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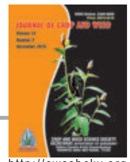

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Structural analysis of coconut palm prior to the design of a coconut palm climber and derivation of allometric relationships- A study at KAU campus

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ABSTRACT

Coconut is one of the important cash crop distributed across tropics. The risky factor with coconut cultivation is the timely harvesting of nuts. Climbing up the palm and harvesting is a long concern for the coconut farmers throughout the world. So it is high time to develop a climbing device which requires less human effort. To design a climbing device for coconut, it is mandatory to know the physical parameters of the palm. Although coconut is a staple crop in every homegardens of Kerala, relatively little is known about its physical properties.The physical parameters like palm height, girth or diameter at different levels, inclination with respect to ground will help to design a coconut palm climbing device. The average DBH of coconut in KAU campus is 26 cm and average height of the coconut palm is 13 m. In addition to this, an allometric relation is developed between coconut palm diameter and crown width and also coconut palm diameter and height. In both cases, majority of the data points comes under 50 % quantiles.The physical properties and their allometric relation are necessary for the design of appropriate climbing device for coconut palm.

***Keywords*:** Allometry,climbing device, coconut, physical parameter, quantile regression

Coconut (*Cocos nucifera*) is an important perennial palm mostly grown in the coastal regions of India (Pham, 2016). With rising populations and industrialization, global demand for coconut and coconut-based health products is predicted to expand (Alrifai and Marcone, 2019). It boosts the economy and is an income source for more than 10 million families in India (Gadhe and Mathur, 2018).

Indonesia (16.8 Million nuts), India (14.6 Million nuts) and the Philippines (14.4 Million nuts) are the world's top coconut producers, accounting for almost half of all coconut produced worldwide (FAOSTAT, 2020). Farmers concentrate on growing coconuts in their lands because of economic worth of coconut. Coconut palms are known as the "Tree of Life" because of their vital role in human life (Kappil *et al*., 2021). Kerala (Keralam, in Malayalam) is known as "the Land of Coconut Trees", which is derived from two Malayalam words: Kera- meaning coconut tree and Alam- meaning land (Kumar and Kunhamu, 2022).

The risky factor with coconut cultivation is the timely harvesting of nuts. From socio-economic perspective, climbing up the palm and harvesting is indubitably a long concern for the coconut farmers across the world.Various types of mechanical climbing devices have been developed and are becoming popular among the common people. Standing type and sitting type are the main categories of climbing devices available in the Indian market so far (Jahan *et al.*, 2018).

A standing type climber, also known as'Joseph Model' or 'Chemberi Model', is the most popular and extensively used climbing device in Kerala. Climbers have accepted this simple-to-use device. However, the primary disadvantage is that prolonged usage of this equipment might result in physical ailments such as musculoskeletal diseases and joint aches (Mohankumar *et al.,*2013). Furthermore, the risk factor rises as the tree becomes taller (Sam *et al*., 2019), as the major injury associated with coconut palm climbing is fall from trees (Mohankumar *et al.,*2013).

So it is high time to develop a climbing device which requires less human effort. To design a climbing device for coconut, it is mandatory to know the physical parameters of the palm. The physical parameters like the height of the palm, girth or diameter at different levels, inclination with respect to the ground will help to design a coconut palm climbing device (Manoharan and Megalingam, 2019). Also, knowing the crown width of the palm may add to the ease of harvesting from the top. Though coconut is a typical small- holder's crop, our knowledge related to this crop is not in proportion to its importance and the data availability regarding the physical measurements are really less. This paper focuses on the structural analysis [collecting some

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physical parameters] of coconut palm, which could be of use to coconut researchers and may lead to a contribution to those working in this field. We use this measured data to scrutinize the coconut palm diameter and crown width allometry. The allometric relation of coconut palm diameter and height was also developed.

Coconut palm structure analysis

Coconut palm trunk is unbranched and have a textured feature. It is cylindrical in shape and yet have a tapering manner when goes from the bottom to top (Friedman, 2019). It may vary in size and thickness from place to place depending upon many factors like climatic, geographical and agricultural conditions.The top of the tree is known as the crown, which bears the fronds (leaves), inflorescence, nuts. It is estimated that, a 40-year-old coconut palm may reach a height of about 20-22 m and 35-40 m when it is 80 years old (Chan and Elevitch, 2006).

