DEVELOPMENT OF A DECORTICATOR FOR NUTMEG (*Myristica fragrans* Houtt.)

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This flower of my life affectionally dedicated to

"AGRONEERS"

DEPARTMENT OF AGRICULTURAL ENGINEERING
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CERTIFICATE

This is to certify that the thesis entitled **"DEVELOPMENT OF A DECORTICATOR FOR NUTMEG (*Myristica fragrans* Houtt.)"** submitted in partial fulfillment of the requirements for the degree of **Master of Technology (Agricultural Engineering)** in **Post Harvest Process and Food Engineering** to the University of Agricultural Sciences, Bangalore, is a record of bonafide research work carried out by **Mr. Said Prashant Pandharinath, ID NO. PAK 9307** under my guidance and supervision and that no part of this thesis has been submitted for the award of any degree, diploma, associateship, fellowship or other similar titles.

……………………………………

Bangalore
July, 2011

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DEVELOPMENT OF A DECORTICATOR FOR NUTMEG (*Myristica fragrans* Houtt)

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ABSTRACT

Nutmeg (*Myristica fragrans* Houtt.) has been used as natural food flavouring in baked goods, syrups, beverages, savory dishes and sweets. The essential oil obtained from nutmeg is used heavily in the cosmetics and pharmaceutical industries. Nutmeg and Mace are two different parts of same fruit of the nutmeg tree - *Myristica fragrans* Houtt. The fruits are pendulous, broadly pyriform, yellow, smooth, 7-10cm long, fleshy splitting open into two halves when ripe, showing the ovoid 2-3cm long dark brown shining seed with hard seed coat, surrounded by a glaciate red aril attached to the base of the seed. The process of decortication of nutmegs to separate kernels is done manually using a hammer or mechanically a cracking device. The traditional decortication process is time and labour consuming. To address this power operated nutmeg decorticator was developed and its performance was evaluated. The developed nutmeg decorticator consisted of a cylinder and a concave. The cylinder was made up of mild steel angle flats of size 24.8×1.9cm and a rubber of thickness 0.5cm was fixed on to these flats to establish impact to the nuts. While the concave was fabricated using 6 mm size M.S. rods. The length of concave was 25cm with slotted opening size of 7.7×1cm. The developed decorticator had the decortication efficiency, total recovery, breakage and capacity of 98.11, 63.92, 3.08 per cent and 56.59 kg/h, respectively, at a cylinder speed 450 rpm. The cost of decorticating 1kg of raw nutmegs at 12% moisture content was ₹ 0.79, only. The cost benefit ratio of the developed decorticator was 1:1.19.

Said Prashant Pandharinath

(M. V. Ramakumar)
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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations /Symbols	Description
%	per cent
/	per
=	equal to
±	plus or minus
˚C	degree Celsius
cm	centimeter
d.b	dry basis
dia.	diameter
e.g.	Example gratia (For example)
et al.	And others
etc.	et cetera
Fig.	Figure
g	gram
h	hour
ha	hectare
hp	horse power
i.e.	id est. (That is)
kg	kilogram
m	meter
m.c.	moisture content
min.	minute
ml	milliliter
mm	millimeter
MT	metric tonnes
No.	Number
qtl	quintal
rpm	revolution per minute
₹	Rupees

s	second
SE	Standard Error
viz.,	namely
w.b	wet basis
Π	pi (= 22/7)

Introduction

I. INTRODUCTION

Nutmeg (*Myristica fragrans* Houtt.) is an important tree spice which produces two distinctly different spices, namely, nutmeg and mace. Nutmeg is the kernel of the seed and mace is the dried aril that surrounds the single seed within the fruit. Nutmeg belongs to a small primitive family Myristicaceae with 18 genera and 300 species.

Nutmeg is an evergreen tree with beautiful architecture. It is conical tree reaching a height of 4 to 10 m. The tree is dioecious with male and female flowers occurring on different trees (Plate 1.1). The fruits are pendulous, broadly pyriform, yellow, smooth, 7-10 cm long, fleshy splitting open into two halves when ripe, showing the ovoid 2-3cm long dark brown shining seed with hard seed coat, surrounded by a glaciate red aril attached to the base of the seed. The seed of nutmeg is large with ruminate endosperm (Krishnamoorthy *et al.*, 2004).

Nutmeg is a native of Moluccas (North-West Borneo) and parts of South-East Asia. Nutmeg performs well under humid tropical climate and can be grown up to an elevation of 1000 m above MSL. A well-distributed rainfall of 150-250 cm and annual mean temperature of 20-30^{0}C are ideal for nutmeg. It is grown in clays in Malaysia and volcanic loams in Moluccas. Well-drained soils having inadequate moisture may be avoided. Areas with soils of clay loam, sandy loam and red laterite are ideal for nutmeg (Pruthi and Satyavarti, 1985). The major nutmeg growing areas are Indonesia and Grenada (West Indies). It is also grown on a smaller scale in India, Sri Lanka, China, Malaysia, Western Sumatra, Zanzibar, Mauritius and the Solomon Islands. In India, nutmeg plantations are at Courtallam of Tirunelveli, Burlier on eastern slopes of Nilgiris in Tamil Nadu, Ernakulam, Kottayam, and Thiruvanadapuram in Kerala state. It is also cultivated

Plate 1.1 : NUTMEG TREE

on small scale in Andhra Pradesh, Assam, Karnataka, Goa and Konkan region of Maharashtra state.

Grenada produces over 23 per cent of the world's nutmeg, which is second to Indonesia which produces 73 per cent of the world's nutmeg. In India, there are two crop seasons for nutmeg. The first begins in April–May and ends by August, being the main season. The next is December-January. In the year 2008-09, the production of nutmeg was 3,200 tonnes. The extra-hot summer of 2009 had hit the production and so did a weak winter in December–January. The production is estimated to be 2,500-2,600 tonnes only from the area of about 13709 ha (Joseph, 2010). The production of nutmeg in the country is still insufficient to meet the demand of the nation and hence a substantial quantity is imported causing a huge loss of valuable foreign exchange (Rema *et al.*, 1997). In Konkan region of Maharashtra, Portuguese introduced nutmeg in some pockets. However, its cultivation remained neglected since long. In late 70's, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth (BSKKV) initiated research work on this crop with the main aim to test its performance as a mixed crop in coconut plantations. It was reported that nutmeg is a good mixed crop in coconut plantation in comparison with other tree spices. The planting of nutmeg in coconut was found to increase the productivity of coconut plantation by about 84 per cent, resulting in high levels of profit from the nutmeg and coconut combination.

The nutmeg seed kernel is rich in various quality parameters such as moisture (40%), protein (7.16%), ether extract (36.4%), carbohydrates (28.5%), fiber (11.7%), mineral matter (1.7%), calcium (0.12%), phosphorus (0.24%) and iron (4.6mg/100g). The principle constituents of nutmeg are fixed oil (fat), volatile oil and starch. The flavour and therapeutic action is due to the volatile oil whose content varies from 6 to 16 per cent based on the origin and quality of nutmeg

(Gopalakrishnan, 1992). The commercial nutmeg butter is usually obtained by pressing ground and cooked or steamed kernels rather than by extraction and yield is 24.30 per cent. It is a solid yellowish red fat possessing the nutmeg colour. Nutmeg fat contains eight fatty acids, myristic acid forming the major constituent. The mace contains moisture (40%), protein (9.91%), ether extract (24.4%), carbohydrate (47.8%), phosphorus (0.10%) and iron (12.6mg/100g). The oil closely resembles nutmeg, but in much smaller amount (Gopalakrishnan, 1992). The general composition of nutmeg and mace are given in Table 1.1.

Table 1.1 Compositions of Nutmeg and Mace

Composition	Nutmeg	Mace
Moisture (%)	40.00	40.00
Volatile oil (%)	11.00	15.30
Non-volatile oil (%)	33.60	21.98
Starch (%)	30.20	44.05
Sugar		
Glucose (%)	0.10	0.17
Fructose (%)	0.07	0.10
Total reducing sugar (%)	0.17	0.27
Sucrose (%)	0.72	0.39
Total sugars (%)	0.89	0.65
Protein (%)	7.16	9.91
Crude fiber (%)	11.70	3.93
Total ash (%)	2.57	1.56
Ash insoluble in HCl (%)	0.20	0.15
Polyphenols		
Total tannins (%)	2.50	-
True tannins (%)	1.00	-

Source: M. Gopalakrishnan, 1992

In Indian cuisine, nutmeg is used in many sweet as well as savory dishes (predominantly in Mughlai cuisine). It is known as *Jaiphal* in most parts of India and as Jatipatri and *Jathi* seed in Kerala. It may also be used in small quantities in garam masala. Ground nutmeg is also smoked in India. The essential oil is obtained by the steam distillation of ground nutmeg and is used heavily in the perfumery and pharmaceutical industries. The nutmeg oil is colourless or light yellow and contains numerous components of interest to the oleo chemical industry and is used as natural food flavouring in baked goods, syrups, beverages, and sweets. The essential oil is also used in the cosmetic and pharmaceutical industries, for instance, in toothpaste, and as a major ingredient in some cough syrups. In traditional medicine nutmeg and nutmeg oil were used for illness related to the nervous and digestive systems (Pruthi, 1998).

