Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(2): 349-355
Received: 03-03-2020
Accepted: 06-04-2020

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Studies on crop parameters of turmeric rhizome towards the development of root crop harvester

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DOI: https://doi.org/10.22271/phyto.2020.v9.i3f.11290

Abstract
The biometric and engineering properties which are relevant to the study were measured for turmeric rhizome *(Curcuma longa* Linn.). The biometric properties *viz*., number of leaves, height of pant, depth of rhizome, plant density, spacing, soil rhizome composite, rhizome weight, rhizome fingers per hill and weight of rhizome with plant and engineering properties which include both physical and frictional properties of turmeric *viz*., size (length, width and thickness), shape, geometric mean, sphericity, rhizome index, surface area, bulk volume. bulk density, the angle of repose, coefficient of friction, angle of repose and texture (firmness). The mean values observed for biometric properties such as number of leaves, height of pant, depth of rhizome, plant density, spacing, soil rhizome composite, rhizome weight, rhizome fingers per hill and weight of rhizome with plant were 9.20, 39.50 cm, 18.15 cm, 10.60, 23.90 cm, 18.60 cm, 0.61 kg, 8.20 and 1.39 kg, respectively. The mean values for obtained for engineering properties of size (length, width and thickness), geometric mean, sphericity, rhizome index, surface area, bulk volume, bulk density, the angle of repose, coefficient of friction, angle of repose and texture (firmness) were (13.83, 10.12, 3.56 cm), 7.83 cm, 0.57, 39.95, 195.20 cm^2, 194.20 m^3, 481.63 kg m^{-3}, 31.69 deg, 0.57 (stainless steel), 0.75 (plywood), 0.60 (GI) and 67.83 N, respectively. These properties were which plays an important role in the selection of the proper design components of the root crop harvester and are essential in the design and development of the digging unit and soil separator unit of the root crop harvester.

Keywords: Turmeric rhizome, root crop harvester, rhizome index and soil rhizome composite

Introduction
Turmeric is a tropical herb and can be grown on different types of soil under irrigated and rainfed conditions. Loamy soils having good drainage are ideal for the crop. It is a shade tolerant crop with shallow roots suitable for inter cropping. India is the world's largest producer of turmeric *(Curcuma longa* Linn.) known as 'Indian Saffron' and considered the best due to its high curcumin content. It is used in diversified industries as condiment, as flavouring and colouring agent and principal ingredient in curry powder apart from pharmaceuticals and cosmetic industry. The country consumes 80 per cent of turmeric production and the rest is exported. Turmeric is grown in as many as 25 states of India with Kerala, Andhra Pradesh, Tamil Nadu, Karnataka and Orissa being the leading producers. Other main producers of turmeric are Gujarat, West Bengal, Assam, Meghalaya, and Maharashtra. India has nearly 246.00 thousand ha under turmeric cultivation with a total production of 1389 thousand million tonnes during the year 2018-19. The area under turmeric during 2017-18 is 2,778 ha and has increased by 5.58 per cent as compared to 2016-17. The area under cultivation of turmeric is highest in Palakkad district during 2017-18 and is 23.58 per cent of the total turmeric cultivation in the state.
Area, production and productivity of turmeric in Kerala (2017-18) were 2780 ha, 6506 tones and 3.17 MT while in India (2018-19) were 246000 ha, 1389000 tones and 5.6 MT, respectively.
Harvesting of turmeric rhizome was done by manually using spades, kodali and fork. In designing a machine for digging and separating of rhizomes, physical properties such as weight, mean and major diameter, shape factor, height, texture and coefficient of friction on different surfaces are important parameters. In recent years, many researchers have reported physical and mechanical properties of different crop relevant to different machines. But there are few studies on the biometric and engineering properties of turmeric rhizome for mechanical harvesting. The determination of physical properties of agricultural materials are important to design machines and processes for harvesting, handling and storage of these materials and requires understanding for converting these materials into food and feed.