The normal variations in the coconut trunkis shown in Fig. 1.The abnormal variationsin the coconut trunk may arise at any portion. This occur due to the pest attack and some disease causing organisms or may be due to some climatic conditions. The abnormal variations on the tree trunk mainly exhibit sudden variations on the tree trunk, generally greater or lesser than the average tree circumference. Abnormal variations are found out by visual examination method. Abnormal variations on the coconut tree trunk near top and bottom portion of the palm trunk is depicted in Fig. 2 and 3 respectively.

Since coconut palms have textured trunks, variations are visible in this context too (Fig.4). They have prominent leaf scars (Venkat, 2012) . The scar is formed when old leaves shed. It helps in determining the age of the coconut palm. The diameter of the crest and trough of the scar shows slight variations of about 2mm to 5mm (Manoharan and Megalingam, 2019).

Man-made carvings on the coconut trunk is made as harvesting steps (Killmann and Fink, 1996) in some parts of our country. This helps in easy climbing and manual harvesting of coconut. These steps like notches or wedges if made deeper may affect the health of the palm (Manoharan and Megalingam, 2019). Defects caused to the coconut stem by the attack of some insect pests, fungi and other organisms may damage the stem and affects the growth of it. Insects like red palm weevil (Azmi *et al.,*2017) and rhinoceros beetle (John and Kenneth, 2020) usually affect the growing parts. Fungi like *Aspergillusniger* and *Rhizopusstolonifer* (Chuku *et al.,* 2007) normally affect the parts of the plant that have lost their vitality due to insects, physical injuries or damages and human interventions.

The feathery leaves of the palm forms the heavy crown on the top of the trunk. It exhibits a spherical shape which is uniformly distributed (Chan and Elevitch, 2006). In general, an adult palm produces 12-16 new leaves every year. Each leaf has its own flower cluster (inflorescence). It is estimated that, a healthy crown have around 30-40 leaves. A leaf stays on the palm for nearly three years before falling off and creating a permanent scar on the trunk. Generally, the age of an adult palm and the number of leaf scars on the palm is correlated. It is considered that, a healthy palm will grow and shed around 13 leaves per year, producing 13 leaf scars on the palm. Thus, the number of scars on the stem, divided by 13 gives the age of the palm (Mahindapala and Pinto,1991).

The condition of the leaf foliage also imparts to the structural appearance of the coconut palm. The leaf distribution pattern, formation of spadix, coconut bunch alignment, the presence of dried portions (Manoharan and Megalingam, 2019) etc. affects the existence of a healthy crown. Trimming coconut palms once or twice a year to remove dead and drooping fronds makes better appearance in the field and better growth of the palm(Westover, 2021). Fig. 6 shows an unhealthy crown.

Physical parameters:

Physical parameters of coconut palms such as height, the number of leaves on the palm, the stem girth at different levels (three levels), crown radius, inclination of the palm with respect to ground are measured. The site of study was at the KAU campus, Thrissur. The age of palms taken as samples come within a range of 20-40 years.

Height of the palm (bole height) is measured from ground level to the top portion where the crown starts. The height of the coconut palm was measured using a hypsometer (Nikon Forestry Pro II Laser Rangefinder). The stem diameter was taken at three different levels on the palm- at breast height, middle of the stem and 1m below top of the crown. Laser calliper (Haglöf Mantax Black Calipers with Gator Eyes) is used to get the diameter. Number of leaves is counted using ‘visual method’(Occular method) Crown radius is measured using ‘vertical sighting method’. Lean of the tree is measured using a plum bob (Demrow, 2008) attached to a protractor.

