, the identified internet sites also automatically show the corresponding color outputs based on the L*a*b* and H-S-B values as shown in Figure 2a. The visual representation confirms that the fresh rhizomes exhibited the most vibrant yellowish orange color, followed by the powder, and last, the dried rhizomes. These generated colors may also be validated with the actual image of the samples (Figure 2b).

As shown in Table 8, dried turmeric rhizomes have smaller bulk density value (0.186 g/cm3) compared to the bulk density of its powdered form (0.423 g/cm3). On the contrary, the average angle of repose of powdered turmeric rhizomes (45.5) is greater than the average angle of repose of dried turmeric (35.8).

Dry fine powders exhibit inter-particle attractive forces which are much higher than its particle weight with the particles tending to aggregate (Castellanos, 2005) making powders more cohesive than granular materials. Powders having an angle of repose from 45°-55° is classified as showing true cohesiveness (de Campos and do Carmo Ferreira, 2013). This explains why turmeric powder has higher angle of repose, and a much higher bulk density than dried turmeric rhizomes. The inter-particle attraction among fine powders are strong and powders are more cohesive compared to loose and large materials.

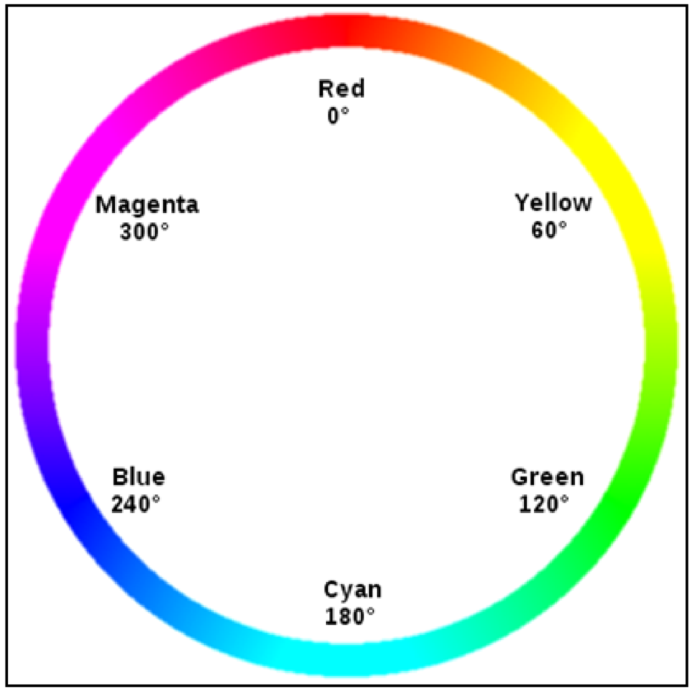

Figure 1. Color wheel

Figure 2. Color of the samples based on HSB values (a) and actual color of the samples (b)

Table 8. Some properties of dried and powdered turmeric

PARAMETER	DRIED TURMERIC		POWDERED TURMERIC	
	Bulk Density (g/cm^3)	Angle of Repose	Bulk Density (g/cm^3)	Angle of Repose
Range	0.18-0.20	32.50-38.50	0.42-0.43	41.50-49.50
Mean	0.186	35.8	0.423	45.5
SD	0.006	1.925	0.002	3.082
CV (%)	3.23	5.38	0.47	6.77

CONCLUSION

Various physical and engineering properties of fresh turmeric rhizomes found in Dumingag, Zamboanga del Sur, Philippines were measured and obtained. In terms of geometric and gravimetric properties, the rhizomes have an average geometric mean diameter, sphericity, and aspect ratio of 32.38 mm, 0.436, and 31.63, respectively. Furthermore, the recorded average surface area, volume, true density, bulk density, and porosity were 3371.21 mm^2, 19044.77 mm^3, 1.002 g/mL, 0.51 g/mL, and 48.77%, respectively. Frictional properties including the average angle of repose and angle of friction for plywood (across and along the grain) and stainless steel were 18.65°, 22.09°,16.33°, and 11.51°, respectively. Likewise, the average coefficient of static friction were 0.408, 0.293, and 0.204, respectively. These values showed that the turmeric samples were larger in comparison to turmeric found in India and thus, machines for turmeric processing should be designed in accordance with the recorded values.

Test on the mechanical properties showed that the average puncture force were 0.1761 kN and 0.1029 kN for the mother and finger rhizomes, respectively. Meanwhile the average shear force for the mother and finger rhizomes were 0.0408 kN and 0.0159 kN, respectively, showing that the finger rhizomes are more susceptible to mechanical damage and are easier to slice than the mother rhizomes. These values are useful when designing a slicing machine for turmeric. The force needed to cut the mother rhizomes should always be considered in the design.

Optical properties of fresh, dried, and powdered turmeric were tested and compared. Results showed that fresh rhizomes displayed the most vibrant yellowish orange color, while the dried rhizomes exhibited a dull and almost brownish color. Since the drying process contributes to the darkening of the color of turmeric, an optimized dryer and drying process will be valuable to increase the marketability of processed turmeric.

Overall, the properties obtained in the study are expected to be of great importance for the design and development of equipment and machinery used for turmeric harvesting, handling, and processing.

RECOMMENDATIONS

For a complete characterization of turmeric native to the Philippines, its thermal properties should be studied. Data on the physical, mechanical and thermal properties of the product can be used in the preparation of design specifications in the development of machinery for turmeric handling, processing and storage. The information can also serve as reference material during the drafting of standards for turmeric products.