Alcoholic extracts of nutmeg show antibacterial activity against micrococcus and cockroaches. Myristicin present in the kernel may be employed as an additive to pyrethrum to enhance the toxicity of the latter to houseflies. The volatile oil from the leaf has weedicidal properties. It may also be used for scenting soaps, dentifrices, chewing gums and tobacco. It is not produced on a commercial scale. The pericarp or rind of the ripe fruit is locally used in pickles; it is also used in the preparation of jellies. In Malaysia, half ripe fruits are preserved in the sugar. The nutmeg rind was found to be a rich source of good quality pectin (12.14%) after suitable processing/curing. The rind was also used in the manufacturing of beverages, jelly, candy, jam, mixed jam and in canned fruit cocktail, oil and vinegar. (Pruthi and Satyavarti, 1985)

Nutmeg fruits are harvested when they split open on ripening. The split of fruits are either plucked from the tree with a hook bill or are collected soon after they drop onto the ground. Nutmeg is dried in large trays by various procedures. The unshelled nutmeg is dried in about a week. The seed cover removed by breaking the hard coat manually by a hammer or mechanically using a cracking device. Seed coat is cracked and removed by hand. The decortications of nuts using these processes are arduous and time consuming. This also increases the cost of kernels i.e. shelled nuts as well as final processed product. In industry, manual decortication of nutmeg causes delay in final product manufacturing. To address the above, a mechanical decorticator is needed to decorticate the nuts and to separate kernels. In this context, the research study on “Development of a Decorticator for Nutmeg (*Myristica Fragrans* Houtt.)” was carried out with following objectives:

1. To study the physical and engineering properties of nutmeg seed
2. To study the different pre-treatments for shell softening and breakage of nutmeg
3. To develop a mechanical decorticator for separation of kernels from nuts
4. To work out the cost economics

Review of Literature

II. REVIEW OF LITERATURE

In view of the objectives of the present investigation, it was necessary to review the literature on the methods that were being used in the past as well as that are presently for decortications of nutmeg and similar kind of nuts such as cashew nut, ground nut, fababeans, jatropha, almond, etc. The literature reviewed on methods and equipments are presented in this chapter.

2.1. Physical Properties

Mohsenin (1970) stated that the increasing economic importance of food material for their handling, storage, processing, preservation, quality evaluation, distribution and marketing, and utilization, a better knowledge of the physical properties of these material are essential to understand. The physical laws governing the response of material to machines, process and handling operations could be designed for maximum efficiency and highest quality of the end product.

Kachru *et al.* (1994) reported that the measurement of engineering properties of food grains were parameters of great importance for analysis behavior of grains during handling, drying, processing storage and designing machinery.

2.1.1. Size

Waziri and Mittal (1983) studied the design related physical parameters of selected agricultural products. The roundness and sphericity were important parameters that determine the geometric shape of agriculture products. The major, minor and intermediate diameters of agricultural products may be determined by the over head projection method for small seeds and grains, and by the vernier calipers/micrometer screw gauge method for comparatively larger seeds, grains, fruits and vegetables.

Shepherd and Bhardwaj (1986) observed non-linear relationship between kernel volume and moisture content of pigeon pea. The best defined approximate shape was found to be prolate spheroid with an effective diameter of 4.83 mm and roundness about 80 per cent at 14.7 per cent moisture content (d.b.).

Oloso and Clarke (1993) reported that the cashew nut was generally kidney shaped with 30 mm long, 22 mm wide and 17 mm thick. It corresponded to edible kernel which was covered by reddish brown testa and a shell. The kernel which fitted tightly into the shell had a mean size of about 24 mm long, 16 mm wide and 12 mm thick indicating fairly uniform shell thickness of about 3 mm.

Visvanathan *et al.* (1996) determined the physical properties of neem nut in the moisture range of 7.6 per cent to 21 per cent (w.b.). The length and stem-end diameter of the nut ranged from 12.87 to 16.20 mm and 6.86 to 8.52 mm, respectively.

Balasubramanian (2001) evaluated the physical properties of raw cashew nut as a function of moisture content. The values of average length, width and thickness of raw cashew nuts at a moisture content of 8.46 per cent (d.b.) were 31, 22.86 and 16.91 mm, while the corresponding values of kernels were 24.67, 12.99 and 12 mm, respectively. About 52 per cent of the nuts had lengths between 30 and 35 mm, whereas 11.5 and 36.5 per cent of nuts categorized under >35 and <30 mm, respectively. The average unit mass values of the nut and kernel were 5.96 and 1.89 g, respectively. The values for average sphericity of raw cashew nut and kernel at a moisture content of 8.46 per cent (d.b.) were found to be 0.747 and 0.633, respectively.

Baryeh (2001) evaluated the physical properties of Bambara groundnut as a function of grain moisture content varying from 5 per cent to 35 per cent (w.b.). In this moisture range, grain length, width, thickness and geometric diameter increased from 10.5 to 14.65 mm, 9.48 to 11.65 mm, 8.50 to 10.90 mm and 9.65 to 12.55 mm, respectively.

Aydin (2002) evaluated the physical properties of hazel nuts and kernels as function of moisture content. The average length, width, thickness, the geometric mean diameter, sphericity, unit mass and volume of nuts were 18.03, 18.97, 16.58, 17.83 mm, 97.58 per cent, 2.41 g and 1.92 cm^3, respectively. The corresponding values for kernels were 14.31, 13.23, 12.68, 13.38 mm, 93.57 per cent, 1.09 g and 1.15 cm^3, respectively.

Kaleemullah and Gunasekar (2002) determined physical properties of areca nut kernels in the moisture range from 88.91-10.51 per cent (d.b.). The kernel shape can be treated as an ovate. As the moisture content decreased from 88.91 to 10.51 per cent (d.b.) the dimension of the major, medium and minor axis decreased by 10.45, 10.49 and 22.84 per cent, respectively. The mean values of roundness and sphericity of kernel decreased by 5.69 and 8.13 per cent, respectively, as moisture content decreased from 88.91 to 10.51 per cent (d.b.).

Olaniyan and Oje (2002) studied some aspects of the physical properties of shea nut. The mean size of nut was about 35 mm long, 25 mm wide and 23 mm thick. Inside the nut kernel was about 29mm long, 23 mm wide and 21 mm thick. It had fairly uniform shell of about 1 mm thick.

Aydin (2003) evaluated several physical properties of almond nut and kernel as functions of moisture content. The average length, width, thickness, the geometric mean diameter, unit mass and volume of nuts were 25.49, 17.03, 13.12, 18.13mm, 2.64g and 2.61cm^3 respectively. Corresponding values for kernel were 21.19, 14.34, 6.38, 11.42mm, 0.69g and 0.71cm^3, respectively.

Omobuwajo *et al.* (2003) stated that the physical properties often required for the designing of cleaning and dehulling grain processing machineries were determined for calabash nutmeg seeds, at moisture content of 7.67 per cent (w.b.). The average of each of the three principal diameters and seed mass were 18.1, 13.7, 12.4 mm and 1.18 g, respectively. Mean values for sphericity and roundness were 67.97 per cent and 64.27 per cent.

Ozguven and Vursavus (2005) determined selected physical properties of pine (*Pinus pinea*) nut at a moisture content of 5.48 per cent (d.b.). The average of each of the three principal diameters, geometric mean diameter and nut mass were 18.67, 8.97, 7.39, 10.72mm and 0.77 g, respectively.

Pliestic *et al.* (2005) determined various physical properties of filbert nut and its kernel as function of moisture content. The average length, width, thickness, equivalent diameter, unit mass, volume and sphericity of nuts were 25.32, 20.54, 17.93, 20.96mm, 3.88g, 4.88cm^3 and 82.86 per cent, while corresponding values for kernels were 20.20, 14.52, 12.64, 15.41, 15.41mm, 1.70g, 1.94cm^3 and 77.02 per cent, respectively, at a moisture content of 6.19 per cent (w.b).

Kashaninejad *et al.* (2006) determined some physical and aerodynamic properties of pistachio nut and its kernel in order to design processing equipment and facilities. In the study, several physical properties of pistachio nut and its kernel were evaluated as a function of moisture content in the range of 4.10–38.10 per cent (w.b). The length, width, height, shell splitting and unit mass of pistachio nut ranged from 16.07 to 17.25 mm, 12.41 to 12.75 mm, 10.98 to 12.24 mm, 3.59 to 4.47 mm and 0.90 to 1.30 g, respectively as the moisture content increased. The respected value for pistachio kernel varied from 15.21 to 16.22 mm, 9.11 to 10.53 mm, 8.73 to 9.66 mm and 0.51 to 0.80 g, respectively.