For agricultural materials, dimensions (length, diameter, thickness) are widely used to describe them. Manjunatha *et al.* (2008) [10] determined engineering properties of garlic to design specific crop production and processing equipment like planting, handling, storing, aeration, drying, bulb breaking, peeling of garlic. Masoumi *et al.* (2006) [11] also studied physical attributes of garlic for development of new methods of sowing, new equipment for processing and control strategies for crop storage. Knowledge of frictional properties of rhizomes is needed for the design of handling equipment. The physical properties increase with an increase in the moisture content except the sphere city and bulk density which decrease as the moisture content increases. (Mohsenin, 1986) [12] Biometric and engineering properties of root crops like weight of plant, plant length, size of turmeric and angle of rolling resistance affects the design parameters of harvester. These properties influences design parameters as spacing between the rods of soil separator, material handling capacity of soil separator, etc. In harvest handling systems of turmeric designed without taking biometric and engineering properties consideration lead to inadequate applications which in turns a reduction in efficiency and increase in harvesting losses. There is no published data on biometric and engineering properties of turmeric. Therefore, the present work was undertaken with objective to study of crop parameters of turmeric rhizome towards the development of root crop harvester.

Materials and Methods

The biometric and engineering properties which are relevant to the study were measured for turmeric rhizome. The biometric properties *viz*., number of leaves, height of pant, depth of rhizome, plant density, spacing, soil rhizome composite, rhizome weight, rhizome fingers per hill and weight of rhizome with plant and engineering properties which include both physical and frictional properties of turmeric *viz*., size (length, width and thickness), shape, geometric mean, sphericity, rhizome index, surface area, bulk volume. bulk density, the angle of repose, coefficient of friction, angle of repose and texture (firmness). The methods used the measurement of parameters are given below.

Biometric properties of turmeric

Biometric properties of turmeric are important for design of a root crop harvester. These properties were measured at the time of harvesting of crop with the help of measuring scale and vernier caliper.

Number of leaves

The crop canopy is indicated by number of leaves spread on cultivated beds. Twenty five beds of 10 m length were randomly selected and number of leaves were counted.

Height

The height of the plant was the decided factor for design of the throat and total length of soil separator unit for proper soil separation. The height of plant decides the handling of crop during harvesting by the machine.

Depth of rhizome

The depth of rhizomes in soil was estimated to find the volume of soil to be handled by digging and soil separator units of the harvester. Randomly selected twenty five plants each from turmeric in the study area were measured by using a scale and a flat plate. Vertical soil section was first cut along the plant to expose the rhizome of a standing plant. A flat plate was kept on the ground and a scale was placed vertically to the soil up to the bottom of root crop plant.

Plant density

The density of plant is an important parameter in determining the volume of crop handled by the digging and soil separator units of the harvester.

Spacing

The turmeric were planted in raised bed system with a bed width of 900 mm and covering two to three rows as shown in Fig.1. The height of raised bed was 300 to 450 mm. The spacing between the rows 200 to 300 mm and plants as 150 to 200 mm were kept to facilitate easy uprooting of the rhizomes.

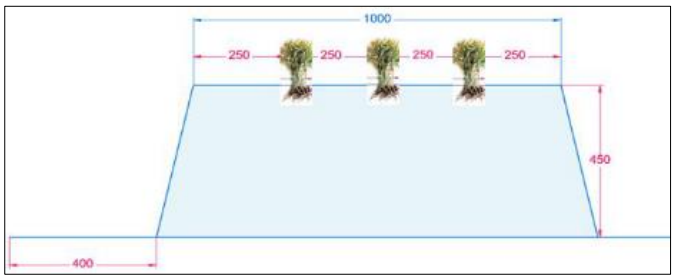

Fig 1: Raised beds for turmeric rhizome

Soil rhizome composite

The spread of rhizome in soil lateral and vertical directions varied w.r.t the varieties (Plate 1). rhizome spread affect the design of digging unit. The spread of twenty five clumps were selected at random and measured using a scale by digging the soil adjacent to the plant on the raised bed. The weight of rhizome alone varies from 250 to 500 g for different varieties of turmeric. Soil is adhered all around the rhizome when it was dug out and hence the complete weight was measured. The weight rhizome without soil was separately weighed and the difference in weight was recorded as weight of the soil. The overall weight of the soil rhizome composite determines the material handling capacity of the machine.

Each hill contains one or more mother rhizomes which produces 4 to 10 primary fingers. Later stages the secondary fingers were usually come out with 8 to 20 shoots. The total number of fingers per hill influences the volume of crop to be handled.

Plate 1: Soil rhizome composite

Physical properties of turmeric rhizome

The physical properties of turmeric *viz*., size, shape, bulk volume, bulk density, rhizome index and surface area were determined by using standard procedures.