Allometry

The term allometry was first introduced by Julian Huxley and Georges Teissier in the early 1930s (Pretzsch *et al.*, 2015). They developed ‘relative growth equation’ considering x and y which quantify the size of plant or total plants. Their growth is expressed as the differential element of the functions x and y with respect to time (dx/dt and dy/dt). The relation between the growth rate (x) and size (y) is given as

$$\frac{dy}{y} = \frac{\alpha\, dx}{x} \quad (1)$$

Or this can be expressed as a power law equation for describing allometric relationships as

$$y = bx^{\alpha} \quad (2)$$

Where, x and y represents two traits of interests.

If we consider a log-log plot, b represents the intercept and α represents the slope or scaling exponent

The logarithmic representations are commonly used to draw the relationship between x and y (Hulshof *et al*., 2015)

$$\ln y = \ln b + \alpha \ln x \quad (3)$$

$$\ln y = a + \alpha \ln x \quad (4)$$

where a = ln *b*

If we consider y as height and x as the diameter of the plant. Then the allometry can be described as the relative change of height, dy/y in relation to the relative change of diameter (relative change of plant dimension in relation to the relative change of second plant dimension.) (Pretzsch *et al.*, 2015). The allometric exponent α is defined as the ratio between the relative changes of the plant dimensions, y and x which is considered to be a constant. The allometric exponent α, is a distribution coefficient for the growth between the parts y and x. To be more clear, we can interpret as, when x increases by 1%, y increases by α% (Pretzsch *et al.*, 2015)

The most basic characteristic of plant or organism is its size. Height and stem diameter are the major components that determine the size of a plant / tree (Niklas,1993). Scaling of plant height with respect to stem diameter was done by Henry and Aarssen 1999.

The data about the coconut palm collected from the KAU Main campus at Thrissurcan be explained as following. Coconut palm diameters at three different levels were taken and it is clear that the diameter at breast height (DBH) is always greater than the diameter at mid portion and the top portion. Tapering of coconut and diameter range is an important criterion for designing different shape tree attaching part of the coconut palm climbing deviceThe DBH ranges between 20-32 cm (19.49-31.97 cm), whereas the diameter at mid portion and the top portion ranges between 17.5-30.5 cm and 17-29.5 cm respectively. To accommodate all these variations in the diameter, the palm attaching portion of the climber must have an adjusting character while designing.

Palm height is a key factor for lifting height of any machine to lift a worker to the palm crown for cultural operations. Height of the coconut palm comes under a range of 8 to 18 m. It varies depending upon many factors like sunlight availability, soil type, water availability etc. The harvester to be designed should be capable of reaching this height without any flaws. We should consider the fact that, as height increases, difficultness in climbing also increases (Maheswaran *et al.,*2017). Most of the trees were straight in structure, except two trees with 85^0 inclination, one tree each with 80^0,75^0 and 70^0 inclination with respect to ground.

The maximum number of leaves on the coconut palm selected for the study is 35 whereas the minimum number of leaves is 24. Most of the palms have around 30-32 leaves on it. The crown width lies in the range of 7-11.2 m. Though, these values do not have direct impact on designing aspect, it does affects the performance of the climber.

Allometric relationship

Allometric study was carried out using the quantile regression method. This approach enables regression models to be fitted to any conditional (heterogenous) quantiles of the distribution of dependent variable (Li *et al.,*2011). A quantile can be explained as a phrase that describes a portion of a data set;which specifies how many values in a distribution are above or below a certain limit. The quartile (quarter), quintile (fifth), and percentiles (hundredth) are special quantiles (Satista, n.d.).

Quantile regression can be considered as an extension of linear regression-generally used when the conditions of linear regression are not met (Dye, 2020). This method helps us to recognize the relationships between variables that lie far outside the mean data. It enables to explore the different aspects of the relation between the dependent variable and the independent variables (Flom, 2018). Moreover, quantile regression also helps us to know the lower and upper boundary relationships. We can fit eq.(4) for 95 % quantile, 50 % quantile and 5% quantile.

In healthy trees, significant allometric relationship is found out between stem diameter at breast height andcrown diameter (Coombes *et al*., 2019) (2019). This relation can be used to predict the space requirement for the palms within an orchard.Palm height and DBH are the two most essential measurements used in tree volume estimation. They are further used for the calculation ofbiomass evaluation and carbon estimation.The allometric equation of tree height and DBH can be used in modelling individual tree (Liu *et al*., 2017; Sumida *et al*., 2013). Allometric relations helps to predict one parameter from the other relatable parameter, which in turn provide data for designing a palm climbing device.This can be clearly manifested in the prediction of height, which is often estimated visually and associated with significant proportion of error. Applying allometric relations for height prediction using diameter significantly reduce this issue.