Aydin (2007) evaluated some physical properties of peanut fruit and kernel as functions of moisture content. At the moisture content of 4.85 per cent (d.b.); the average length, thickness, width, geometric mean diameter and sphericity were 44.53mm, 15.71mm, 16.68mm, 23mm and 51.60 per cent, respectively. Corresponding values for kernel at the moisture content of 6 per cent (d.b) were 20.95mm, 8.80mm, 10.44mm, 12.60mm and 57.05 per cent, respectively.

2.1.2. 100 seeds and kernels mass

Fraser *et al.* (1978) found that the thousand grain mass of fababean was 405 g at 8.5 per cent moisture content (w.b).

Balasubramanian (2001) reported that the 100 nut mass of raw cashew nut varied from 610.6 to 735.1 g at a moisture content of 8.46 per cent and increased linearly with increase in moisture content.

Kaleemullah and Gunsekar (2002) found that 100 kernel mass of areca nut were 1.159 and 0.594 kg at moisture content ranging from 88.91 and 10.51 per cent (d.b.), respectively.

Aviara *et al.* (2005) determined the physical properties of *Balanites aegyptiaca* nuts as a function of moisture content. For oblong nuts, in the moisture range of 4.72-26.35 per cent (d.b.), the one thousand nut mass of the oblong nuts increased from 2.39 to 3.33 kg. For spheroidal nuts, in the moisture range of 4.71-24.18 per cent (d.b.), the one thousand nut mass increased from 2.26 to 3.11kg.

2.1.3. True density and bulk density

Fraser *et al.* (1978) found that the bulk density of fababeans decreased with increase in moisture content. It decreased from 850kg/m^3 at 8.5 per cent moisture content (w.b.) to 730kg/m^3 at 34.8 per cent moisture content (w.b.).

Shepherd and Bhardwaj (1986) found the bulk and true densities of pigeon pea at the moisture range 6.3 to 28.2 per cent (d.b.) and observed that they decreased linearly from 806 to 745kg/m^3 and 1305 to 1251kg/m^3, respectively.

Balasubramanian (2001) observed that the bulk density of cashew nut decreased from 624.2 to 591.9kg/m^3 as the moisture content increased from 3.15 to 20.06 per cent (d.b.). The true density of nuts followed a linear correlation with moisture content. It increased from 1201 to 1240kg/m^3 as the moisture content increased from 3.15 to 20.06 per cent (d.b.).

Baryeh (2001) found true and bulk densities of Bambara groundnut and was found that they decreased from 1.285 to 1.160g/cm^3 and from 0.795 to 0.696g/cm^3 in the moisture range of 5 to 35 per cent (w.b.).

Aydin (2002) evaluated the physical properties of hazel nuts and kernels as function of moisture content. In the moisture range from 2.87 to 19.98 per cent (d.b), for the rewetted nut the bulk density decreased from 383 to 305kg/m^3, true density from 727 to 674kg/m^3, porosity increased from 47.23 to 48.85 per cent. For the kernel, the corresponding values were 458-539, 887-948kg/m^3 and 43.38-44.85 per cent, respectively.

Aydin (2003) carried out studies on re-wetted almond nut at the moisture range from 2.77 to 24.97 per cent (d.b) and showed that the bulk density decreased from 655 to 525kg/m^3, true density increased from 1015 to 1115kg/m^3, porosity increased from 35.32 per cent to 53.21 per cent. For the kernel, the corresponding values changed from 595 to 475kg/m^3, 900 to 995kg/m^3, 34.23 per cent to 50.29 per cent, respectively.

Omobuwajo *et al.* (2003) stated true density and bulk density of calabash nutmeg seeds were 833.2 and 429.4 kg/m^3, respectively.

Aviara *et al.* (2005) determined the physical properties of *Balanites aegyptiaca* nuts as a function of moisture content. For oblong nuts, in the moisture range of 4.72-26.35 per cent (d.b.), the bulk density decreased from 536.35 to 521.60 kg/m^3. For spheroidal nuts, in the moisture range of 4.71-24.18 per cent, the bulk density decreased from 546.90 to 532.66 kg/m^3.

Ozguven and Vursavus (2005) determined selected physical properties of pine (*Pinus pinea*) nut at a moisture content of 5.48 per cent (d.b). The true density and bulk density were 983.59 and 619.85kg/m^3, respectively.

Pliestic *et al.* (2005) determined various physical properties of filbert nut and its kernel as function of moisture content. In the moisture range from 6.19 to 28.71 per cent (w.b.), studies on the rewetted nut showed that the bulk density of nut and kernel decreased from 530 to 454kg/m^3, and 649 to 569kg/m^3, respectively. The true density of nut and kernel decreased from 907 to 829kg/m^3, while for kernel, it decreased from 1016 to 937kg/m^3.

Studies on rewetted peanuts showed that the bulk density decreased from 243 to 184kg/m^3 and the true density increased from 424 to 545kg/m^3, respectively as the moisture content increased from 4.85 per cent to 32.00 per cent (d.b); for the kernel, the corresponding values changed from 581 to 539kg/m^3 and 989 to 1088kg/m^3, respectively as the moisture content increased (Aydin, 2007).

Burubai *et al.* (2007) investigated Physical and properties of African nutmeg (*Monodora myristica*), a wild perennial edible plant, at a moisture content level of 4.93 per cent (d.b.). The true density and bulk density were found to be 830 and 488kg/m^3, respectively.

2.1.4. Porosity

Shepherd and Bhardwaj (1986) found porosity of pigeon pea decreased linearly with bulk density from 40.4 to 38.2 per cent at moisture range of 5.8 to 14.7 percent.

Baryeh (2001) studied the porosity and angle of repose for Bambara groundnut and observed that both the values were increased with increase in moisture content up to 43.8 per cent and 23.5^0, respectively, at 20 per cent moisture content.

Aydin *et al.* (2002) determined the physical properties of mahaleb (*Prunus mahaleb* L.) kernel as a function of moisture content. In the moisture range from 2.9 to 10.2 per cent (d.b.) the porosity of mahaleb decreased from 0.507 to 0.490.

Aviara *et al.* (2005) determined the physical properties of *Balanites aegyptiaca* nuts as a function of moisture content. For oblong nuts, in the moisture range of 4.72-26.35 per cent (d.b.), porosity increased from 41.86 per cent to 47.46 per cent. For spheroidal nuts, in the moisture range of 4.71-24.18 per cent, the porosity increased from 44.10 per cent to 49.37 per cent.

Pliestic *et al.* (2005) determined various physical properties of filbert nut and its kernel as function of moisture content. In the moisture range from 6.19 to 28.71 per cent (w.b.), studies on the rewetted nut showed that the porosity of nut increased from 41.53 per cent to 45.24 per cent, while porosity of kernel increased from 36.18 per cent to 39.44 per cent.

2.1.5. Frictional properties

2.1.5.1. Angle of repose

Fraser *et al.* (1978) found that the angle of repose of fababeans varied from 0.36 rad at 8.5 per cent to 0.41 rad at 2.9 per cent moisture content.

Shepherd and Bhardwaj (1986) found the angle of repose of pigeon pea increased from 0.38 to 0.44 rad in the moisture range 5.8 to 14.7 per cent (d.b.).

Omobuwajo *et al.* (2003) found that the dynamic angle of repose of Calabash nutmeg on the four structural materials ranged from 28.10^0 to 32.22^0.

Aviara *et al.* (2005) determined the physical properties of *Balanites aegyptiaca* nuts as a function of moisture content. For oblong nuts, in the moisture range of 4.72-26.35 per cent (d.b), the angle of repose increased from 22.36^0 to 33.66^0. For spheroidal nuts, in the moisture range of 4.71-24.18 per cent, the angle of repose increased from 22.84^0 to 32.97^0, respectively.

Ozguven and Vursavus (2005) determined selected physical properties of pine (*Pinus pinea*) nut at a moisture content of 5.48 per cent (d.b). The dynamic angle of repose for the three structural materials namely plywood, galvanized steel sheet and fiberglass were found to be 26.18^0, 23.52^0 and 15.21^0, respectively.

2.1.5.2. Co-efficient of static friction

Fraser *et al.* (1978) found the static coefficient of friction for fababeans ranged from 0.28 to 0.46 on plywood and 0.32 to 0.38 on galvanized steel, at the moisture range of 50.5 to 21.6 per cent.

Shepherd *et al.* (1986) observed the static coefficient of friction of pigeon pea against a galvanized steel surface increased from 0.26 to 0.37 in the moisture range 6.4 to 28.5 per cent (d.b.).

Balasubramanian (2001) observed the static co-efficient of friction for cashew nuts increased linearly with moisture content irrespective of surface employed, namely, glass (0.19-0.25), aluminium (0.25-0.30), galvanized iron (0.25-0.30) and cardboard (0.25-0.31).

Baryeh (2001) found the co-efficient of static friction for Bambara groundnut increased from 0.39 to 0.66, 0.29 to 0.58 and 0.25 to 0.49 for plywood, galvanized iron and aluminium, respectively.

