

# Studies on some physical properties of WCT Coconut relevant to the design of processing equipment\*

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## Abstract

Some physical properties of West Coast Tall variety coconut were evaluated as a function of moisture content. The minimum, maximum and mean length of the fruit were 16.50, 23.50 and 20.14 cm, respectively. The minimum, maximum and mean value of sphericity of fruit were 69.85, 97.0, and 81%, respectively which indicates that West Coast Tall variety of coconut is like a sphere as the values are in the range of 69.85 % and above. The bulk density of kernel decreased from 464.23 to 411.674 kg / m<sup>3</sup> when the moisture content decreased from 94.93 to 6.15% d.b. The variation in bulk density was found to be linear with the moisture content. The true density of kernel decreased from 524.364 to 450.316 kg / m<sup>3</sup> when the moisture content decreased from 94.93 to 6.15 % d.b., respectively. The angle of repose of kernel increased from 30.24 to 34.67° as the coconut kernel moisture content decreased from 94.93 to 6.15% d.b., respectively. The porosity decreased non-linearly from 11.29 to 8.58% as the moisture content decreased from 94.93 to 6.15 % d.b. The static coefficient of friction at any moisture content on any surface was higher than the kinetic coefficient of friction within the range studied.

*Key words:* - Coconut, sphericity, bulk density, angle of repose

## Introduction

Coconut is commercially cultivated in 93 countries especially on the small and marginal holdings over an area of 11.8 million hectares and produced about 10.26 million tonnes (copra equivalent) in the year 2002 (Rethinam, 2003). India is the single largest market for coconut, consuming almost the entire production of 12.6 billion nuts. Indonesia is the next largest market, consuming nearly 11.2 billion nuts accounting for about 74% of its production. As much as 50.8% of the total coconut area is concentrated in Kerala and the state accounts for 43.63% of the total production. Kerala is a small state along the west coast of India, which accounts for only 1.18% of the total land area of the country.

Lack of basic engineering properties of plant material is an identified problem in the development of new equipment for processing and control conditions for crop storage. According to Mohsenin (1970), knowledge

of physical and mechanical properties constitutes important and essential engineering data in the design of machines, storage structures, processes and controls. The value of this basic information is not only important to engineers but it is also useful to those who may exploit these properties and find new uses for the plant material. Many scientists have worked on physical and mechanical properties of oil seeds but there are no reports for WCT coconut. Bosco(1997) has reported that the relative proportions of water, shell and kernel were 6, 16, and 23%, respectively in case of fully matured East Coast Tall variety of coconut. Jayasuria and Perira (1985) stated that the relative proportions of shell and kernel were 22.5 and 35.6%, respectively in case of dry coconut of dwarf palm. Obetta (2000) reported that the bulk density of palm kernel was in the range of 450 to 325 kg/m<sup>3</sup> This paper examines some physical properties of West Coast Tall coconut which is abundantly grown in Kerala. The properties include major constituents of coconut, size,

\* Part of Ph.D thesis submitted to Gandhigram Rural Institute, Deemed University.

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shape, mass, bulk density, true density, porosity, angle of repose, static and kinetic coefficient of friction.

## Materials and Methods

### Materials used

Fully matured West Coast Tall variety (WCT) of coconut was used for all the experiments. The average moisture content of the freshly harvested nuts was in the range of 94.93 to 81.81% d.b. and it was dried up to 6.0 to 6.25% d.b. for safe storage and analysis. The characters like weight of fruit, nut, copra and shell, thickness of husk and kernel (both wet and dry), husk percentage and minimum perimeter were measured. The sample size was 64 coconuts.

### Size

The size of the coconut was determined by taking randomly sixty four coconuts and measuring their three linear dimensions namely, length, (L) breadth, (B) and thickness (T) (breadth and thickness are almost equal) using a vernier calipers. The geometric mean diameter  $D_p$  of fruit was calculated using the following relationship as reported by Sreenarayanan *et al.* (1985).

$$D_p = (LWT)^{\frac{1}{3}}$$

where,

$D_p$  = geometric mean diameter, cm

### Degree of sphericity

The degree of sphericity was calculated as per the equation suggested by Mohsenin (1970).

$$\text{Sphericity} = \left( \frac{\text{Volume of solid}}{\text{Volume of circumscribed sphere}} \right)^{\frac{1}{3}}$$

$$\phi = \left( \frac{\frac{\pi}{6} LWT}{\frac{\pi}{6} L^3} \right)^{\frac{1}{3}} = \left( \frac{WT}{L^2} \right)^{\frac{1}{3}} = \frac{(LWT)^{\frac{1}{3}}}{L}$$

where,

$\phi$  = sphericity, decimal

$L$  = length of coconut, cm

$B$  = breadth of coconut, cm

$T$  = thickness of coconut, cm

## Mass

The mass of 50 split coconut was taken on an industrial balance. The mean of the mass of 50 coconuts of five replications was calculated. This is important in the design of machine for calculating the total load on the rotating shaft of any machine.

