Indian Journal of Ecology (2022) 49(3) (SI): 1220-1224
DOI: https://doi.org/10.55362/IJE/2022/3648

Manuscript Number: 3648
NAAS Rating: 5.79

Investigation on Biometric and Engineering Properties of Tapioca

N.L. Kalyan Chakravarthi and P.R. Jayan

Kelappaji College of Agricultural Engineering and Technology, Tavanur-679 573, India
E-mail: nlkalyan954@gmail.com

Abstract: Various biometric, engineering and frictional properties of tapioca (*Manihot esculenta*) were investigated. The plant height, stem girth diameter, tuber depth, tuber spread and weight of tuber soil clump were determined as 2390 mm, 31.02 mm, 250.3 mm, 501.3 mm and 15.46 kg, respectively. The major diameter, intermediate diameter, minor diameter, geometric mean diameter and arithmetic mean diameter of tapioca roots were 52.76 mm, 49.60 mm, 33.36 mm, 42.50 mm and 45.24 mm. The sphericity and surface area were 0.81 per cent and 5869.73 mm^2, respectively. The tuber volume and bulk density observed was 425.8 cm^3 and 0.57 g/cm^3, respectively. The angle of repose of tapioca roots was 34.62° and the coefficient of friction on three different material surfaces varied from 0.55 to 0.79 on wood, 0.41 to 0.67 on galvanized sheet and 0.30 to 0.55 on stainless steel. The moisture content varied from 74.22 to 68.20 per cent (w.b.).

Keywords: Tapioca, tuber, Biometric properties, Stem girth diameter, Harvester

Roots and tubers play an important role in the global food chain, particularly in the developing countries. Tropical root and tuber crops consist of both dicots like sweet potato (*Ipomoea batatas*), cassava/tapioca (*Manihot esculenta*), monocots like yams (*Dioscorea spp.*), edible aroids like taro (*Colocasia esculenta*) and elephant foot yam (*Amorphophallus spp.*). Tapioca is the most significant tuber crop in the tropical region, and it ranks fourth, after rice, sugarcane, and maize. It is the most important source of calories in the human diet and major carbohydrate food for around 500 million people throughout the world (Oriola and Raji 2014). Globally, tapioca is grown in an area of 18.51 million ha with a production of 276.65 million tonnes. India acquires significance in the global tapioca scenario due to highest productivity of 27.92 t/ha. It is cultivated in an area of 0.26 million ha in country with a production of 7.2 million tonnes. Kerala state currently contributes about 31 per cent of total production in the country (Anonymous 2018). Tapioca is a perennial tuber crop which is propagated by stem cutting and the root grows into a long and tapered tuber with firm homogeneous flesh encased in a detachable bark, rough and brown on the outside. The tuber shape tapers from top to bottom divided into three sections: the periderm, the cortex and the central portion (Nwachukwu and Simonyan 2015).

Tapioca grows and produces best under warm humid tropical conditions where rainfall is well distributed and fairly abundant and roots are ready to harvest 9-10 months after planting (Anonymous 2016). Harvesting is a major constraint for cultivation of tapioca due to bigger size and goes deeper into the soil. Manual harvesting is a time-consuming activity, stressful and involves drudgery, especially during the dry season. In designing a machine for digging and separating of tuber, physical properties such as weight, mean and major diameter, shape factor, depth and coefficient of friction on different surfaces are important parameters. In recent years, many researchers have reported physical and mechanical properties of various crops relevant to different machines. But there are few studies on the physical properties of tapioca roots for mechanical harvesting. The determination of physical properties of agricultural materials is important to design machines and processes for harvesting, handling and storage of these materials. This research is focused on the objective to study the biometric and engineering properties of tapioca roots. Moreover, the results from this research will be useful for further research in developing a tractor operated tapioca harvester.

MATERIAL AND METHODS

The biometric and engineering properties relevant to the research were measured for tapioca root. The biometric properties are number of leaves, plant height, stem girth diameter, number of roots per plant, tuber depth, tuber spread, weight of tuber soil clump, tuber weight, plant density, plant spacing and engineering properties includes both physical and frictional properties of tapioca *viz.,* size, sphericity, surface area, aspect ratio, tuber volume, bulk density, angle of repose and coefficient of friction.