Omobuwajo *et al.* (2003) showed that the coefficient of static friction of Calabash nutmeg seeds was 0.47 parallel to the plywood grain, 0.73 perpendicular to the plywood grain, 0.52 on galvanized steel, 0.58 on mild steel and 0.47 on formica.

Aviara *et al.* (2005) determined the physical properties of *Balanites aegyptiaca* nuts as a function of moisture content. For oblong nuts, in the moisture range of 4.72-26.35 per cent (d.b.), the static co-efficient of friction on different structural surface increased from 0.194 to 0.577.

Ozguven and Vursavus (2005) determined selected physical properties of pine (*Pinus pinea*) nut at a moisture content of 5.48 per cent (d.b.). The coefficient of static friction was 0.46 on plywood, 0.43 on galvanized steel sheet and 0.35 on fiberglass.

Burubai *et al.* (2007) investigated frictional properties of African nutmeg (*Monodora myristica*), a wild perennial edible plant, at a moisture content level of 4.93 per cent (d.b). The average values for coefficient of static friction on four test surfaces ranged from 0.502 (for galvanized iron sheet) to 0.702 (for rubber).

2.1.6. Compressive strength

Balasubramanian *et al.* (1986) studied mechanical properties of areca nut (*Areca catechu* Linn.) as related to dehusking. Areca nut subjected to compression, impact and shear loading along two major planes to evaluate the behavior of the nut in relation to dehusking. Studies indicated that axial compression was more efficient than the lateral compression with a saving in load of 58.1 per cent, at comparable deformations. Under impact loading, lateral impact resulted in an energy saving of 65.1 per cent compared to the impact loading along the axial direction. It was found that lateral shearing required 55.0 per cent lesser energy compared to the energy for axial shearing. A moisture content of 5-6 per cent (w.b) was found to be ideal for dehusking not only for saving energy but also to minimize the breakage of the kernels.

Olaniyan and Oje (2002) found that the average rupture force, deformation, toughness and firmness, when shea nuts were compressed over a range of moisture contents, temperatures and loading positions were 86.40N, 1.63mm, 8.98mJ/mm^3 and 96.36N/mm, respectively.

Koyuncu *et al.* (2004) were studied the cracking characteristics of walnut. Nut of Yalova-3 walnut (*Juglans regia* L.) variety were compressed with a universal testing machine. Force, energy and specific deformation before initial rupturing and kernel extraction quality were investigated as the function of shell thickness and geometric mean diameter at different compression positions (length, width and suture). Results obtained were shown in following table.

Table 2.1 Mean value of force, energy, specific deformation and kernel extraction quality of walnut

Parameters	Compression positions		
	Length	Width	Suture
Force, kN	0.333	0.472	0.441
Energy, J	0.381	0.440	0.273
Specific deformation, decimal	0.088	0.071	0.068
Kernel extraction quality, grade	89.47	86.31	70.00

Ozguven and Vursavus (2005) determined selected mechanical properties of pine (*Pinus pinea*) nut at a moisture content of 5.48 per cent (d.b.). Cracking forces of pine nut for loading on the lateral axis, vertical axis and thickness were determined to be 429.27, 639.53 and 468.18N, respectively.

Ogunsina *et al.* (2008) investigated fracture behaviour of dika nut under quasi-static loading along the longitudinal axis and the transverse axis. The force required to crack the nut increased with nut diameter but was not significantly different in both loading orientations. The mean cracking force was in the range of 2.06 to 3.67kN. Dika nuts loaded along the transverse axis required less energy for nutshell fracture than those loaded along the longitudinal axis. Minimum toughness occurred with the small size nuts loaded along the transverse axis, thus providing base-line data in future design of an appropriate nutcracker.

2.2. Effect of Pre-Treatments, Type of Drum, Drum Speed and Feed Rate on decortication

2.2.1. Effect of pre-shelling treatments

Pominski *et al.* (1952) developed a new method for the removal of skin from peanut kernels by water-treatment, drying, and blanching in a standard split-nut blancher developed on a pilot-plant scale. Optimum conditions for approximately 98 per cent skin removal from U.S. No. 1 shelled Spanish peanuts were water-treatmed at room temperature, dried with forced circulated air at 48.89°C to 51.67°C, to approximately 4.5 per cent moisture in the peanuts, and blanching.

Nambudiri and Lakshminarayana (1965) reported about processing of cashew nut by roasting. The nuts brought from store were kept in heaps and thoroughly soaked in water by regularly spraying for two days, covered with moist gunny bags and providing water to drain from the floor immediately. Then the nuts were considered to be moist enough for roasting (15-20 per cent) to desire moisture level.

Thivavarnvongs (1981) reported that the cashew nut pre-shelling treatment was evaluated at 30 minutes boiling time and then 24 hours drying, producing an average whole kernel recovery at 82.7 per cent.

Noomhorm *et al.* (1992) studied the effect of processing on kernel quality. Quality was assessed in terms of whole kernel recovery and its whiteness. Hot water treatment resulted in better quality and the nuts were much easier to shell than untreated nuts. 5min hot water bath was found to be an optimal exposure. Kernels were dried at 70^0C for 2 hours to achieve maximum whiteness.

Sachan *et al.* (1993) studied preconditioning of seeds before processing to make decortication easier for many pulses, and work was undertaken to study the effect of physical grain characteristics and preconditioning on the dehulling efficiency of Australian field peas.

Chattopadhyay (1996) observed that the steam roasting was commonly used by most of the cashew processing units. Raw cashew nuts were steam roasted at about 7.03kg/cm^2 pressure for 25-30 minutes. The cashew nuts were allowed to cool for 24 hours and then shelled.

Nagaraja and Balasubramanyam (1998) reported that the steam boiling was followed as preliminary conditioning process with steam pressure 2.11- 10.55kg/cm^2 and duration 30-90 minutes. It differed from industry to industry. It was further reported that 7.03kg/cm^2 pressure for 30 minutes was generally recommended for recovery of higher percentage of whole cashew kernel recovery.

Robert *et al.* (1998) reported that for blue type pea for good dehulling qualities, various treatments were investigated which included soaking in water, solution of sodium bicarbonate (10g/kg), sodium chloride (10g/kg), with vegetable oil (10g/kg), and preheating seeds (50g) soaked in 100ml of water or salt solution at room temperature (20^0C for 10min). Excess liquid was removed with tissue paper and seeds were dried for 30min in an oven at 70^0C for edible treatment. 50g seeds were thoroughly smeared with 0.5g of refined peanut oil then dried in oven for 30min at 70^0C. The preheating treatment consisted of heating for 30min in an oven at 70^0C.

Anonymous (1999) evaluated three different methods viz., hot oil bath, steam roasting and drum roasting of cashew nut. All the methods produced satisfactory results as indicated by the percent recovery of whole kernel after shelling. In addition, the other criteria for selecting the method were operating cost, price of equipment and convenience of the users. Based upon the results of the initial evaluation, the process that would best satisfy the above criteria was drum roasting. Although the steam roasting was the most modern and convenient to use, the equipment cost was too high even, if it was fabricated locally. The oil bath method was not convenient to use, as it required accurate measurement of oil temperature and time of roasting to produce the best results. The oil quality also deteriorated frequently causing unsatisfactory quality of roasted product. A prototype drum roaster was fabricated at BPRE and based on initial test result; roasting time of 30 minutes with a capacity of 10kg per batch would produce the best quality nuts and would match the capacity of mechanized cashew nut sheller.

Chadha (2001) mentioned that steam-boiling method was adopted in Indian factories where hand and leg operated shelling machines were employed. After conditioning, the nuts were given mild roasting for 20 to 25 minutes at 7.03-8.43kg/cm^2 pressure to loosen kernel from shell in order to make its removal easy.

Dandekar and Salvi (2003) found the treatment to cashew nut at 1.406kg/cm^2 pressure for 15min exposure in autoclave was better for higher recovery up to 83 per cent. The treatment was accepted as the best sensory evaluation and drying behavior.

Ogunsina and Bamgboye (2007) carried out study to determine the effects of pre-treatment by hot oil roasting and steam boiling on the physical properties of cashew nut. The cashew nuts were subjected to pre-treatment by steam boiling and hot oil roasting. The physical properties of raw and pre-treated cashew nuts were determined using standard methods. The results showed that nuts could be classified as medium large and extra large i.e. 22-35mm. The pre-shelling treatment showed significant difference ($P<0.05$) in the means of length and width of cashew nut, and no significant difference for thickness, aspect ratio and sphericity index. The treatment showed significant difference ($P<0.05$) in true and bulk densities but showed no difference in the porosities of the nuts. The moisture content of raw kernel was significantly different ($P<0.05$) from that of roasted and steam-boiled kernels. The physical properties of cashew nuts were found to be affected by pre-treatment by hot oil roasting and steam boiling.