### Bulk density, true density and porosity

The bulk density of fruit, de-husked nuts, split nuts and copra, shell and husk were determined based on the volume occupied by the bulk sample, by filling a box of 100 cm length, 75 cm breadth and 77 cm height with coconut. The container was then weighed and the bulk density was calculated. Ramming was not employed to avoid compaction. The true density is defined as the ratio of a given mass of sample to its true volume and the same was determined by water displacement method as suggested by Shepard and Bharadwaj (1986). Both the densities were determined with five replications. The porosity of the bulk coconut is the ratio of the volume of internal pores in the coconut to its bulk volume and was determined by using the equation given below

$$\epsilon = \left( 1 - \frac{P_b}{P_t} \right) \times 100$$

where,

$\epsilon$  = porosity, %

$p_b$  = bulk density, kg / m<sup>3</sup>

$p_t$  = true density, kg / m<sup>3</sup>

### Angle of repose

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined for fruit by using a hollow cylinder of 100 cm diameter and 75 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 150 cm and was filled with coconut. The cylinder was raised slowly until it formed a cone on a circular plate. The height of the cone was recorded. The angle of repose was calculated using the formula.

$$\epsilon = \tan^{-1} \left( \frac{2H}{D} \right)$$

where,

$\epsilon$  = angle of repose, degree

$H$  = height of cone, cm

$D$  = diameter of cone, cm

### Static and kinetic coefficients of friction

The coefficient of sliding friction is present during movement of the material and it affects the force which is exerted on the nuts and the walls of the containing vessel. The experimental set up for the determination of static and kinetic coefficients of friction of coconut was similar to the one used by Kaleemullah (2002). The experimental set up consisted of a frictionless pulley fitted on a frame, a plastic hollow box of dimensions, 30x30x30 cm, loading pan and test surfaces. The box was connected by means of a string parallel to the test surface and passed over a frictionless pulley and a loading pan hanging from it.

The hollow plastic box was placed on the test surface and was filled with a known quantity of kernel and copra and weights were added to the loading pan until the hollow box began to slide over the test surface. The static and kinetic coefficients of friction of kernel and copra were calculated by assuming the energy loss over the frictionless pulley and the contact between hollow box and the surface material as negligible. It was also assumed that there was no rotational motion in the coconut kernel during the experiment. The static coefficient of friction was determined using the formula given below.

$$\mu_s = \frac{F_s}{N}$$

where,

$\mu_s$  = static coefficient of friction, decimal

$F_s$  = weight of pan and weight kept on the pan to move the box, kg

$N$  = weight of coconut and box, kg

The kinetic coefficient of friction was determined with the same coconut in the plastic box used in determining the static coefficient of friction. Enough weights were placed on the pan so that the box moved uniformly when a slight push was given. This was determined using the formula given below.

$$\mu_k = \frac{F_k}{N}$$

$F_k$  = weight of pan and weight kept on the pan to move the box with material, after giving a slight push, kg

$N$  = weight of coconut and box, kg

The static and kinetic coefficients of friction were determined at different moisture contents of coconut kernel and copra using different test surfaces namely, bamboo ply wood (BPV), stainless steel (SS), aluminum (Al), galvanized iron (GI) and mild steel (MS).

## Results and Discussion

### Constituents of coconut

The minimum, maximum and mean length of the fruit was 16.50, 23.50 and 20.14 cm, respectively. The minimum, maximum and mean breadth of the fruit was 13, 18 and 14.75 cm, respectively whereas there was wide variation with respect to fruit weight, the minimum, maximum and mean values were 535, 1800 and 955 g respectively. Ratnambal *et al.* (1995) reported similar results in case of coconut of West Coast Tall variety.

The coefficient of variation was below 10% for length, breadth and minimum perimeter of the nut. The coefficient of variation for other characters was below 20% except fruit weight. With coefficient of variation 20%, the sample size requirement estimates within 5% relative error was 64. Meunier *et al.* (1977) reported that sample size should be of 34-36 nuts for error to be less than 5% and 18 nuts for error greater than 7% in case of coconut. Thus the sample size used in the study is adequate to estimate the various fruit characteristics except fruit weight.