Biometric properties: Biometric properties of tapioca root are important for the design of soil engaging components of tuber harvester. These properties were measured at the time of harvest using standard test procedure.

Number of leaves: The crop canopy is indicated by number of leaves on the plant. Twenty beds of 10 m length were randomly selected and number of leaves was counted.

Plant height: The height of the plant was the deciding factor for design of throat and total length of soil separator unit for proper soil separation. Twenty five plants were selected randomly and plant height was measured using measuring tape and the mean value was determined.

Stem girth diameter: Crop stem girth diameter is an important parameter which influences the design of crop handling unit of the tuber harvester. Twenty five plants were randomly selected and stem girth diameter was measured using vernier caliper with 0.01 mm least count.

Number of roots per plant: The total number of roots per plant influences the volume of crop to be handled. The number of roots was counted from twenty five harvested hills selected at random.

Tuber depth: The volume of soil to be handled by digging unit of the harvester was indicated by tuber depth. Twenty five plants were selected randomly and the depth of tuber was measured using a 30 cm steel rule and flat plate. Vertical soil section was first cut along the plant to expose the tuber of a standing plant. A flat plate was kept on the level ground and a scale was placed vertically to the soil up to the bottom of tuber root (Basavaraj and Jayan, 2020).

Tuber spread: The spread of tuber in soil lateral and vertical directions varied with respect to the plant variety (Fig. 1). Tuber spread affects 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.

Weight of tuber soil clump: Soil is adhered around the tuber when it was dug out and hence the complete weight was measured. The tuber weight without soil was weighed separately and the difference in weight was recorded as weight of the soil. The overall weight of tuber soil clump determines the material handling capacity of the machine.

Plant density: The plant density is an important parameter in determining the volume of crop handled by the machine per unit width of blade per unit time. Average value of plant density in one square meter area at ten different locations was measured randomly.

Engineering properties of tapioca: The determination of some engineering properties of tapioca roots was carried out for designing the tuber harvester. 25 samples of tapioca roots were selected randomly and the engineering properties *viz.*, size, sphericity, surface area, aspect ratio, bulk volume and bulk density were determined according to established standards and procedure.

Determination of moisture content of samples: Moisture content of tuber is an important parameter which has direct impact on harvesting and quality of the tuber. The moisture content of randomly selected and cleaned tubers was measured by gravimetric method. The cleaned tubers were sliced transversely with a knife. The moisture content was determined by dehydrating the samples at 105 ºC for 24 h in a drying oven. The moisture content was calculated using the formula given by Jahanbakhshi et al (2018).

$$MC_{wb} = \frac{M_w - M_d}{M_w} \times 100$$

where, MC_{wb} is the moisture content of tapioca root on wet basis (%), M_w is the mass of tapioca root before drying (g), M_d is the mass of tapioca root after drying (g).

Size: The root size in terms of the major diameter (a), intermediate diameter (b) and minor diameter (c) and length (d) of the roots were measured using a digital caliper with the precision of 0.01 mm (Fig. 2).

The geometric mean diameter, arithmetic mean diameter and aspect ratio for 25 tapioca roots were calculated using the formula given by Bahnasawy (2007) and Chainarong et al (2020).