Oluwole *et al.* (2007) conducted study to determine the effect of moisture content on shelling efficiency of bambara groundnut using a centrifugal cracker. The cracker was evaluates at three different moisture contents such as 5.3, 9.6, and 12.2 per cent (d.b.). Results showed that both moisture content and impeller angulations have a significant effect on these performance indices. The most effective performance was obtained at moisture content of 5.3 per cent (d.b.), at which the shelling efficiency, percentage of damaged seeds, percentage of partially shelled pods and percentage of unshelled pods were 96, 3.4, 0.6 and 0 per cent.

2.2.2. Type of drum, drum speed and feed rate

Channaveerswami *et al.* (1986) conducted study to determine the effect of seed moisture content, cylinder speed and retardable gate opening on seed breakage during maize shelling. Minimum seed breakage was found at 16.47 per cent seed moisture content, 15.30m/s cylinder speed and 22.5 mm retardable gate opening.

Nair and Gopinathan (1993) studied the problems of processing of cashew nut. Steaming was observed to be an alternate method to roasting. Well dried raw nuts were steam cooked at about 8.43-9.8kg/cm^2 pressure.

Okokon *et al.* (2007) analysed the impact forces on melon seeds during shelling. Melon seeds are shelled in a rotating impeller – type machine to obtain the cotyledons. The analysis showed that the factors affecting the impact force were impeller speed, seed cross-section area at impact and mass ratio. The mean forces to break melon seeds were 13.14×10^{-3}, 19.62×10^{-3} and 19.55×10^{-3}N for orientations breadth wise, lengthwise with tip up and lengthwise with tip down, respectively.

2.3. Design and Evaluation of Decorticator/Sheller

Sharp (1957) reported that an all purpose hand operated decorticator was developed in 1997 under the Indian University of Technical Assistance Programme, which consisted of vertically mounted discs faced with 0.94cm sheet rubber. The roasting disc had curved radial feed grooves cut into the rubber facing. Feeding was effected at the center above the discs through the hopper and handle. The unit decorticated 34kg of castor seeds or 23kg of mahua seeds in an hour.

Sosulski and Fleming (1977) developed the manually operated rotary beater type groundnut decorticator. The decorticator had a hopper and rotary beater driven with a handle and a spur gear mechanism. The bigger spur gear, fixed with handle had 42 teeth and smaller gear fixed to the beater shaft had 15 teeth. A V-pulley of 300mm diameter was fixed to the other end of beater shaft for transmitting power to of the blower. The concave made of 6mm MS square bars placed at 10mm apart had a length of 300mm and width of 100mm.

Singh and Shrivastava (1978) designed and fabricated different components of groundnut decorticator. The various parameters such as blower speed, airflow rate, eccentric speed, cylinder speed and feed rate have been studied during the experiments. The highest decorticating efficiency of 98 per cent was obtained at 100rpm cylinder speed, 150kg/h feed rate and 15 per cent moisture content at a clearance of 15mm.

Hussain *et al.* (1980) designed and developed the power operated rasp-bar cylinder type castor bean decorticator. The decorticator consisted of a rasp-bar cylinder on the periphery of which flats of 43×40×6mm size were welded at a spacing of 20mm. When used as groundnut decorticator, the rasp-bar was changed and open type concave was used. Three round bars of 9.5mm diameter and 430mm length were attached on each flat. The optimum peripheral speed of cylinder was 207m/min. A concave was provided below the cylinder with elliptical holes of 14×7mm size, and the clearance between the cylinder and concave was kept at 35mm. Two sieves 18.75mm and 6.25mm perforations were provided for separation of kernels from unshelled kernels and other foreign materials.

Baboo (1981) developed pedal operated scissors mechanism for dehusking dry and green areca nuts. Up to 60kg of dry areca nuts could be dehusked by an unskilled worker in a day of eight hours. The immature nut (chali) remained attached to one of the split halve of husk and could be taken out manually by a simple knife.

Mandvikar and Gandhi (1981) compared manual decortication with manually and power operated decorticator and reported that the capacity of the manual and power operated groundnut decorticator was 30kg/man-h and 78kg/man-h compared to 0.7kg/man-h in traditional manual method on kernel basis. Decortication efficiency was 95 to 99 per cent in both the decorticators and 100 per cent in conventional manual method but about 2-3% breakage was observed in both decorticators. There was no adverse effect of mechanical decortication on germination.

Luan and Liang (1983) developed macadamia nut husker which gave improved husking efficiency (96 per cent) and reduced the number of damaged nuts to less in 0.2 per cent by mass. Energy consumption of the machine was also lower. Separation of husks and nuts was satisfactory. Performance was affected little by nut variety, nut size, and husk moisture content. A capacity of 340kg/h of nuts can be expected from this husker.

Krishna Murthy (1984) conducted tests on performance of hand operated rocking and rotating drum type groundnut decorticators which gave more dehusking percentage compared to latter but there was an increase in percentage of breakage compared to latter. The performance of both machines remained the same in respect of saving time and labour. The soaking of pods for 40 minutes gave minimum breakage of 5.2 per cent at 14.28 per cent moisture content.

Singh *et al.* (1985) developed and tested ground nut decorticator to recommend the values of selected operational variables. The decorticating efficiency was very high (99.6 per cent). At 180kg/h feed rate, 200rpm (197.4m/min peripheral speed) of cylinder and 16mm cylinder concave clearance, the breakage was 12.67 per cent. The maximum efficiency of 80 per cent was achieved at 300rpm (292.0m/min peripheral speed) of cylinder and 14mm cylinder concave clearance with 150kg/h feed rate.

Varshney and Patel (1985) developed a castor decorticator and evaluated its performance. The decorticator could be operated by a 3hp electric motor and had a capacity of 2.55q/h. The external damage and shelling efficiency were 0.28 and 97.13 per cent, respectively.

Satapathy and Swain (1987) evaluated performance of a low cost ground nut decorticator. The shelling capacity was found to increase linearly with concave grate clearance. The highest dehusking capacity was 25.7 and 29.5kg/h for varieties AK-12-24 and TMV-2, respectively. The percentage of broken kernels varied non-linearly with increase of grate clearance. The percentage of un-dehusked kernels varied non-linearly with increase in grate clearance. The highest per cent of un-dehusked pods was found to be 2.30 and 1.17 per cent for variety AK-12-24 and TMV-2, respectively at 28mm grate clearance. The dehusking capacity and broken kernels increased with decrease in pod moisture content.

Hamam *et al.* (1989) developed and tested a power operated groundnut decorticator. The decorticator was of vertical box type, the frame of which was made of welded MS angles. The unit consisted of hopper, slotted semi-circular sieve made of MS, a channel at the rear end of an inclined plane and a blower fan at the fore end. Roller beaters were made of wood or iron with 6 corrugated strips or hexagonal or pentagonal wooden rollers padded with hard rubbers. Best results were obtained by hexagonal wooden rollers having full rubber padding. The decorticator yielded 57-63 per cent sound kernels, 8-14 per cent splits and 4-5 per cent undecorticated pods, and the capacity was 150kg/h.

Duraisamy and Manian (1990) developed and evaluated a hand/power operated caster bean sheller. It consisted of a fed hopper, a screw auger, shelling discs, flywheel and blower. The unit can be operated by 0.5 hp electric motor with blower. The output and shelling efficiency of power/hand operated castor bean sheller was 163.00 and 52.65kg, 97.29 per cent and 98.72 per cent with a kernel breakage of 0.82 per cent and 0.88 per cent, respectively.

Gore *et al.* (1990) suggested that the best performance of the power operated groundnut sheller was achieved at 180 rpm cylinder speed and 18 mm concave clearance with feed rate of 400kg/h of pods at 13 per cent m.c. (w.b). The shelling capacity, shelling efficiency and breakage were 280kg/h, 98.05 and 4.53 per cent, respectively.

Sankat (1992) worked on the mechanical shelling of Grenadian nutmeg seeds. The manual method was slow and tedious, while the mechanical, impact type devices produced high levels of kernel damage (14 per cent) and left many uncracked/partially cracked seeds

(28 per cent). A minimum of 4 pairs of fixed counter rotating cracking rolls on each of 203mm in diameter with sets or clearances of 15.2,17.4, 20.2 and 23.4mm were used to crack nutmeg seeds previously graded into diameter ranging 16-18.1, 18.1-20.8, 20.8-24 and 24.1-27.9mm. The quality of perfectly shelled kernels averaged 49.2 per cent, while that of damaged kernels was less than 1.0 per cent. The quality of partially cracked seeds averaged 21.8 per cent but could be reduced to 11.7 per cent by a single recycling of seed.

Dakshinamurthy (1993) reported that neem seeds could be decorticated in a neem seed decorticator to obtain kernels. A person could decorticate about 2-3kg/h by hand shelling. The hand operated sheller had the capacity of 30-35kg/h and the power operated unit had a capacity of 90-100kg/h.