Fig. 1: Normal tree trunk of coconut palm

Fig. 2: Abnormal tree trunk variation near the tree top

Fig. 3: Abnormal tree trunk variation at the base

Fig. 4: Tree trunk variation due to leaf scars

Fig. 5: Showing some of the defected tree trunks

Fig. 6: Unhealthy crown

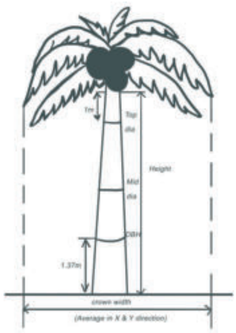

Fig. 7: Physical parameters measurements in coconut palm

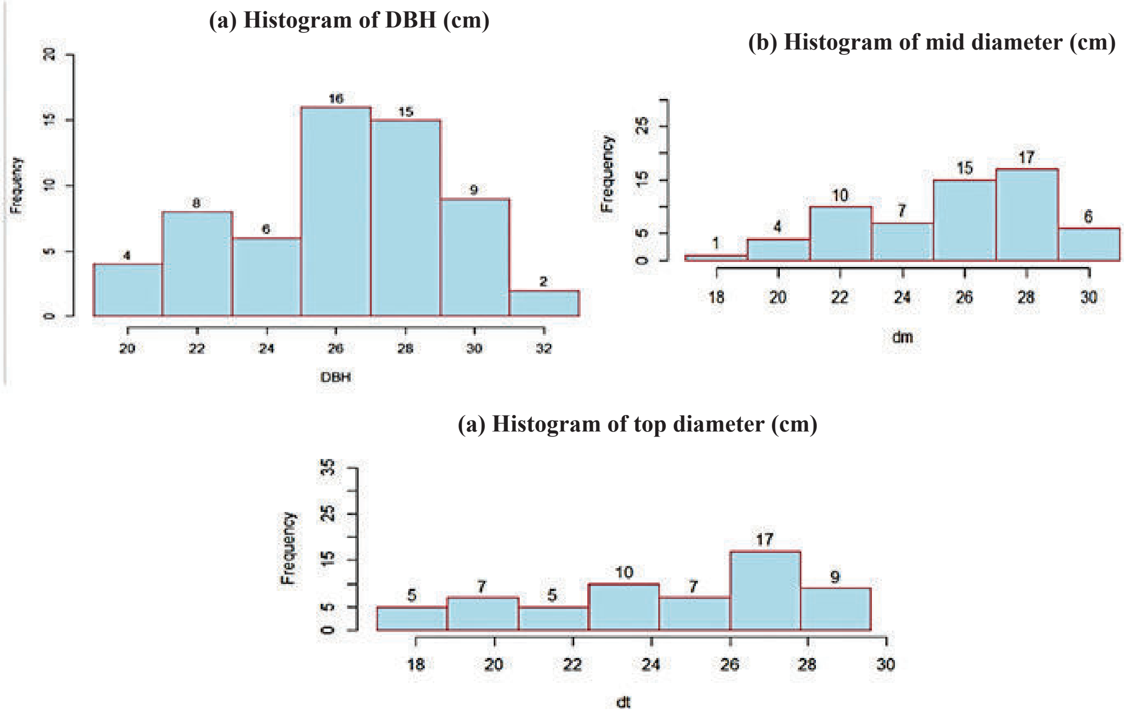

Fig. 8: Histogram of (a) DBH (b) Mid diameter (c) Top diameter