Size

The size of rhizome was determined by measuring the dimensions along the three principal axes namely, major (length), intermediate (width) and minor (thickness) using vernier callipers least count of 0.01 cm and thickness were measured using digital callipers. The size was recorded for ten rhizomes and an average size was computed (Jayashree and Visvanathan, 2011). The geometric mean of the turmeric were determined by measuring the major, minor and intermediate axes of the rhizome. The geometric mean was calculated using the equation described by Mohsenin (1986) [12].

$$\text{Geometric mean} = (xyz)^{1/3} \quad \ldots (1)$$

Where,
x = Major diameter of rhizomes, mm
y = Intermediate diameter of rhizomes, mm
z = Minor diameter of rhizomes, mm

Sphericity

The sphericity is defined as the ratio of the diameter of the largest circumscribing sphere (mm) to the diameter of the smallest circumscribing sphere (mm). Diameters of the rhizome at the larger and smaller circumscribing sphere were recorded and sphericity was calculated.

$$S = \frac{\sqrt[3]{yz}}{x} \ldots . (2)$$

Where,
S = Sphericity

Bulk volume

The bulk volume of the rhizomes was determined by using Archimedes's principle as described by Nelkon (2005) [13]. The sample was weighed and immersed in a measuring cylinder containing a known volume of water thus leading to an increase (rise) in the water volume. The difference between the new level of water in the measuring cylinder and the initial level of water was recorded as the bulk volume of the rhizome.

Bulk density

The bulk density of the turmeric was determined as the ratio of bulk weight of rhizome to the bulk volume of rhizome (Ajav and Ogunlade, 2014) [1]. A container of known volume of inner dimensions 550 x 280 x 350 mm was taken and weighed in a physical balance. Then it was completely filled with freshly harvested rhizome and was weighed again. The bulk density was calculated by using the formula,

$$B_R = \frac{W_{tc} - W_c}{V_c} \quad \ldots (3)$$

Where

B_R = Bulk density of rhizome, kg m^{-3}
W_{tc} = Weight of container filled with rhizome, kg
W_c = Weight of empty container, kg
V_c = Volume of container, m^3

Rhizome index (I)

rhizome index is the percentage ratio of rhizome's greater length to the product of greater width and greatest thickness of rhizome.

$$I = \frac{L}{WT} \times 100 \quad \ldots (4)$$

Where

I = rhizome index
L = Greatest length of rhizome, mm
W = Greatest width of rhizome, mm
T = Greatest thickness of rhizome, mm

Surface area

The surface area was estimated using the relationship given by Asairo and Anthony (2011) [3]. The surface area was measured for ten samples and the mean value was calculated.

$$S = \pi G m^2 \quad \ldots (5)$$

Where

S = Surface area, mm^2
Gm = Geometric mean diameter, mm

Moisture content

Moisture content of rhizome is an important parameter which has direct impact on harvesting and quality of the rhizome. The moisture content of rhizome was measured by gravimetric method. 50 g of sample were weighed and put in the empty weighed moisture box, the weight of sample with box were recorded. The moisture box is kept in hot air oven at 105°C ± 2 °C for 24 hours. After 24 hours the weight of the moisture box with sample is measured. The moisture content of rhizome can be measured by using the following formula.

$$M_w = (M_2 - M_3) / (M_2 - M_1) \quad \ldots . (6)$$

Where

M_w = Moisture content, % (w.b)
M_1 = weight of moisture box, g
M_2 = weight of moisture box + rhizome before drying, g
M_3 = weight of moisture box + rhizome after drying, g

Frictional properties of rhizome

The frictional properties of turmeric rhizome *viz*., coefficient of friction, angle of repose and texture(firmness) were determined by the following standard procedures.

Coefficient of friction

The static coefficient of friction was determined with respect to each of the following three structural materials on the tilting table: stainless steel, plywood and glass. The rhizomes of turmeric were placed parallel to the direction of motion and the table was raised gently by a screw device. The angle at which the rhizomes begin to slide (the angle of inclination) was observed on a graduated scale fitted on the tilting table. This was repeated three times for each material. The coefficient of friction was calculated as the tangent of this using the equation given by (Olaoye, 2000) [14].