$$GMD = (a \times b \times c)^{1/3}$$

$$AMD = \frac{(a \times b \times c)}{3}$$

$$Ar = b/a$$

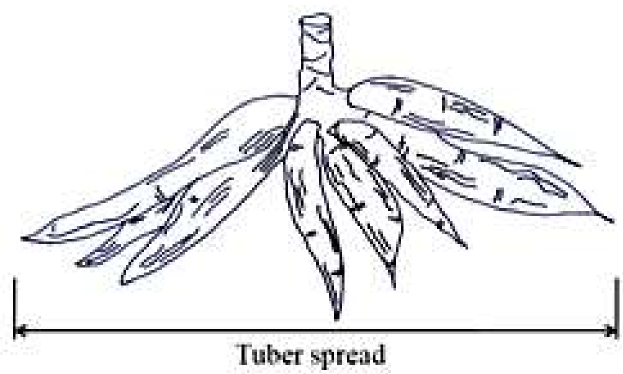

Fig. 1. Schematic diagram of tuber spread measurement of tapioca root

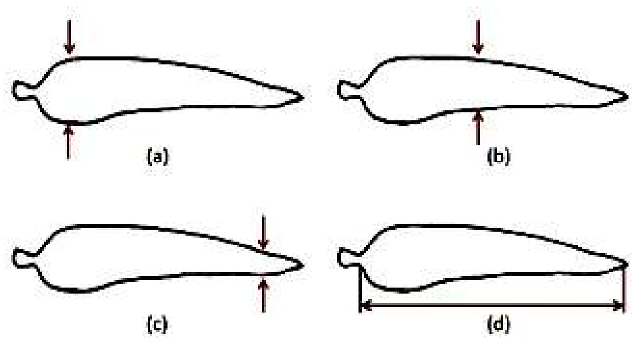

Fig. 2. Size measurement of Tapioca root

where, GMD is geometric mean diameter (mm), AMD is arithmetic mean diameter (mm), a is major diameter (mm), b is intermediate diameter (mm), c is minor diameter (mm), Ar is Aspect ratio.

Sphericity and surface area: The sphericity and surface area of tapioca roots was determined by using the formula given by Basavaraj and Jayan (2020).

$$\text{Sphericity} = \frac{GMD}{a}$$

$$S_a = \pi \times GMD^2$$

where, GMD is geometric mean diameter, S_a is surface area (mm^2)

Tuber volume: The tuber volume of tapioca roots was determined experimentally using water displacement method. The sample was immersed in a measuring cylinder containing known volume of water, thus leading to an increase in the volume of water. The difference between the final level of water in the measuring cylinder and the initial level of water was recorded as the volume of the tuber. This was done for 25 samples.

Bulk density: The bulk density of tapioca roots was determined by weighing the tubers packed in a container of known weight and volume. The tubers were placed in such a way that it filled the container to the brim and then it was weighed using the electronic weighing balance. The volume of the container was determined. The bulk density of the tapioca roots was calculated by using the formula given below.

$$\rho b = \frac{M_b}{V_c}$$

where, ρ_b is bulk density of the tubers (g/cm^3), M_b is mass of the tubers (g), V_c is volume of the container (cm^3).

Frictional Properties of Tapioca

Angle of repose: The angle of repose is an angle made by tapioca roots with the horizontal surface when heaped from a known height. A bag containing 30 kg of tapioca roots 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 given by Basavaraj and Jayan (2020).

$$\mu = \frac{F}{N}$$

where, θ is Angle of repose (deg), h is height of the heap of tapioca roots (mm) and l is bottom diameter of heap formed by the tapioca roots (mm).

Coefficient of friction: The coefficient of friction apparatus consists of a horizontal plane and a pan to add weights. The experiment was determined on three test surfaces namely stainless steel, galvanized sheet and wood. The tapioca roots were placed parallel to the direction of motion and the weights were added in the pan and at the instant at which the pan weight exceeds tuber weight; tuber starts to slide movement. The force at which tuber begin to slide was observed and repeated three times for each material. The coefficient of friction was calculated by using the equation given by Chowdareddy and Dronachari (2014).

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

where, μ is Coefficient of friction, F is Frictional force (force applied) and N is Normal force (weight of the tuber).

RESULTS AND DISCUSSION

Crop parameters such as biometric, engineering and frictional properties were studied for the tapioca roots. The biometric properties include number of leaves, plant height, stem girth diameter, number of roots per plant, tuber depth, tuber spread, weight of tuber soil clump, tuber weight, plant density, plant spacing. The data related to these parameters were used in the design of functional components of the tuber harvester.

The number of leaves per plant varied from 438 to 346 for tapioca. The plant height of tapioca ranged from 2480 to 2280 mm and stem girth diameter varied from 36.50 to 24.00 mm. The number of roots per plant is an important parameter as it determines the volume of crop to be handled by the machine. The number of roots per plant ranged from 14 to 12. The depth of tuber in soil varied from 270 to 230 mm with an average value of 250.30 mm. The tuber spread of tapioca plant ranged from 546 to 458 mm. The weight of tuber soil clump is an important parameter which determines the total volume of crop to be handled by the machine. The weight of tuber soil clump ranged from 16.48 to 14.53 kg whereas, the tuber weight varied from 10.40 to 7.20 kg. The plant density of