The correlation matrix of fruit characteristics of WCT coconuts is presented in Table 1. From the Table 1, it is clear that copra showed significant correlation with breadth of fruit, fruit weight, nut weight and shell weight. Thickness of kernel does not show significant correlation with copra weight whereas breadth of fruit was found to be correlated with copra weight. Length of the fruit was correlated with the thickness of kernel. Round nuts were found to have more copra. These correlations are for the sample size studied and so it should not be taken as conclusive. These parameters are important in selection of sieve or screen size in design de-shelling and separation equipment.

### Size

The geometrical minimum, maximum and mean diameter of fruit was ( $D_p$ ) 14.07, 19.67 and 16.38 cm, respectively. The geometrical mean diameter values calculated by using the equation proposed by Sreenarayanan *et al.*, (1985) gives values very close to the observed values. Hence, the equation proposed by Sreenarayana *et al.*, (1985) can be used for calculating

the geometrical mean diameter of West Coast Tall variety of coconut.

### Degree of sphericity

The minimum, maximum and mean value of sphericity of fruit calculated using the equation 3.5 was 69.85, 97.0, and 81%, respectively which indicates that WCT is like a sphere as the values are in the range of 69.85% and above. Thus for all practical purposes the nuts of WCT coconuts can be considered as spherical. The coefficient of variation was in the range of 6.22 to 9.04%. Similar results were reported by Patil (1984) in case of WCT. Ratnambal *et al.*, (1995) reported the shape of WCT variety as oval.

### Mass of fifty split coconut

The mass of fifty split nuts (two halves) was in the range of 19.75 to 21.51 kg with a mean value of 21.07 kg. Thus the mass of 1000 coconuts will be approximately 421.30 kg. These values will be useful in calculating the total load on the de-shelling machine for design of de-shelling chamber and calculating the horse power of prime mover.

### Bulk density

The bulk density of coconut kernel decreased from 464.23 to 411.67 kg/m<sup>3</sup> when the moisture content decreased from 94.93 to 6.15% d.b. (Fig.1). The decrease in bulk density with decrease in moisture content indicated that the decrease in weight owing to moisture loss in the sample was greater than the accompanying volumetric contraction of the bulk volume. Similar trends have been reported for coffee parchments (Chandrasekar & Vishwanathan, 1999). The variation in bulk density ( $\lambda_b$ ) was found to be linear with the moisture content (M) and can be represented by the following regression equation

$$\lambda_b = 0.5541 M + 412.32$$

with a  $R^2$  value of 0.98

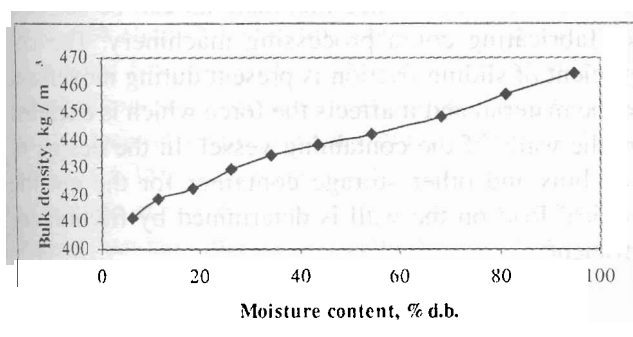


Fig. 1. Effect of moisture content on bulk density of coconut kernel

The bulk density of fruit, de-husked nut, split coconut cups, copra and husk varied from 260.57 to 268.49, 462.40 to 496.86, 459.97 to 502.79; 402.96 to 417.77 and 109.98 to 113.86 with mean values of 263.57, 487.78, 497.97, 411.67 and 111.83 kg / m<sup>3</sup>, respectively. Similar results were reported by Senthil (1986) and Bosco (1997) in case of East Coast Tall variety of coconut. The bulk density of split coconut with shell intact decreased from 488.643 to 309.96 when the moisture content decreased from 94.93 to 6.15% d.b.