ACKNOWLEDGEMENT

The authors are very grateful to the Department of Agriculture- Bureau of Agricultural Research (DA-BAR) for funding the project ‘Improvement and Promotion of a Technology Package for the Production of Powder from Turmeric for Commercial Application’. The authors would also like to acknowledge the implementing agency, Center for Agri-Fisheries and Biosystems Mechanization (BIOMECH), CEAT, UPLB, as well as the collaborating agency, the Municipal Government of Dumingag, Zamboanga del Sur, for facilitating the conduct of the study.

LITERATURE CITED

AHANGARNEZHAD N., G. NAJAFI, AND A. JAHANBAKHSHI. (2019). Determination of the physical and mechanical properties of a potato (the Agria variety) in order to mechanise the harvesting and post-harvesting operations. Research in Agricultural Engineering 65: 33–39.

AJAV, A. and C. A. OGUNLADE. (2014). Physical Properties of Ginger (Zingiber Officinale). Global Journal of Science Frontier Research: Agriculture and Veterinary, Volume 14 Issue 8 Version 1.0 ISSN: 2249-4626 & Print ISSN: 0975-5896

AMALRAJ, A., A. PIUS, S. GOPI, and S. GOPI. (2017). Biological activities of curcuminoids, other biomolecules from turmeric and their derivatives – A review. *Journal of Traditional and Complementary Medicine, 7*(2), 205-233. doi: 10.1016/j.jtcme.2016.05.005

ASAE (1979) ASAE Standard S368.4: Compression test of food materials of convex shape. American Society of Agricultural Engineering. 2001, 2950 Niles Road, St Joseph, MI, USA.

BALAKRISHNAN, K. V. (2007). Postharvest Technology and Processing of Turmeric in Turmeric – the Genus Curcuma, Medicinal and Aromatic Plants Industrial Profile, CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300Boca Raton, FL

BALASUBRAMANIAN, S., A. MOHITE, K. SINGH, T. ZACHARIAH and T. ANAND. (2012). Physical properties of turmeric (Curcuma longa L.). Journal of Spices and Aromatic Crops, 21(2), 178-181.

BUREAU OF AGRICULTURE AND FISHERIES PRODUCT STANDARDS (BAFS). (2013). Philippine National Standard: Fresh Vegetable - Turmeric Classification and Grading (pp. 3-4). Quezon City.

CASTELLANOS, A. (2005). The relationship between attractive inter-particle forces and bulk behaviour in dry and uncharged fine powders. Advances in Physics, Vol. 54, No. 4, June 2005.

DE CAMPOS, M. M. and M. DO CARMO FERREIRA (2013). A Comparative Analysis of the Flow Properties between Two Alumina-Based Dry Powders. Advances in Materials Science and Engineering Volume 2013, Article ID 519846. http://dx.doi.org/10.1155/2013/519846

ERCISLI S. (2004). A short review of the Rhizome germplasm resources of Turkey. Genetic Resources and Crop Evolution, 51: 419-435.

GAN H., E. CHARTERS, R. DRISCOLL, and G.SRZEDNICKI. (2017). Effects of Drying and Blanching on the Retention of Bioactive Compounds in Ginger and Turmeric. Horticulturae, 2017; 3(1):13. https://doi.org/10.3390/horticulturae3010013

KERAMAT-JAHROMI M, S. RAFIEE, A. JAFARI, BMR GHASEMI, R. MIRASHEH and S.S. MOHTASEBI. (2008). Some physical properties of date rhizome (cv. Dairi). International Agro Physics, 22: 221-224.

KUMAR, D., and A. KUMAR. (2016). Physical and Engineering Properties of Turmeric Rhizome. Journal of Food Research and Technology, 4 (1), 30-34. Retrieved from http://www.jakraya.com/journa/jfrt

LOKHANDE, S. M., R. V. KALE, A. K. SAHOO, AND R. C. RANVEER. (2013). Effect of curing and drying methods on recovery, curcumin and essential oil content of different cultivars of turmeric (Curcuma longa L). International Food Research Journal 20(2): 745-749 (2013).

MOHSENIN, N.N. (1986). Physical properties of plant and animal materials. Second revised. Gordon and Breach Sci. Publ., New York.

OBOMEGHEI, A. A. and P. A. EBABHAMIEGBEBHO. (2020). Physical and Engineering Properties of Some Nigerian Sweet Potato Roots [Ipomoea Batatas (L.) Lam]. Open Access *Journal of Agricultural Research*, Volume 5 Issue 2. DOI: 10.23880/ oajar-16000242

PAGLIARINI, M., D. PAZ, V. TRINDADE, P. SANTOS and R. CASTILHO. (2021). Light Levels Influence on Development and Leaves Reflectance Index of Imperial Zoysia Grass. *Brazilian Journal of Development, 7*(1), 1566-1577. doi: 10.34117/bjdv7n1-107 P

NS/BAFPS 120-2013 ICS 67.080.20. Philippine National Standard (PNS) for Fresh Vegetables – Turmeric or “Luyang Dilaw” – Grading and Classification. Bureau of Agriculture and Fisheries Product Standards. Department of Agriculture. Diliman, Quezon City, Philippines.

PLOTTO, A. (2004). Turmeric: Post-Production Management. *INPhO-Postharvest Compendium. Food and Agriculture Organization of the United Nations*. Edited by F. Mazaud, A. Röttger, K. Steffel, 22/04/2004.

SINGH, G., S. ARORA, and S. KUMAR (2010). Effect of mechanical drying air conditions on quality of turmeric powder. *Journal of Food Science and Technology*, *47*(3), 347-350. doi: 10.1007/s13197-010-0057-6

WANDKAR, S., P. UKEY, and D. PAWAR. (2012). Determination of physical properties of soybean at different moisture levels. Agricultural Engineering International: The CIGR e-journal. 14(2). ■