Table 1. Biometric observations of tapioca crop

Parameter	Range	Mean
No. of leaves per plant	438-346	392
Plant height, mm	2480-2280	2390
Stem girth diameter, mm	36.50-24.00	31.02
No. of roots per plant	14-12	13
Tuber depth, mm	270-230	250.30
Tuber spread, mm	546-458	501.30
Weight of tuber soil clump, kg	16.48-14.53	15.46
Tuber weight, kg	10.40-7.20	8.81
Plant density, no. of plants/m^2	2.00	2.00
Plant to plant distance, mm	1200-800	950
Row to row distance, mm	1600-1400	1460

Table 2. Engineering properties of tapioca roots

Parameters	Unit	Minimum	Maximum	Mean	Standard deviation
Diameter					
Major diameter (a)	mm	35.73	71.68	52.76	10.68
Intermediate diameter (b)	mm	29.69	69.99	49.60	10.42
Minor diameter (c)	mm	17.50	50.48	33.36	8.10
Length (d)	mm	110.00	420.00	256.60	86.97
Geometric mean diameter	mm	25.63	58.60	42.50	8.13
Arithmetic mean diameter	mm	27.64	61.70	45.24	8.64
Aspect ratio		0.69	1.48	0.95	0.16
Sphericity	%	0.69	1.01	0.81	0.08
Surface area	mm^2	2061.86	10784.24	5869.73	2232.94
Tuber weight	g	174.00	1075.50	464.37	225.91
Tuber volume	cm^3	150	985	425.8	210.59
Bulk density	g/cm^3	0.55	0.58	0.57	0.01

Table 3. Frictional properties of tapioca roots

Parameters	Unit (°)	Minimum	Maximum	Mean	Standard deviation
Angle of repose		33.35	37.72	34.62	1.88
Coefficient of friction					
Wood		0.55	0.79	0.68	0.09
Galvanized sheet		0.41	0.67	0.52	0.09
Stainless steel		0.30	0.55	0.44	0.07

tapioca crop was found to be 2 numbers per square meter. Plant to plant spacing of tapioca crop varied from 1200 to 800 mm whereas, row to row spacing varied from 1600 to 1400 mm. The moisture content of tuber is an important parameter which has direct impact on harvesting and quality of the tuber. The moisture content varied from 74.22 to 68.20 per cent (w.b.). The engineering properties of tapioca roots *viz*., size, sphericity, surface area, aspect ratio, bulk volume and bulk density are presented in Table 2.

The major, intermediate and minor diameter of tapioca roots was 52.76, 49.60 and 33.36 mm. The length of the tapioca roots varied from 110 to 420 mm. Accordingly, geometric mean diameter, arithmetic mean diameter and aspect ratio was found out as 42.50, 45.24 mm and 0.95. Sphericity and surface area ranged from 0.69 to 1.01 and 2061.86 to 10784.24 mm^2. Sphericity values of most agricultural produce have been reported to range between 0.32 and 1.00 and the more regular an object is, the lower the sphericity (Basavaraj and Jayan 2020). The average tuber volume and bulk density were found out as 425.8 cm^3 and 0.57 g/cm^3 respectively.

The major frictional properties of tapioca roots affecting the tuber harvester *viz.,* angle of repose and coefficient of friction were determined. The range of angle of repose for tapioca roots was 33.35 to 37.72° with an average of 34.62°. The angle of repose is the determining factor in the design of soil separation unit. The coefficient of friction of tapioca roots for wood, galvanized sheet and stainless steel surface varied from 0.55 to 0.79, 0.41 to 0.67 and 0.30 to 0.55, respectively. The average coefficient of friction for wood, galvanized sheet and stainless steel surface were 0.68, 0.52 and 0.44, respectively.

CONCLUSION

In the present research, biometric parameters of tapioca crop such as number of leaves, plant height, stem girth diameter, number of roots per plant, tuber depth, tuber spread, weight of tuber soil clump, tuber weight, plant density and plant spacing were studied which influence the design of tuber harvester. Engineering and frictional properties of tapioca roots such as diameter (major, intermediate and minor), length, geometric mean, arithmetic mean, aspect ratio, sphericity, surface area, tuber weight, tuber volume, bulk density, angle of repose and coefficient of friction were studied which plays an important role in selecting the proper design components of the harvester.

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Received 16 May, 2022; Accepted 30 June, 2022