### True density

The true density of kernel decreased from 524.364 to 450.316 kg / m<sup>3</sup> when the moisture content decreased from 94.93 to 6.15 % d.b., respectively (Fig. 2). The decrease in true density with decrease in moisture content indicated that the decrease in weight owing to moisture loss in the kernel was greater than the volumetric contraction of the individual kernel. Similar trends have been reported for coffee parchments (Chandrasekar &

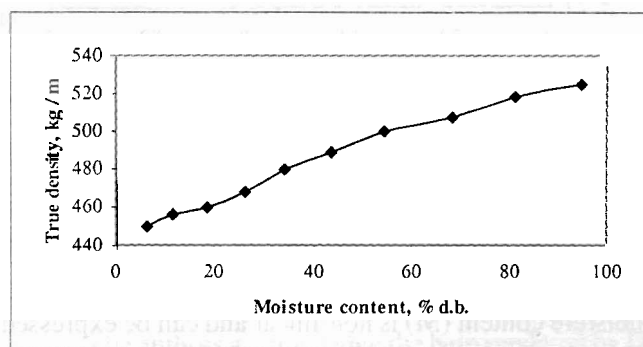


Fig. 2. Effect of moisture content on true density of coconut kernel

Vishwanathan, 1999). The variation in true density ( $p_t$ ) was found to be linear with the moisture content (M) and can be represented by the following regression equation.

$$p_t = 0.8696 M + 447.29$$

with a  $R^2$  value of 0.98

The experimentally observed data on bulk and true densities resulted in the following linear equation

$$\lambda_b = 0.6372 \lambda_t + 127.31$$

with a  $R^2$  value of 0.99

### Porosity

The porosity of coconut kernel calculated from relevant experimental data revealed that the porosity decreased non-linearly from 11.29 to 8.58 % as the moisture content decreased from 94.93 to 6.15 % d.b. It was reported that the porosity increased with the decrease

in moisture content in the case of coffee parchment (Chandrasekhar & Viswanathan, 1999), but decreased in the case of guna seeds (Aviara *et al.*, 1999).

### Angle of repose

Experimentally determined values of angle of repose of coconut kernel are plotted against moisture content as shown in Fig. 3. From this it was observed that the angle of repose increased from 30.24 to 34.67° as the coconut kernel moisture content decreased from 94.93 to 6.15% d.b. respectively. This may be due to the fact that at lower moisture content the coefficient of friction was more thereby increasing the angle of the

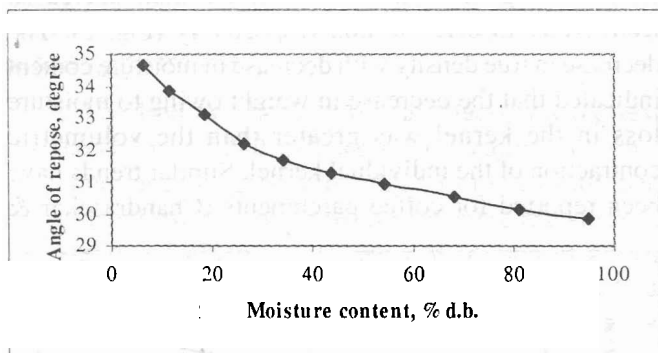


Fig. 3. Effect of moisture content on angle of repose of coconut kernel

cone. Kaleemullah (1992) reported similar type of results in the case of groundnut kernels.

The relationship between angle of repose ( $\theta$ ) and moisture content ( $M$ ) is non-linear and can be expressed as

$$\theta = -1.0099 \ln(M) + 38.148$$

with a  $R^2$  value of 0.99

This property of the nut is essential in determination of relative size of the length and height of an appropriate packaging or storage structure of the material.

### Static and kinetic coefficients of friction

The effects of moisture content and surface nature of materials on the static and kinetic coefficients of friction of coconut kernel are shown in Figs. 4 and 5. The static coefficient of friction on the stainless steel surface (SS) varied from 0.436 to 0.284, on the galvanized iron sheet (GI) from 0.561 to 0.343, on the mild steel sheet (MS) from 0.624 to 0.424 and on the bamboo plywood surface (BPW) from 0.668 to 0.448 while the kinetic coefficient of friction on the stainless surface varied from 0.346 to 0.173, on the galvanized iron sheet from 0.447 to 0.271, on the mild steel sheet from 0.519

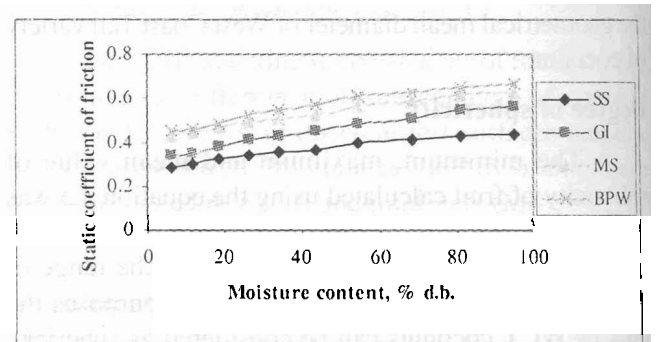


Fig. 4. Effect of moisture content on static coefficient of friction of coconut kernel on different surfaces