$$\mu = \tan \theta \quad \ldots (7)$$

Where

μ = Static Coefficient of friction, decimal

θ = Angle of Inclination, deg

Angle of repose

The angle of repose is an angle made by rhizomes with the horizontal surface when heaped from a known height (Olaoye, 2000) [14]. A bag containing 25 kg of turmeric rhizomes was heaped over a horizontal surface. The slant height of the heap was determined and radius of the heap was calculated from the circumference of the heap. The angle of repose was calculated by using the formula:

$$\theta = \tan^{-1}\left(\frac{h}{l}\right) \quad \ldots (8)$$

Where

θ = Angle of repose, deg

h = Height of the heap of rhizomes, cm

l = Bottom diameter of heap formed from the rhizomes, cm

Texture

Important quality parameters which affect the consumer acceptability of turmeric is firmness. This parameter was determined using Texture Analyzer. The instrument Shimadzu (EZ) texture analyser has Trapezium texture analyzer software installed to a personal computer. The instrument consists of the test-bed and the adjustable controller. It is a system with a maximum stroke of 500 mm and a capacity of 500 N. It has a test speed range from 0.001 to 1000 mm m^{-1} (at all loads) and the maximum return speed is 1500 mm/min. This system is ideal and effective for testing of texture profile analysis. It can be fixed with a variety of jigs and fixtures. The sample was kept on the test bed of the instrument and was subjected to compression by tooth pushed jig with depth of 50 mm. From interactive data processing screen of the texture analysis software, the force deformation curve was used for the measurement the firmness or hardness (peak force).

Table 1: Biometric observations of rhizome in the field at the time of harvesting

Sl. No.	Parameter	Turmeric	
		Range	Mean
1	Number of leaves	6 - 12	9.20
2	Height of plant, cm	20 - 50	39.50
3	Depth of rhizome,cm	15 - 21	18.15
4	Plant density, no/m^2	9 - 12	10.60
5	Plant to plant spacing, cm	20 - 25	23.90
6	Row to row spacing, cm	25 - 30	28.30
7	Rhizome spread, cm	17 - 20	18.60
8	Rhizome weight, kg	0.45 - 0.75	0.61
9	No. of rhizome finger per hill,	3 - 12	8.20
10	Weight of rhizome with plant, kg	1.3 - 1.5	1.39

Table 2: Physical properties of turmeric

Sl. No	Size (cm)			Geometric mean, dia, (cm)	Sphericity	Rhizome Index	Surface area (cm^2)	Bulk volume (cm^3)	Bulk density (kgm^{-3})
	Length	Width	Thickness						
1	17.27	14.23	3.1	9.13	0.52	39.14	261.87	185	445.80
2	19.31	11.5	3.5	9.19	0.47	47.9	265.39	191	432.90
3	9.25	12.4	4.2	7.83	0.84	17.76	192.60	196	484.00
4	13.27	10.4	4.05	8.23	0.62	31.50	212.78	200	479.80
5	9.5	6.5	3.5	6.00	0.63	41.75	113.09	204	510.90
6	12.2	8.1	4.1	7.39	0.60	36.73	171.56	189	489.21
7	14.5	9.2	3.8	7.97	0.54	41.47	199.55	187	472.30
8	15.38	10.04	3.5	8.14	0.52	43.76	208.16	201	493.50

9	14.23	9.8	2.8	7.30	0.51	51.85	167.41	204	498.34
10	13.47	9.12	3.1	7.20	0.53	47.64	162.86	185	509.50
Range	10.06	7.73	1.40	3.19	037	34.09	152.3	19.0	78.0
Mean	13.83	10.12	3.56	7.83	0.578	39.95	195.20	194.20	481.63
S.D.	3.12	2.19	0.473	0.945	0.105	9.77	45.9	7.70	25.53
CV, %	22.56	21.63	13.26	12.05	18.27	24.45	23.49	3.96	5.30

Table 3: Frictional properties of turmeric

Sl. No.	**Coefficient of friction**			**Angle of repose (deg)**	**Firmness (N)**
	Stainless steel	**Plywood**	**GI**		
1	0.53	0.73	0.64	28.74	81.48
2	0.54	0.74	0.69	29.47	59.67
3	0.59	0.72	0.71	31.58	60.95
4	0.61	0.79	0.66	33.14	71.57
5	0.58	0.78	0.61	35.51	65.47
Range	0.08	0.07	0.10	6.77	21.81
Mean	0.57	0.75	0.66	31.69	67.83
S.D	0.0339	0.0311	0.039	2.754	8.94
CV,%	5.95	4.14	5.99	8.69	13.18

Results and Discussion

Crop parameters such as biometric, physical and frictional parameters were studied turmeric rhizome. The biometric parameters include with number of leaves, height of plant, depth of rhizome, plant density, spacing, rhizome weight and number of rhizome fingers per hill. The data related to these parameters were used in the design of functional components of the root crop harvester. The biometric observations of root crops in the field at the time of harvesting presented in table 1.