Singh (1993) modified a simple rocking type groundnut decorticator to facilitate fabrication and adjustment of gap between its crushing shoes and concave grate. The concave grate design was based on the physicomechanical characteristics of groundnuts. The capacity of the decorticator was 70-80kg/h with breakage 3.7 to 6.5 per cent.

Ajav (1996) designed, fabricated and tested a low cost cashew nut cracker. Locally available construction materials were used and the cost was affordable to peasant farmers in Nigeria. The machine was tested using small, medium and large nuts and machine efficiencies were observed to be 69.4, 75.5 and 75.7 per cent for the three sizes, respectively.

Jain and Kumar (1997) developed a power operated cashew nut sheller based on the principle of compression and shear. The rated capacity of the sheller was observed to be 18kg/h of roasted nuts with a shelling efficiency of 70 per cent. The yields in terms of whole, half split and broken were 50, 22 and 28 per cent, respectively.

Varghase and Jacob (1998) developed and evaluated a power operated areca nut dehusker. The major parts of the dehusker are the hopper, feeder, lead plate, cutting blade, shearing roller, friction plate and scraper. The feeder receives the dried and graded nut from the hopper and delivers it on the lead plate. The nut was held pressed between the rotating shearing roller and the lead plate. The teeth on the roller peel off the husk and the kernel was ejected through the slot on the lead plate and the husk was removed. A single phase 0.5hp motor operates the machine which gave an output of 9.0kg dried nut/h for a single unit with 84.5 per cent dehusking efficiency.

Omobuwajo *et al.* (1999) designed a machine in order to remove the drudgery involved in dehulling the calabash nutmeg seeds. The machine comprised of a roller which cracks the hull, an oscillating cam follower which removes the cracked hull through repeated shearing against a stationary wall, and an aspiration unit which sifts the hull from the endosperm. A prototype was constructed and tested. It found that the throughput was 64kg/h with the efficiency of 75 per cent. The percentage of breakage was found to be 1.0 per cent.

Adewumi (2000) developed a manually operated cashew nut decorticator and tested with steamed cashew nuts having five grades. The machine had a power requirement of 182.4W. The performance of the machine was compared with hand shelling using parameters such as shelling capacity (C), shelling efficiency (η), percentage of broken nuts (B) and percentage of unshelled seeds (S). The values of C, η, B and S for the machine ranged from 194 to 309nuts/h, 70 to 95 per cent, 7 to 32 per cent and 0 to 10, respectively.

Helmy (2001) evaluated the performance efficiency of a reciprocating peanut sheller at various shelling box speeds, feed rates air velocities and peanut moisture contents. The shelling efficiency, mechanical damage and unshelled seeds (total losses), sheller productivity, unit energy consumption, seed recovery and degree of cleanliness were estimated. The results showed that these parameters were 95.44 per cent, 5.55 per cent, 4.56 per cent, 70×10^{-3}Mg/h, 3.36kWh/Mg, 99.67 and 96.1 per cent, respectively, at shelling box speed of 1.4m/s feed rate of 80kg/h, air velocity of 8.37m/s and peanut moisture content of 17.12 per cent (d.b) as an optimum condition of peanut sheller.

Adedeji and Ajuebor (2002) developed a power operated groundnut sheller that shells groundnut by mechanical shearing and cleans the shelled seeds from chaff pneumatically. The best performance of the sheller was achieved at 260rpm shelling speed, 30–40mm concave clearance, feeding rate of 150kg (pods)/h giving an output of 80kg seed/h. The shelling efficiency and breakage were 98 and less than 5 per cent, respectively. A blower speed between 1000–1400rpm was adequate for the effective separation when chute sloped at 20^0 to the horizontal.

Singh (2003) developed a power operated water chestnut decorticator. The decortication efficiency was found maximum (99.10 per cent) at 35rpm. Broken percentage was observed maximum at 100rpm, whereas, minimum broken percentage was obtained at 25rpm followed by 35rpm. The capacity of the machine was computed as 150kg/h at 35rpm.

Adewumi and Fatusin (2006) designed and tested a manually operated impact-type machine for breaking cocoa pods. The major components of the machine included a frame, rail, hammer, pulley, bearings and rope. The machine had a power requirement of 201.6W. The pods used for testing the performance of the machine were classified into small (5.00–6.40cm), medium (6.50–8.00cm) and big (8.10–9.60cm) sizes according to the dimension of their mid-diameters. The machine had less than 1 per cent seed damage with its efficiency and capacity ranging from 93 to 100 per cent and 377 to 738kg/h, respectively.

Ojolo and Ogunsina (2007) developed a prototype machine to crack roasted cashew nuts. The box-like machine had a hinged and spring-loaded mild steel cracking lid with grooves to hold a cast aluminum feeding tray which was machined to hold 25 nuts at a time. Nuts get cracked by the impact of the lid against the feeding tray. The percentage of whole kernels produced was 66.66 per cent, and the capacity of machine was about 18.3kg/h.

Ogunsina *et al.* (2008) fabricated a machine for cracking dika nut. The nut is fed by hand in between a toggle mechanism comprising of the slider and a fixed block. Fracture mechanism was based on the deformation characteristics of dried dika nut under uniaxial compression. When actuated, the slider compresses the nutshell to failure along its line of symmetry. The experimental machine gave 100 per cent cracking efficiency but with 24 per cent kernel breakage in cracking sun-dried dika nut at 6.6 per cent moisture content (w.b). The machine provided a viable and effective technique for safe dika kernel extraction.

Jarimopas *et al.* (2009) developed and tested a prototype betel nut husking machine. The husking mechanism was composed of two identical husking wheels mounted in series. Each husking wheel consisted of a rubber tyre and a concave sieve constructed from steel rods. The dry betel nut was fed into the space between the running tyre surface and the sieve surface of the husking mechanism. The optimum machine settings, identified by the greatest production score, were characterised by (a) a tyre pressure of 138kPa, a tyre speed of 440rpm, and 15mm spacing between the surface of the tyre and the sieve; (b) the optimal betel nut fruit moisture content was 6.31 per cent (w.b). Performance testing of the prototype based on the optimum settings produced the following results: optimally husked full nuts (64.4 per cent); broken nuts (15.2 per cent); unhusked nuts (20.5 per cent), and a production score of 76.9 per cent.

John Wesley *et al.* (2010) modified groundnut thresher for decorticating groundnut pods and castor. The groundnut thresher was modified by changing the main cylinder, concave and sieves for kernel separation and tested with groundnut TMV-2 (local), K-134 (Vemana) and castor (Kranthi) varieties. The sieve size of 18 × 9mm and 22 × 11mm was found suitable for TMV-2 and K-134 groundnut variety, respectively. The sieve size of 27 × 6 mm gave good results for castor shelling.

Pradhan *et al.* (2010) constructed a small, continuous, hand-operated machine for decortication of Jatropha fruits. The major components of the machine were the frame, hopper, decorticating chamber, concave sieve, rotating blades, discharge outlet and a vibrating separator with sieve to separate seed and shell. The performance parameters of the machine were evaluated at four different moisture content (7.97 per cent, 10.53 per cent, 13.09 per cent and 15.65 per cent (d.b)) with combinations of concave clearance (18, 21, 24 and 27mm) between concave sieve and rotating blades. The best set of conditions under which the decorticator could be operated was at a fruit moisture content of 7.97 per cent (d.b) with concave clearance of 21mm between the concave and the blade at which the maximum whole seeds of 67.94 per cent was achieved with a machine efficiency of 90.96 per cent.

Material and Methods

III. MATERIAL AND METHODS

Present study was carried out after studying different research reports which are mentioned in previous chapter i.e. Review of Literature.

The material used for construction of decorticator and various experimental methods employed for evaluation of the developed prototype are documented in this chapter. The study entitled "Development of a Decorticator for Nutmeg (*Myristica fragrans* Houtt.)" was conducted in the Post Harvest Technology Scheme, University of Agricultural Sciences, GKVK, Bangalore, during the years 2010 and 2011. The study was divided into four parts *viz.,*

i. Determination of physical and mechanical properties of nutmeg,
ii. Pretreatments to nutmeg nut to soften its shell,
iii. Development of the prototype decorticator, and
iv. Performance evaluation of developed prototype decorticator.

3.1 Raw material

The nutmeg (*Myristica fragrans* Houtt.) nuts of variety "*Viswashree"* were procured from Sirsi district of Uttara Kannada (Karnataka). The nuts were stored in polythene bags to avoid the possible moisture migration into the nuts and also insect attack.

3.2 Physical and mechanical properties of nutmeg nut and kernel

3.2.1 Size

To determine the average size of the nut and kernel, a sample of 100 nuts was randomly picked and their three major dimensions namely, length (l), width (b) and thickness (t) were measured using a digital vernier caliper (Model CD-6BS-Mitutoyo Corporation, Japan) with an accuracy of ±0.01 mm (Plate 3.1).

