SUMMARY AND CONCLUSION
Coconut production in India increased from 3.4 billion nuts in 1949-50 to 6.0 billion nuts in 1974-75 and further increased to 12.6 billion nuts in 2002. 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. Coconut serves as the basic raw material for a series of agro-processing activities and sustains the livelihood of over 10 million people in the country. In Kerala coconut processing is still being carried out in a traditional way.

The main unit operations in copra processing are de-husking, splitting, de-shelling and drying. In India, coconut is broken transversely into two cups using a traditional knife having a long handle and a sharp splitting edge. In the traditional method of copra making (when the moisture content of copra decreases to about 25-30%, w.b.), copra is scooped out from the shell using a traditional wooden knife. This is done by taking one half cup in hand and scooping out the kernel.

Conventional method of copra drying is sun drying. During rainy season, when sun drying is not possible, drying by artificial method is the only viable solution. Direct type kiln dryers are not desirable as the copra becomes inferior in quality due to smoking and improper drying. All the above said post harvest operations are labour intensive and time consuming and no attempt has been made so far to develop mechanical splitting and de-shelling devices. Also there is a need to develop a small dryer for the farmers which provides even temperature distribution for uniform drying. Studies on physical, mechanical and thermal properties of coconut which are required for designing nut splitting device, de-shelling machine and copra dryer are very less.

Keeping the above mentioned facts in mind, the present study was carried out to analyze the practices adopted and constraints experienced by the farmers and processing
units in splitting, de-shelling and drying of coconut. The objectives were also to determine physical, thermal and mechanical properties of coconut and sorption isotherms of copra and to develop nut splitting device, de-shelling machine and a copra dryer based on thin layer and deep bed drying tests and quality characteristics of copra.

The study was conducted in Kerala state. Three districts, viz., Kasaragod, Ernakulam and Thiruvananthapuram were selected for this study. From each district three panchayats and twenty fanners were randomly selected from each panchayat. Also, 35 coconut farmers adopting small holder’s copra dryer were also included in the study. Besides individual farmers, three large scale processing units situated in Kasaragod and Kannur districts of Kerala state were also included in the study. Data on different methods adopted for splitting, de-shelling and drying were also collected.

The physical properties such as size, shape, mass, bulk density, true density, porosity, angle of repose, static and kinetic coefficient of friction on different surfaces were determined, using standard procedures.

The thermal conductivity of coconut was determined based the following empirical relationship proposed by Anderson (1950) and Sweat (1973)\(^1\) The specific heat of coconut was calculated using the equation proposed by Charm (1971). The thermal diffusivity was calculated indirectly by using the values of thermal conductivity and specific heat. The nut splitting force required to split nuts was found by using a pendulum impact test apparatus. Bevel angles of 15, 20, 25, 30, and 35° were used to find out the best angle of the knife for designing a splitting device.

The calorific values of shell and husk at different stages of maturity were determined using Bomb calorimeter. Equilibrium moisture content of copra was determined both in desorption and adsorption conditions at three temperature levels (25, 35 and 45 °C) and eight relative humidity levels of 11 to 87 % using static method.
A manually operated splitting device was designed and fabricated. A batch type
de-shelling machine was designed and fabricated to hold 200 split nuts (400 halves).
Experiment was conducted to optimize the speed of the de-shelling chamber and moisture
content of copra for maximum de-shelling efficiency.

A laboratory model thin layer dryer was developed to study the drying characteristics
of the coconut. Preliminary experiments were conducted to determine the effect of
temperature on drying characteristics of coconut and to optimize drying air temperature
based on quality characteristics in the temperature range of 50-100 °C and air velocity
of 0.5 m / s. A second experiment was carried out to study the effect of air velocity
viz., 1 and 1.5 m / s at 50 to 100 °C hot air temperatures on drying characteristics of coconut.
Another experiment was conducted to study the drying characteristics of coconut in hot air
oven. The drying air temperature was optimized based on nine point scale developed. Oil
extracted was used to assess the influence of drying temperature on oil output and fatty acid
composition. The fatty acid profile was analysed using Gas Chromatograph.

Three thin-layer drying models viz., Lewis (1921), Hustrulid and Flikke (1959) and
Page (1949) were selected to represent the experimental data of thin-layer drying of coconut
at 50, 60, 70, 80, 90 and 100 °C. An empirical model was developed as standard models
were not suitable to describe experimental data.

