# MECHANICAL CHARACTERIZATION OF WHOLE COCONUT SHELL

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***Abstract***
*The article is focused on the description of whole coconut shell under compression loading. The coconuts (Cocos nucifera) were used for this experiment. The coconuts were measured and pressed in longitudinal and latitudinal direction. Compressive force and deformation energy were determined. The compressive force and deformation energy required for coconut extraction are significant smaller in the latitudinal direction.*

***Key words:*** *coconut husk; cracking of coconuts; agriculture product.*

## INTRODUCTION
Being a nutritious and multi usable fruit, coconut is a popular drupe, of a tree with scientific name as “Cocos nucifera”, a member of the family “Arecaceae” (palm family) (*Moore & Howard., 1996*). Like the other fruits, it has three layers: exocarp, mesocarp, and endocarp. The exocarp is the botanical term for the outermost layer of the pericarp (or fruit). It forms the tough and waterproof outer skin of the coconut fruit weighing about 0.025–0.43 kg (*Gulve, Chakrabarty & Vyas, 2009*). The exocarp and the fibrous mesocarp make up the “husk” of the coconut. The mesocarp comprises of fibro vascular bundles of coir embedded in a nonfibrous connective tissue, usually referred as pith (*Khan, 2007*).
Inner stone or endocarp (outside shell), is the hardest part of the nut which has three germination pores that are clearly visible on the outside surface once the husk is removed. The radicle emerges through one of these germination pores when the embryo germinates. Adhering to the inside wall of the endocarp is the testa, with a thick albuminous endosperm (the coconut “meat”), the white and fleshy edible part of the fruit. The shell and husk becomes harder with maturity. The shell has three germination pores (stoma) or eyes that are clearly visible on its outside surface once the husk is removed (*Varghese, Francis & Jacob, 2017*). A thin brown layer (testa) separates the shell from the endosperm (kernel, flesh, meat), which is approximately 1–2 cm thick. A cavity within the kernel contains the coconut water (*Canapi, Augustin, Moro, et al., 2005*).
Only a few researchers studied the physical and mechanical properties of the different varieties of coconut. For example some authors (*Jarimopasa & Kusonb, 2007*) found some physical and mechanical properties of the young coconut for developing the young coconut opening machine. They investigated the size and the shape of the young coconut which include the diameter and the height and also found the mechanical properties which include the shell rupture force and husk moisture content.
For designing the coconut husking machine, it is very important to study the physical and mechanical properties of the coconut (*Varghese, Francis & Jacob, 2017*). The aim of this article is to determine the compressive force and deformation energy for cracking of whole coconut shell.

## MATERIALS AND METHODS
Commercially available old coconuts, the fruits of the coconut tree (*Cocos nucifera*), were used for this experiment. All coconuts were initially centre-drilled to allow removal of coconut water. The dimensions of coconuts were determined using vernier calliper. All obtained results were expressed as mean of three replicates. For measuring of mass of each coconut an electronic balance (*Kern 440–35, Kern & Sohn GmbH, Balingen, Germany*) was used. The mass of nuts were determined without coconut water. To assess the mechanical properties and dimensions, the tests were performed on the both axis of the coconut, in directions analogous to lines of longitude and latitude on a globe (in the “equatorial” region), henceforth labelled “longitudinal” and “latitudinal” (Fig. 1). In total, 50 pieces of coconut, which were randomly divided into five groups (Set 1 – Set 5) were used for this experiment.