The geometric mean diameter (D) was determined using the following equation (Mohsenin, 1970):

$$D=(lbt)^{\frac{1}{3}} \qquad \text{...........3.1}$$

Sphericity (S) of the nut was calculated as (Mohsenin, 1970):

$$S=\frac{(lbt)^{\frac{1}{3}}}{l} \qquad \text{.............3.2}$$

3.2.2 Shape

The shapes of nutmeg nuts and kernels were determined through visual observations and by comparing with the standard shapes (Kachru, 1994).

3.2.3 100 nuts and 100 kernels mass

The mass of 100 individual nuts and kernels were measured separately using an electronic balance (Model PS200/2000/C/2-RADWAG, Poland) with an accuracy of ±0.001 g.

3.2.4 True density

The true density of nutmeg was measured using toluene displacement method. 50 ml of toluene was taken in a 100 ml measuring jar and weighed, then sample of nuts were poured into the jar. The change in the level of toluene in the jar was recorded. The true densities of the samples were calculated using the formula (Mohsenin, 1970).

$$\text{True density (kg/m}^3\text{)}=\frac{\text{Mass of nuts (kg)}}{\text{Volume of nuts (m}^3\text{)}} \qquad \text{.......3.3}$$

$$\text{Volume of nuts}=\begin{Bmatrix}\text{Initial toluene level}\\ \text{in measuring jar}\end{Bmatrix}-\begin{Bmatrix}\text{Final toluene level}\\ \text{in measuring jar}\end{Bmatrix} \qquad \text{.......3.4}$$

3.2.5 Bulk density

The bulk density was determined as per the method described by Mohsenin (1970). The nuts were filled into a container of standard size 10×10×10 cm up to the top level. The excess nuts were removed off so that the top surface was perfectly level and even. Then the nuts in the container were weighed by using an electronic balance. The bulk density was calculated using following formula:

$$\text{Bulk density (kg/m}^3\text{)}=\frac{\text{Mass of nuts (kg)}}{\text{Volume of nuts (m}^3\text{)}} \qquad \text{……………3.5}$$

3.2.6 Porosity

The porosity is also known as the packing factor and it was determined from bulk density and true density of grains and expressed by following expression (Mohsenin, 1970)

$$\text{Porosity (\%)}=\frac{\text{True density-Bulk density}}{\text{True density}}\times 100 \qquad \text{……….3.6}$$

3.2.7 Frictional properties

3.2.7.1 Angle of repose

The angle of repose indicates the cohesion among the individual units of a material. Higher the cohesion, higher is the angle of repose. The dynamic angles of repose of nutmeg nuts and kernels were measured by the emptying method. For the emptying method, a bottomless cylinder was used. The cylinder was placed over a plain surface and nutmeg nuts or kernels were filled in. The cylinder was raised slowly allowing the sample to flow down and form a natural slope. The dynamic angle of repose was calculated from the height and diameter of the pile as:

$$\theta=\tan^{-1}\frac{2h}{D} \qquad \text{…………..3.7}$$

Where, θ - Angle of repose (^{0}),
h - Height of the pile (cm), and
D - Diameter of the pile (cm).

3.2.7.2 Co-efficient of static friction

The coefficient of static friction (μ_s) was tested on different material surfaces such as plywood, galvanized steel sheet, asbestos and glass. The nut was placed on each of the surface and raised gradually by screw until the nut began to slide. The angle that the inclined surface makes with the horizontal when sliding of the nut begins was measured. The coefficient of static friction was calculated using:

$$\mu_s = \tan\theta \qquad \text{..........3.8}$$

Where, μ_s = coefficient of static friction,
θ = angle of inclination of material surface.

3.2.8 Compressive strength

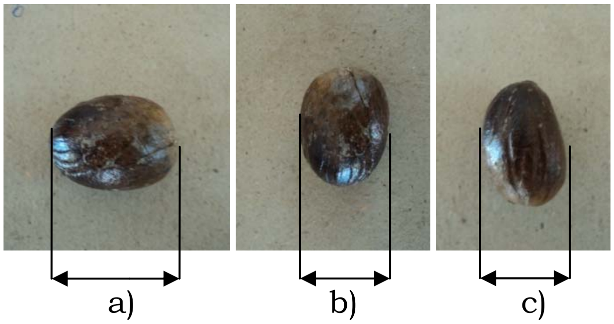
The following steps were followed while determining the compressive strength of nutmeg nuts:

a) The nutmeg nut was mounted in the testing frame (Plate 3.2).
b) The load was applied through the movement of a piston (at the rate of 1.25 mm per minute). Maximum load corresponding to the failure of the specimen was recorded from the gauge and the compressive strength was assessed.

The procedure was repeated for 5 nuts and average compressive strength was determined.

3.2.9 Moisture content

The moisture content of the nuts was determined using ASAE Standard (ASAE, 1993). The nuts were dried in an air ventilated oven at 90°C for 48 h. then the moisture content (wet basis) was calculated as:



Where, a) - length, b) - width, and c) – thickness

Plate 3.1 Physical dimensions of nutmeg

Plate 3.2 Compression tester for measurement of compressive strength

$$\text{Moisture Content, \% (w.b.)} = \frac{\begin{pmatrix}\text{Initial mass}\\ \text{of nut /kernel}\end{pmatrix} - \begin{pmatrix}\text{Final mass}\\ \text{of nut/kernel}\end{pmatrix}}{\text{Initial mass of nut/kernel}} \times 100 \qquad \ldots\ldots\ldots\ldots 3.9$$

3.3 Pretreatments to nutmeg nuts

Pre-treatments such as steaming and roasting (sand roasting) were imposed with a main focus to soften the shell and result in easy decortication.

3.3.1 Steaming

In steaming process, the nutmeg nuts of different moisture contents were steamed in autoclave at 0.15 kg/cm^2 pressure for 1 min and then dried immediately under shade for 3 h.

3.3.2 Roasting (Sand roasting)

In sand roasting process, nutmeg nuts were mixed with fine sand pre-heated at 60^0C for around 20 min. Then sand was sieved out from the nuts. The roasted nuts were cooled at room temperature and used for decortication operation.

3.3.3 Treatment details

The performance of the decorticator was tested for raw, steamed and roasted nutmeg nuts. The tests were carried out for two different moisture contents (12 and 14 per cent (w.b.)) of nutmeg nuts at two different speeds of cylinder. The moisture contents were selected on the strength of performance of nutmeg cracker developed by Sankat (1992). The combination of treatments used to determine the optimum parameters of decortication were as follows:

			M_1	M_2
F	T_1	N_1	FT_1N_1	FT_1N_1
		N_2	FT_1N_2	FT_1N_2

F	T_2	N_1	FT_2N_1	FT_2N_1
		N_2	FT_2N_2	FT_2N_2
F	T_3	N_1	FT_3N_1	FT_3N_1
		N_2	FT_3N_2	FT_3N_2

Where, F – feed,
T_1, T_2, T_3 –without pre-treatment (raw), with pre-treatments (steaming and sand roasting),
N_1, N_2 – speeds of rotor pulley (300 and 450 rpm), and
M_1, M_2 – moisture content (12 and 14% (w.b)).

3.4 Design and development of decorticator for nutmeg (*Myristica fragrans* Houtt.)

The equipment was designed and fabricated for the removal of outer shell from the dried nut to separate kernel. The decoricator was developed and fabricated in the workshop of Post Harvest Technology Scheme, University of Agricultural Sciences, GKVK, Bangalore. The machine was developed on the lines of the other decorticators already in commercial use such as groundnut decorticator developed by the Post Harvest Technology Scheme, University of Agricultural Sciences, GKVK, Bangalore.

Before attempting the development of nutmeg decorticator, the traditional method of decortication of nutmegs was studied. It was observed, that this method was very time and labour consuming, resulting in meager interest in nutmeg processing by the industries.

The following factors were considered while developing the decorticator for nutmeg

1. Suitability of machine for decortication of nutmeg to separate kernel
2. Ease of operation and maintenance
3. Low cost of operation and energy efficient

4. Minimum damage to kernels

The various physical properties affecting the design and testing, like physical dimension, angle of repose of nuts and compressive strength were measured and their geometric mean diameter and sphericity were calculated. The angle of repose of material was important in the design of hopper and concave. The compressive strength of material was important in selecting the type of cylinder used in decorticator. The material of construction and methods used in fabrication and testing were discussed.

3.4.1 Materials for fabrication

The materials used for the development and fabrication of decorticating machine, the quantity and cost of material used are presented in Appendix I. The material used were M.S. sheet, M.S. angle, M.S. flats, pulley, rubber belt (V-Belt), M.S. shaft, bale bearings, M.S. rods (dia.-6 mm), tyre rubber and an electric motor (0.5 hp) with speed reduction.