The dryer developed for thin-layer drying was modified and used as deep bed dryer
by increasing the depth of the drying chamber from 20 to 40 cm to study the effect of bed
thickness on drying time and to optimize drying air temperature.

A copra dryer was designed and developed to make copra at cheaper cost and in less
time. The capacity of the dryer was 1000 nuts per batch. The fuel used was coconut shell.
The thermal efficiency of the dryer was calculated using standard equation.
The following are some of the main conclusions drawn from the studies carried out on improving engineering aspects of copra processing and optimization of drying parameters in Kerala.

Majority of the farmers interviewed were having more than 25 years of experience in coconut farming. Most of the farmers adopted the traditional knife for splitting and wooden knife for de-shelling coconut. The survey report revealed that 84.7 % farmers would like to have improved devices for splitting and de-shelling.

The survey also revealed that 30.6 % of the farmers adopted the traditional smoke drying, 67.2 % adopted sun drying and 2.2 % adopted indirect method for copra production. Further, 42.8 % farmers wanted to have an improved dryer utilizing locally available material.

The large scale coconut processing plants surveyed had a capacity of 10,000 to 30,000 nuts / day and the nuts were split with a traditional knife and de-shelling was done manually using a wooden knife and improved tools were not used.

The minimum, maximum and mean length of the West Coast Tall variety fruit was 16.50, 23.50 and 20.14 cm respectively. The ANOVA of fruit characteristics of coconuts showed a significant correlation with breadth of fruit, fruit weight, nut weight and shell weight. The bulk density of coconut kernel decreased from 464.23 to 411.674 kg / m$^3$ when the moisture content decreased from 94.93 to 6.15 % d.b. The mean values of bulk density of fruit, de-husked nut, split coconut cups, copra and husk varied was 263.57, 487.78, 491.97, 411.67 and 111.83 kg / m$^3$, respectively.

Regression equation relating to the variation in bulk density ($p_b$) and moisture content ($M$) of copra was established as

$$p_b = 0.5541 M + 412.32$$

The true density of copra decreased from 524.364 to 450.316 kg / m$^3$ when the moisture content decreased from 94.93 to 6.15 % d.b. The variation of true density of copra
(\(p_t\)) was found to be linear with the moisture content (M) and can be represented by the following regression equation developed

\[ p_t = 0.8696M + 447.29 \]

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

\[ p_b = 0.6372p_t + 127.31 \]

Angle of repose of copra increased from 30.24 to 34.67 \(^\circ\) as the coconut kernel moisture content decreased from 94.93 to 6.15 % d.b. The relationship existing between angles of repose (\(\theta\)) and moisture content (M) is non-linear and can be expressed as

\[ \theta = -1.0099 \ln (M) + 38.148 \]

The static coefficient of friction on the stainless steel surface varied from 0.436 to 0.284, on the galvanized iron sheet from 0.561 to 0.343, on the mild steel sheet from 0.624 to 0.424 and on the bamboo plywood surface from 0.668 to 0.448 while the kinetic coefficient of friction on the stainless steel surface varied from 0.346 to 0.173, on the galvanized iron sheet from 0.447 to 0.273, on the mild steel sheet from 0.519 to 0.358 and on bamboo plywood surface from 0.558 to 0.377 for moisture content between 94.93 and 6.15 % d.b., respectively.

The thermal conductivity values obtained in the moisture range varying from 94.93 to 6.25 % d.b. was found to lie between 0.358050 and 0.280249 W/ m K. The specific heat of coconut kernel in the moisture range varying from 6.15 to 94.93 % w.b. was found to vary from 1425.246 to 2344.710 J/ kg K, respectively. The thermal diffusivity of coconut kernel in the moisture range varying from 94.93 to 6.25 % d.b. was found to lie between
A relationship between thermal diffusivity, \( a \) (m\(^2\) / s) and moisture content, \( M \) (w.b.) can be expressed as

\[
a = -9E-08 \ln (M) + 2E-07
\]

The rate of increase of total surface area of coconut was linear throughout the fractionation range studied. Regression equations were developed for surface area and weight of kernel, copra weight and nut weight and nut weight and shell weight.