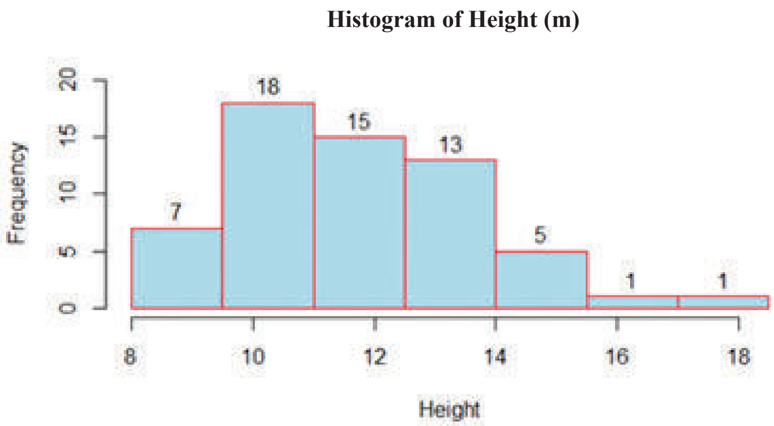

Fig. 9: Histogram of height

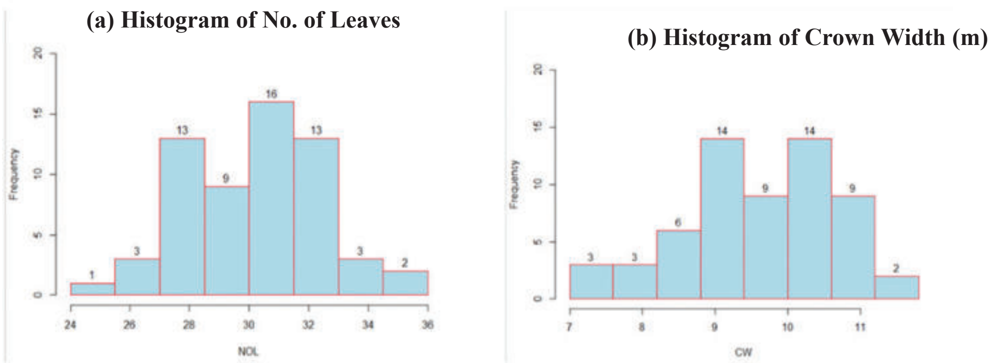

Fig. 10: Histogram of (a) Number of leaves (b) Crown width

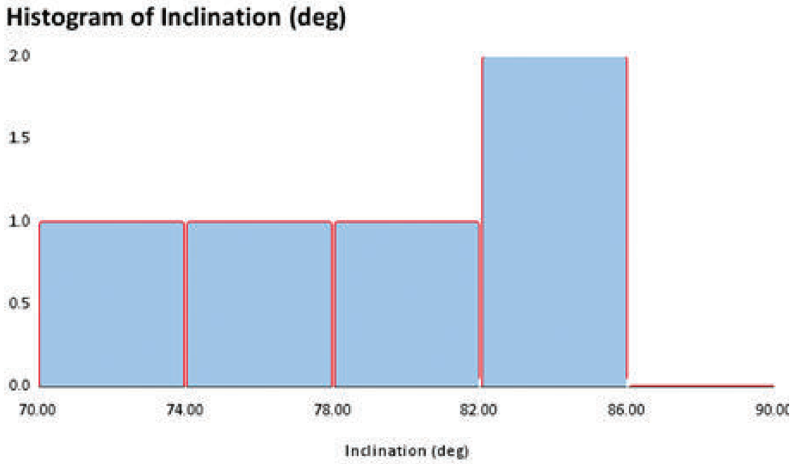

Fig. 11: Histogram of inclination of coconut palm

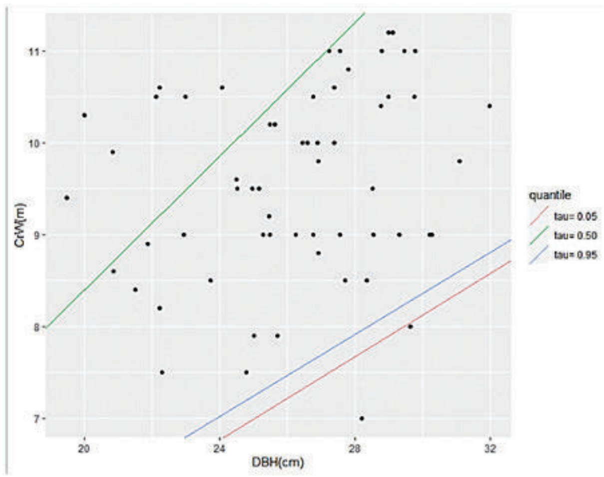

Fig. 12: Quantile regression results (95%, 50%, and 5% quantiles) for the allometric relationship ln(cr) = a + α ln(d)