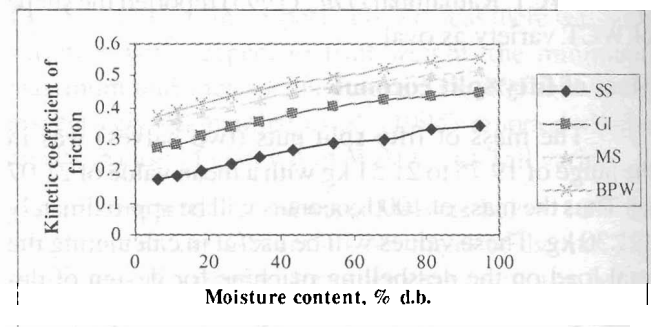


Fig. 5. Effect of moisture content on kinetic coefficient of friction of coconut kernel on different surfaces

to 0.358 and on the bamboo plywood surface from 0.558 to 0.377 for moisture contents between 94.93 and 6.15% d.b., respectively.

The static coefficient of friction at any moisture content on any surface was higher than the kinetic coefficient of friction. Similar type of result was quoted in the case of groundnut kernels (Kaleemullah, 1992). The maximum static and kinetic coefficient of friction were noted on bamboo plywood surface, followed by mild steel, galvanized iron and stainless steel surfaces. Chandrasekhar and Viswanathan (1999) reported that the maximum coefficient of friction was in the case of mild steel surface, followed by galvanized iron, aluminum and stainless steel surfaces, at all moisture contents. Since the static and kinetic coefficient of friction was more in case of mild steel, hence this material can be selected for fabricating copra processing machinery. The coefficient of sliding friction is present during movement of the material and it affects the force which is exerted on the walls of the containing vessel. In the design of silo bins and other storage container for the nut the vertical load on the wall is determined by friction coefficient.

### Conclusion

The investigation of various physical properties

Table 1. Correlation matrix of fruit characteristics of West Coast Tall variety of coconut

Trait	Length of fruit (cm)	Breadth of fruit (cm)	Weight of fruit (g)	Thickness of husk (cm)	Weight of nut (g)	Husk percentage	Thickness of kernel (wet)	Thickness of kernel (dry)	Minimum perimeter (cm)	Weight of copra (g)	Shell weight (g)
Length of fruit (cm)	1										
Breadth of fruit (cm)	0.200	1									
Weight of fruit (g)	-0.025	0.789*	1								
Thickness of husk (cm)	0.440**	0.156	-0.142	1							
Weight of nut (g)	0.003	0.732**	0.931	-0.095	1						
Husk percentage	-0.033	0.560**	0.662	-0.149	0.363**	1					
Thickness of kernel (wet), cm	0.291*	0.029	-0.007	0.322*	-0.005	-0.008	1				
Thickness of kernel (dry), cm	0.283*	0.134	0.120	0.205	0.126	0.077	0.827**	1			
Minimum perimeter (cm)	0.383**	0.501**	0.374**	0.477**	0.355**	0.161	0.381**	0.288*	1		
Weight of copra (g)	0.157	0.382**	0.587**	0.061	0.752**	-0.034	0.080	.179	0.314*	1	
Shell weight (g)	0.033	0.681**	0.761**	-0.042	0.803**	0.349**	-0.142	-0.071	0.311*	0.604*	1

\*\* Correlation is significant at the 0.01 level (2-tailed)

\* Correlation is significant at the 0.05 level (2-tailed)

of coconut revealed the following.

The minimum, maximum and mean length of the fruit was 16.50, 23.50 and 20.14 cm, respectively. The minimum, maximum and mean value of sphericity of fruit was 69.85, 97.0, and 81%, respectively which indicates that West Coast Tall coconut is like a sphere as the values are in the range of 69.85% and above. The bulk density of kernel decreased from 464.23 to 411.67 kg/m<sup>3</sup> when the moisture content decreased from 94.93 to 6.15% d.b. The variation in bulk density was found to be linear with the moisture content. The true density of kernel decreased from 524.36 to 450.32 kg/m<sup>3</sup> when the moisture content decreased from 94.93 to 6.15% d.b. respectively. The angle of repose of kernel increased from 30.24 to 34.67° as the coconut kernel moisture content decreased from 94.93 to 6.15% d.b., respectively. The static coefficient of friction at any moisture content on any surface was higher than the kinetic coefficient of friction within the range studied.

### Acknowledgements

The authors acknowledge the help rendered by Dr. K.Murlidharan, Sr.Scientist in statistical analysis of data and to Dr. C. Palaniswamy, Sr. Scientist for helping in preparing the graphs.

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