The number of leaves per plant varied from 6 - 12 for turmeric with an average of 9.20. The plant height of root crops ranged from 20-50 cm with a average value of 39.50 cm for turmeric. The depth of the rhizome in soil was varied from 15-21 cm with an average of 18.15 cm for turmeric. The plant density of rhizome were found out as 9-12 numbers for turmeric. Plant to plant spacing of rhizome were varied from 20-25 cm and an average values of 23.90 cm for turmeric where as row to row spacing of rhizome varied from 25-30 cm with mean of 28.30 cm for turmeric.

The rhizome soil composite varied from 17-20 cm with a mean of 18.60 cm for turmeric was observed under field conditions. Also noted that distribution of the crops in horizontal and vertical directions on the soil surface ranged from 10.60 to 20.70 cm with an average of 14.60 cm. The weight of the rhizome soil composite is an important parameter in the design of soil separator unit of the harvester. The weight of rhizome varied from 0.45-0.75 kg and the mean values were 0.615 kg for turmeric. The number of fingers per hill is also an important parameter as it determines the volume of crop to be handled by the machine. The number of rhizome fingers per hill was ranged from 3-12 and mean value were 8.20.

The weight of rhizome with leaves is an important parameter which determines the total volume of crop to be handled by the machine as well as the length of the soil separator to be decided. The weight of rhizome with plant were ranged from 1.3-1.5 kg and the average values were 1.39 kg for turmeric.

The physical properties of rhizomes *viz*., size, geometric mean diameter, sphericity, rhizome index, surface area, bulk volume and bulk density were determined and analyzed statistically and presented in table 2. The major, minor and intermediate diameter of turmeric were found out as 13.83, 10.12 and 3.56 cm. Accordingly the geometric mean diameters were found out as 7.83 cm for turmeric. The average values of sphericity were 0.57 for turmeric. The average bulk volume and bulk density were found out as 194.2 cm^3 and 481.63 kg m^{-3} for turmeric, respectively. The bulk density of the rhizomes are important parameter in designing the soil separator unit. The rhizome index were found out as 39.95 per cent for turmeric. The average surface area were determined 195.20 cm^2 for turmeric. The moisture content of rhizomes at the time of harvest is another important parameter in digging out the rhizome from soil. The moisture content varied from 70.75 to 75.27 per cent (w.b.) with an average of 73.51 per cent. Since the moisture content of rhizomes at the time of harvest is very high, the soil has a tendency to adhere to the rhizome and it comes out along with the soil which increase the weight of rhizome soil composite by the machine. The physical properties increased with an increased in the moisture content except bulk density which decreased as the moisture content increased.

The major frictional properties of turmeric affecting the root crop harvester *viz*., coefficient of friction, angle of repose and texture were determined and analyzed statistically and presented in table 3. The range of coefficient of friction of turmeric for stainless steel, plywood and galvanized iron were found out as 053 to 0.61, 0.72 to 0.79 and 0.61 to 0.71 respectively. The mean coefficient of friction for stainless steel, plywood and galvanized iron were found out as0.57, 0.75 and 0.66, respectively. The coefficient of variation of stainless steel, plywood and galvanized iron were found out as 5.95, 4.14 and 5.99, respectively.

The angle of repose of turmeric was measured as 31.69 deg. The angle of repose is the determining factor in the design of the lifting the fingers of the soil separator unit. The values obtained are in accordance with the results of Yerima *et al*., (2016) [15]. Firmness is the characteristic of a material expressing its resistance to permanent deformation. Firmness of turmeric is an indicator of good edible quality of the rhizome with more consumer appeal. The maximum and minimum firmness for turmeric were found out as 59.67 and 81.44 N, respectively. The average value, standard deviation and coefficient of variation of firmness for turmeric were found out as 67.83 N, 8.94 and 13.18, respectively.

Conclusions

In this research work, biometric parameters of crop such as number of leaves, height of plant, plant density, rhizome spread, weight, spacing and rhizome fingers per hill which influence the design of root crop harvester. Physical and frictional properties of turmeric such as diameter (major, minor and intermediate), geometric mean, sphericity, bulk density, volume, surface area, rhizome index, angle of repose, coefficient of friction and texture (firmness) which plays an important role selecting the proper design components of the harvester and are essential in the design and development of the digging unit and soil separator unit of the root crop harvester.

Acknowledgement

Acknowledgement The authors are very grateful to the staff of KCAET, Tavanur and for their assistance while the experiments lasted.

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