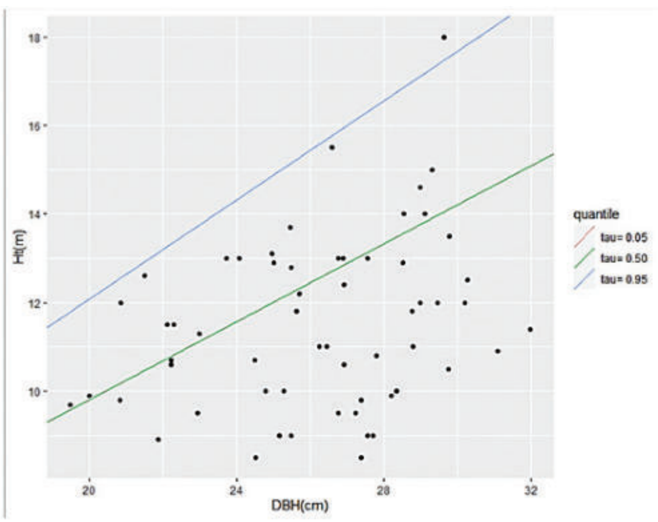

Fig. 13: Quantile regression results (95%, 50%, and 5% quantiles) for the allometric relationship ln(h) = a + α ln(d)

The physical properties and their allometric relationare necessary for the design of appropriate climbing device for coconut palm. The measurements of physical properties of trees will help to design climbing machine structure and dimensions. It clears that any new climbing device must be adopted with local cultivation conditions and any coconut cultivation in the area needs different climbing device from others. Detailed understanding of physical properties simplifies the designer to further explore various mechanical properties like palm trunk, tensile strength in different directions, Coefficient of friction between machine and palm trunk.

Crown width Vs DBH

A log-log graph is plotted with the diameter at the breast height (DBH) on X axis and crown width on Y axis.The slope of the regression line on this log-log scale is used to describe the connection between crown width and stem diameter (DBH). Fig. 10. Shows95%, 50 % and 5% quantile crown width-DBH allometric regression lines.The allometric scaling exponent is the slope of this regression line.The majority of the data points comes under 50 % quantiles (green line). At 95^{th} quantileand 5^{th} quantile, we have an effect of 0.22 slope whereas the intercept (b) is 1.66 and 1.30 respectively. But it shows a maximum slope at 50^{th} quantile (ie.,an increase of 1 % in log DBH can be related to log crown width with an increment of 0.36%)

Height Vs DBH

The slope of the height versus diameter regression line on a log-log scale is used to describe the connection between stem diameter and height. Fig. 13 shows the 95%, 50 % and 5% quantile height-DBH allometric regression lines. The scaling exponent (α) for 5^{th} quantile is very close to zero whereas the intercept (b) is 2.04. the majority of the data points comes under the $50^{\%}$quantiles (green line). The scaling exponent for 95^{th}quantile is higher with a value of 0.56.

CONCLUSION

The coconut palm structure has an undecidable feature- each palm is unique in many ways. The availability of structural data of coconut palm is very less in our knowledge circle. These parameters play a key role in designing a coconut climbing device. Generally the coconut palm is having a tapered stem structure. The stem diameter decreases as it goes on to the top portion. The maximum diameter at the breast height and top portion is recorded as 31.97 cm and 29.5cm respectively. The maximum height of the palm was observed as 18m. The crown width and number of leaves on the palm help to determine visually whether the palm is healthy or not. The allometric relation between crown width-DBH and height-DBH was done. Fundamentally, the allometric relation of various parameters of coconut palms help in knowing the growth behaviour of coconut palms.These information are needed to be considered while designing a coconut climbing device to make the design more effective.

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