Regression equation relating to the fractionation (F) and surface area (SA) of kernel was established as

\[
SA = 0.0016 F + 0.0477
\]

The following regression equation was obtained with respect to weight (W)-surface area (SA) relationship of square shaped kernel pieces

\[
SA = 0.2677 W + 0.0006
\]

Copra weight (Y) - nut weight (X) relationship is represented by the following regression equation

\[
Y = 0.25^X + 63.636
\]

A regression equation to predict the shell weight (Z) with respect to nut weight (X) is represented by the following regression equation

\[
Z = 0.2696^X + 20.03
\]

The thickness of the shell along the equatorial circumference opposite to all the eyes varied between 2.9 and 7.3 mm. The relationship between measurements on the thickness of the shell opposite to the three eyes was explored by fitting different curves such as linear, quadratic, logarithmic and exponential. In both the cases, the linear fit was found to be the best based on the R\(^2\) value. Linear equation fitted for shell thickness opposite to the larger eye (Y) to the thickness opposite to other eyes (X) was established as

\[
Y = 1.3833 + 0.8721 X \text{ (least thickness opposite to other two eyes)} \text{ and}
\]

\[
Y = 1.1433 + 0.8669 X \text{ (intermediate thickness observed opposite to other two eyes)}
\]
The mean calorific value of coconut shell of fully matured, matured and immature nut was 4640, 4290 and 2150 kcal / kg, respectively. The mean calorific value of husk of fully mature, mature and immature nut was 2500, 2200 and 1460 kcal / kg, respectively.

The EMC values of copra decreased with increase in surrounding air temperature in both adsorption and desorption at constant ERH. The adsorption and desorption isotherms exhibited the phenomenon of hysteresis, in which the EMC was higher at a particular ERH for desorption curve than for adsorption. The adsorption and desorption EMC of copra at 25, 35 and 45 °C were varying between 10.6 and 11.2 % d.b. at RH greater than 84 %.

A simple manually operated nut splitting device was designed, fabricated and performance evaluated. From the results, it was concluded that 25° bevel angle of the knife was found better than other angles studied for splitting the nuts. The splitting force required to split the nut was in the range varying from 0.155 to 0.456 N. The capacity of splitting device was 514 nuts / h. The cost of the device was Rs 2000 and the cost of splitting 1000 nuts was Rs.5.00.

A power operated de-shelling machine was designed and developed. The capacity of the machine was 200 nuts per batch. The horse power required to rotate the cylindrical de-shelling chamber at 10 RPM was calculated as 3.0. The optimum average moisture content for maximum de-shelling efficiency (92.16 %) was 35 % d.b.

Relationship between moisture content (M) and de-shelling efficiency ($D_e$) is non linear and can be represented by the following regression equation

$$D_e = 215.46 \exp^{-0.0338 \cdot M}$$

The optimum speed of the de-shelling machine was 10 RPM and the time taken for de-shelling was four minutes per batch.

Relationship between number of rotations (R) and de-shelling efficiency ($D_i$) is non linear and can be represented by the following regression equation

$$D_i = 45.4791 \ln(R) - 78.044$$
The cost of de-shelling machine was worked out to be Rs. 27100. The cost of de-shelling 1000 nuts was worked out using standard procedures and found to be Rs. 53.00 / 1000 nuts. The cost involved in deshelling using human labour was Rs. 36.00 / 1000 nuts but the time taken is more than four times as compared to machine. Hence the use of de-shelling machine will reduce the drying time drastically and improve the quality of copra.

From thin layer drying studies at constant air velocity of 0.5 m/s the drying air temperature was optimized as 80 °C. Duncan’s Multiple Range Test for grouping the effect of air velocity (0.5 to 1.5 m/s) at different drying air temperature (50 -100 °C) in thin layer drying indicated no significant difference on drying time. The results indicated that drying air temperatures up to 80 °C does not have any effect on quality characteristics of copra. The optimized drying air temperature of 80 °C was based on the maximum score obtained on the basis of nine point scale developed. The fatty acid composition did not vary significantly due to change in copra drying temperature in the range of 40 to 110 °C. The fatty acid composition of coconut oil observed in this experiment followed the typical fatty acid composition of coconut oil.

Lewis, Hustrulid and Flikke and Page model failed to describe the moisture ratio in thin layer drying and hence new regression models were developed. The best fitted model was selected based on variability explained by a model, the pattern of residuals, standard error of estimates (E_s) and mean relative percentage deviation (E_m). Based on the lowest values of the statistics E_s and E_m, and pattern of residuals the best fitted model was selected for each temperature. Except for 50 °C, the best fitted model was a sum of two Hustrulid and Flikke models as given below

\[ MR = A \exp(-kx) + B \exp(-lx) \]
After fitting models at different temperatures, a general model that characterizes the moisture ratio at any temperature between 50 to 100 °C was also proposed. The proposed model is given below

\[ MR = A \exp(-la) + B t \exp(-l/x) + C t^2 \exp(-mx) \]

From the deep bed drying tests conducted it was found that for the optimized air temperature of 80 °C; the optimum bed thickness was 30 cm.