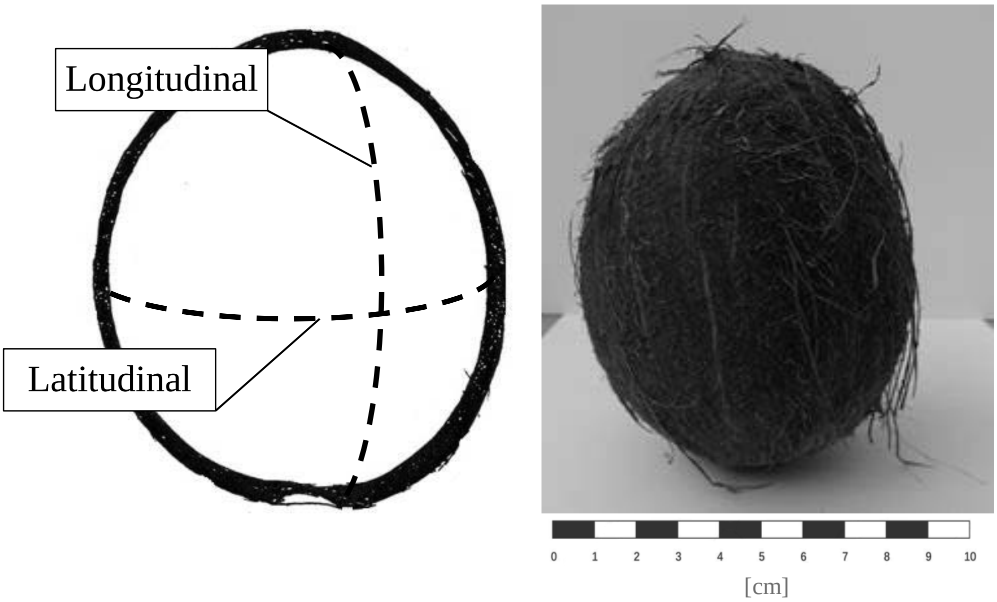


**Fig. 1** Directions of measurement (a), overview of fruit of the coconut tree (Cocos nucifera) (b)

To determine the relationship between compression force and deformation, compression device (*ZDM, model 50, Germany*) was used to record the course of deformation function. The coconuts were measured and pressed in two directions (longitudinal and latitudinal) at the rate of 1 mm.s$^{-1}$ under the temperature of 20 °C. The experiment was repeated twenty-five times for each direction and individual measurements were digitally recorded.

## RESULTS AND DISCUSSION

Individual coconuts were divided into 5 groups (Set 1 – Set 5). The dimensions and masses of each group are shown in Tab. 1. One of the most important tests for designing the coconuts extracting machines is compression test. The compression loading of whole coconuts is presented in Fig. 2. It is observed the compression load is higher in longitudinal direction than that registered in latitudinal direction by 35%. This is attributed to the structure and shape of coconut (*Kadam, Chattopadhyay, Bharimalla, et al., 2014*). The relationship between compression force and deformation of coconuts is presented in Fig. 3.

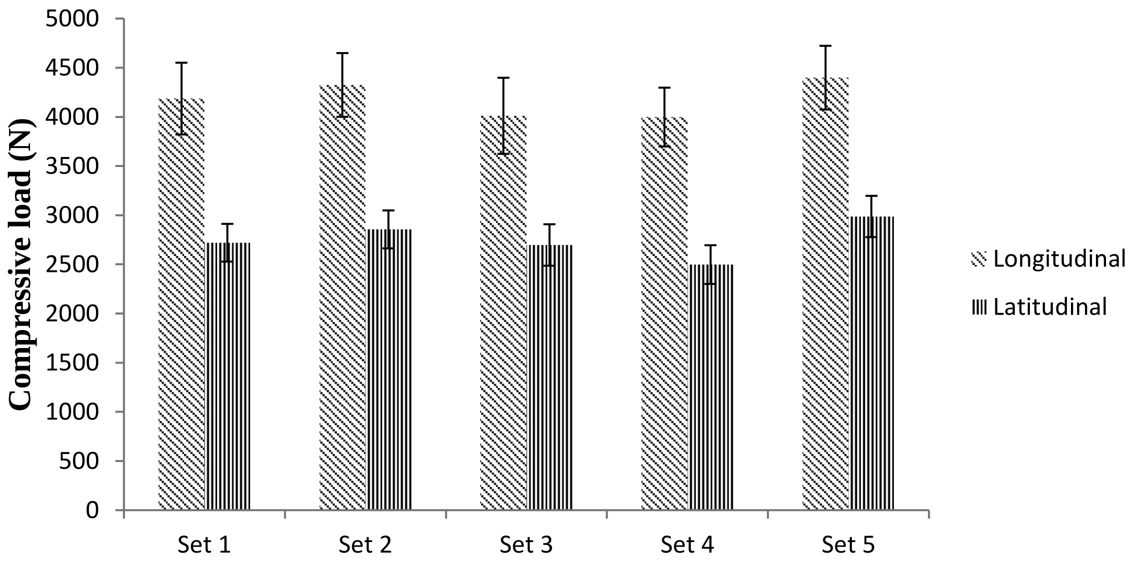


**Fig. 2** Compressive load of coconuts (Cocos nucifera) in two different directions

As is also seen in Fig. 3, the coconuts which are loaded in longitudinal directions reach higher values of deformation energy, which is characterized as an area below a deformation curve.

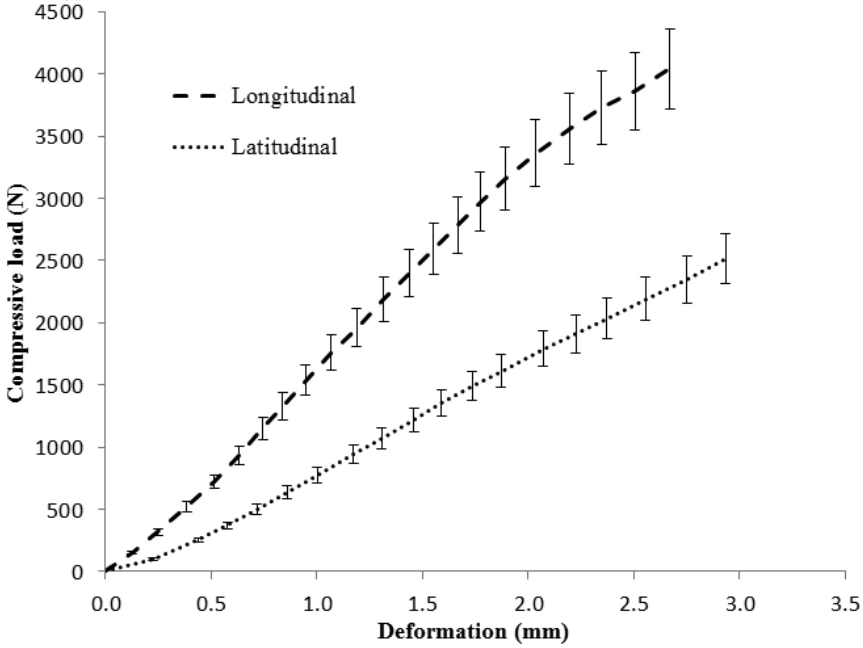


**Fig. 3** Relationship between compression force and deformation of coconuts in two directions

The values of deformation energy of coconuts in two directions are shown in Tab. 1.

**Tab. 1** Physical properties and deformation energy of coconuts (Cocos nucifera)

| Sample | | Longitudinal | | Latitudinal | |
|---|---|---|---|---|---|
| | Mass g | Dimension mm | Deformation energy J | Dimension mm | Deformation energy J |
| Set 1 | 335 ± 17 | 126 ± 4 | 15.86 ± 1.71 | 89 ± 4 | 10.14 ± 1.05 |
| Set 2 | 349 ± 24 | 131 ± 6 | 16.34 ± 1.38 | 95 ± 3 | 10.78 ± 1.02 |
| Set 3 | 310 ± 22 | 124 ± 5 | 15.55 ± 1.47 | 87 ± 3 | 9.47 ± 0.85 |
| Set 4 | 307 ± 17 | 118 ± 7 | 14.47 ± 1.31 | 85 ± 5 | 8.62 ± 0.78 |
| Set 5 | 378 ± 34 | 133 ± 4 | 17.33 ± 1.67 | 97 ± 3 | 10.98 ± 1.06 |

There is a significant difference in the compressive load of longitudinal and latitudinal direction. At first, a two-choice F – test was used for a statistical comparison of particular measured values for an analysis of an agreement of variance. After verifying the agreement of variance, T-test of a significance of differences of two chosen means was subsequently used. The parameters of T-test are shown in Tab. 2.

**Tab. 2** T-test compressive force. Statistical comparison between longitudinal and latitudinal loading of coconuts

| Sample | $T_{stat}$ - | $t_{crit}$ - | $P_{value}$ - |
|---|---|---|---|
| Set 1 | 32.483 | 6.388 | 0.228 |
| Set 2 | 37.141 | 6.388 | 0.228 |
| Set 3 | 33.484 | 6.388 | 0.224 |
| Set 4 | 25.987 | 6.388 | 0.245 |
| Set 5 | 38.456 | 6.388 | 0.274 |

The mechanical behavior of coconut shell was also examined by other authors (*Gludovatz, Walsh, Zimmermann, et al., 2017*). Similar values of compressive force were also determined by other authors (*Kadam et al., 2014*).

## CONCLUSIONS

In the present study, the mechanical properties of coconuts were observed. The deformation energy required for coconut extraction is significant smaller in the latitudinal direction. Therefore, it is recommended that feeding of the shell in the machine should be in the latitudinal direction for ease of coconut cracking.

## ACKNOWLEDGMENT

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