The standard models viz., Lewis, Hustrulid and Flikke and Page failed to describe the moisture ratio in different layers of deep bed drying and hence new empirical models have been developed. Except for 40 cm depth, the best fitted model for describing moisture ratio was a linear combination of two Hustrulid and Flikke models which is given below

\[ MR = A \exp(-kx) + B \exp(-lx) \]

A copra dryer was designed and developed and performance evaluated to dry coconut in 24 h. The capacity of the dryer developed was 1000 nuts per batch. The drying air temperature in the drying chamber was 80 °C. It took 22, 21, 26 and 25 h to dry coconut from the average initial moisture content of 90.14, 88.34, 92.12 and 86.23 to 6.25 % d.b., respectively in the four replicate tests conducted at full load. The quality of copra obtained was light brown in colour. The burner designed generated heat for 5 hours without tending and the heat is retained for one more hour.

The oil content was in the range of 62.48 to 63.55 % indicating no loss of oil for the copra dried at drying air temperature of 80 °C. The average free fatty acid content was 0.0865 %. The average acid value, peroxide value and saponification number were 0.265, 0.3375 and 253, respectively.

The thermal efficiency of the dryer at full load was in the range of 25.25 to 26.48 % but decreased when the load was reduced to half to 9.41 %. Heat utilization factor was in the range of 0.13 - 0.19 and the coefficient of performance was in the range of 0.81 - 0.86
Monthly variation of mean ambient relative humidity, rainfall, temperature and sunshine hours based on monthly means from the year 1974 to 2002 was evaluated for suggesting drying zones for the farmers. The higher value of relative humidity i.e. above 80 % exists throughout the year in the forenoon session and the RH is above 80 % during the period June to August. During the same period the rainfall was above 700 mm / month and bright sun shine hours are about three hours only and the maximum temperature was in the range of 28.6 to 30 °C. Thus during the three months (June to August) copra drying in open sun was found impossible. Copra dryer developed can be most effectively used during the above mentioned period.

The copra dried in sun and stored for one month at room temperature had $22.0 \times 10^6$ bacteria, $77.0 \times 10^4$ fungi and $11.0 \times 10^3$ actinomycetes cfu / g of copra. The microbial analysis clearly indicated that copra dried in smoke dryer and dried in sun and stored at room temperature for 3 months was highly contaminated with fungi and actinomycetes whereas the same treatment for one month and two months period has lower levels of microbial population. The copra dried in copra dryer and stored for 1, 2 and 3 months has less microbial growth as compared to copra dried in smoke dryer.

The dryer developed as compared to the most commonly used small holder’s dryer has the main advantage of feeding fuel once in 6 h which was one of the major constraints reported by farmers. The other advantage is that the drying air temperature is kept at 80 °C which reduced the drying time by 12.5 h as compared to small holder’s dryer. Though the cost of dryer developed is double the cost of small holder’s dryer the capacity is more than doubled. The thermal efficiency is also found comparatively higher in the newly developed dryer.

Lewis, Hustrulid and Flikke and Page model failed to describe the moisture ratio and hence new regression models were developed. The best fitted model of moisture ratio of the
The cost of the dryer was estimated to be Rs. 15,000.00. The cost involved to dry one kilogram of copra in the copra dryer was worked out and found to be Rs. 5.33. The cost of drying one nut excluding the cost of nut works out to be Rs. 0.93.

dryer developed is a polynomial of order three which explained variation completely. The proposed model is

\[ MR = b_0 + b_1x + b_2x^2 + b_3x^3 \]
SUGGESTIONS FOR FUTURE LINE OF WORK

1. The physical, mechanical and thermal properties and sorption isotherm of copra of different varieties of coconut can be taken up to study the difference, if any.

2. The splitting device developed can be modified by using compression techniques for splitting nuts using power, so that the capacity can be increased to about 2000-2500 nuts / h.

3. The power operated de-shelling machine developed can be provided with automatic loading and unloading facility using conveyor belt mechanism. A vibrator can also be provided for separating the copra and shell.

4. The copra dryer developed can be scaled up to dry 10000 nuts / batch so that large processing units can also utilize the technology.