3.4.2 Instrumentation

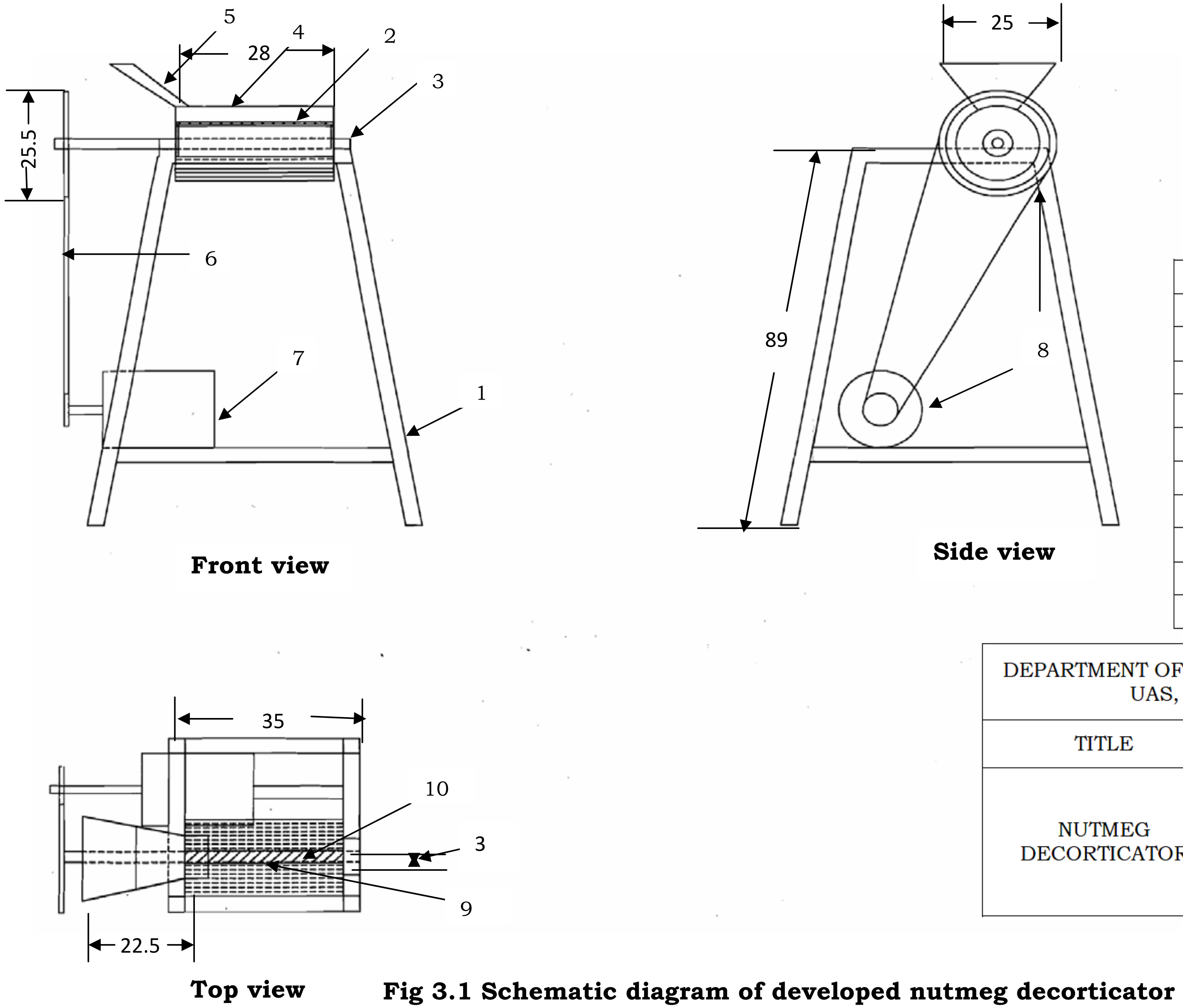
a) **Tachometer:** A tachometer was used to measure the speed in rpm of the motor and the machine pulleys. The range of instrument was 10-10000 rpm.

b) **Vernier calipers:** A vernier was used to measure the physical dimensions of the nutmeg viz., length, width and thickness, diameter of rotor shaft, thickness of M.S. sheet, flat, M.S. angle, diameter of rods, etc. It had the least count of 0.01mm.

c) **Measuring tape and scale:** A measuring tape and a metal scale were used for measuring length of flat, angles, shaft, pulley, belt, tyre rubber and bearings.

3.4.3 Design details

The schematic diagram of machine is shown in Fig 3.1. The important machine parts are described below:



Front view

Side view

Top view

Item no.	Qty	Description
1	1	M. S. frame
2	1	Concave
3	1	Shaft
4	1	Cylinder cover
5	1	Hopper
6	1	V-Belt
7	1	Motor
8	2	Pulley
9	1	Cylinder
10	4	Tyer Rubber strips

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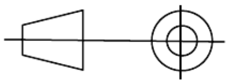
TITLE	DWG NO. 1/5
NUTMEG DECORTICATOR	SCALE 1:10 (ALL DIMENSIONS ARE IN cm)
	

Fig 3.1 Schematic diagram of developed nutmeg decorticator

3.4.3.1 Diameter of rotor shaft

The shaft was a rotating member having circular cross section, to which transmitting elements such as pulley, belt and rolling element bearings, were mounted.

The material used for shaft was high carbon steel of grade 40C8, ultimate tensile strength of 560-670Mpa and yield strength of 320Mpa.

Shaft design

The shaft design primarily consists of the determination of the optimum shaft diameter to ensure sufficient strength and rigidity, when the shaft was transmitting power under various operating as well as loading conditions.

The shaft was subjected to torque only so the diameter of shaft was obtained by using the equation (Khurmi and Gupta, 2001).

$$\frac{\pi}{16} \times Fs \times d^3 = T \qquad \ldots\ldots\ldots\ldots 3.10$$

Where, Fs = maximum allowable stress for high carbon steel (Mpa)

We know, yield stress = 320Mpa (Lingaiah, 1989)

Fs = 160 Mpa

d = diameter of shaft required (cm)

T = torque developed on the shaft (kg-cm)

T=F × perpendicular distance from the shaft × No. of flats with tyre rubber

F = Force required to shear the pepper berries (N)

The force was considered as 39.24N for each brush to shear the nut.

T = 39.24×4×6 = 941.76 Ncm

Therefore, d = 0.6735 cm…………………from equation 3.10

Hence, 2.5 cm diameter of standard size shaft was selected keeping a factor of safety about 4, which was the result of feeler studies conducted before the actual experimentation.

3.4.3.2 Power requirement

As the torque transmitted by the shaft was known, the horsepower was calculated by using the formula:

$$hp = \frac{2\pi NT}{4500} \quad \text{............3.11}$$

Where, N = speed (rpm) = 300 rpm

T = torque (kg m) = 0.96 kgm

hp = 0.4 hp

Therefore actual horsepower required was 0.46 hp.

3.4.3.3 Diameter of pulley shaft

The diameter of pulley shaft was obtained from the velocity relationship, (Murgesan and Tajuddin, 1997).

$$N_1D_1 = N_2D_2 \quad \text{..........3.12}$$

Where, N_1 = speed of motor pulley = 1487 rpm (measured value)

N_2 = speed of motor shaft = 300 rpm

D_1 = diameter of motor pulley = 5.08cm

D_2 = diameter of rotor pulley (cm)

Therefore, from equation 3.12

D_2 = 25.18 cm

3.4.3.4 Length of belt

Here, the belt was considered as an open drive. This type of belt drive was employed when the two parallel shafts have to rotate in the same direction. The length of belt was obtained by using the formula (Gopalkrishna, 2002).

$$L=\frac{2C+\frac{\pi}{2}\times(d_1+d_2)+(d_1+d_2)^2}{4C}$$

.............3.13

Where, C = length of central distance (cm)

d_1 = diameter of large size pulley (cm)

d_2 = diameter of small size pulley (cm)

Therefore, length of belt L= 1.732m

3.4.3.5 Horsepower required

The calculated horsepower of the machine was 0.46 hp; the motor efficiency and belt efficiency of the machine were calculated as 70% and 75%, respectively.

The recommended horsepower of machine was calculated by using the formula

$$\text{Required hp}=\frac{\text{Actual power required (hp)}}{\text{Motor}(\eta)\times\text{belt }(\eta)}$$

...........3.14

The horsepower of machine was 0.5 hp.
Hence, an electric motor of 0.5 hp was selected.

3.4.4 Constructional features

The following sections illustrate the constructional details of different machine parts of the decorticator.

3.4.4.1 Frame

The iron frame of the machine was fabricated in the trapezoidal shape to provide strength and firmness to the machine. The frame was made of M.S. angle iron section of 0.4×0.4×0.06 cm. The size of top portion of frame was 62.8×32.8 cm, bottom portion of frame was 62.8×53.4 cm and height was 88.5 cm. The frame was well braced to mount and support other parts of the machine and also withstand the vibrations during operation.

3.4.4.2 Hoper

The hopper was fabricated in trapezoidal shape, using mild steel sheet of 18 gauge thickness and had a dimension of 26.1cm in length; 3.2cm in width; 25.3cm height and base length of 8.9cm. It was designed in such a way that one can feed nutmeg continuously in the form of layer.

3.4.4.3 Cylinder

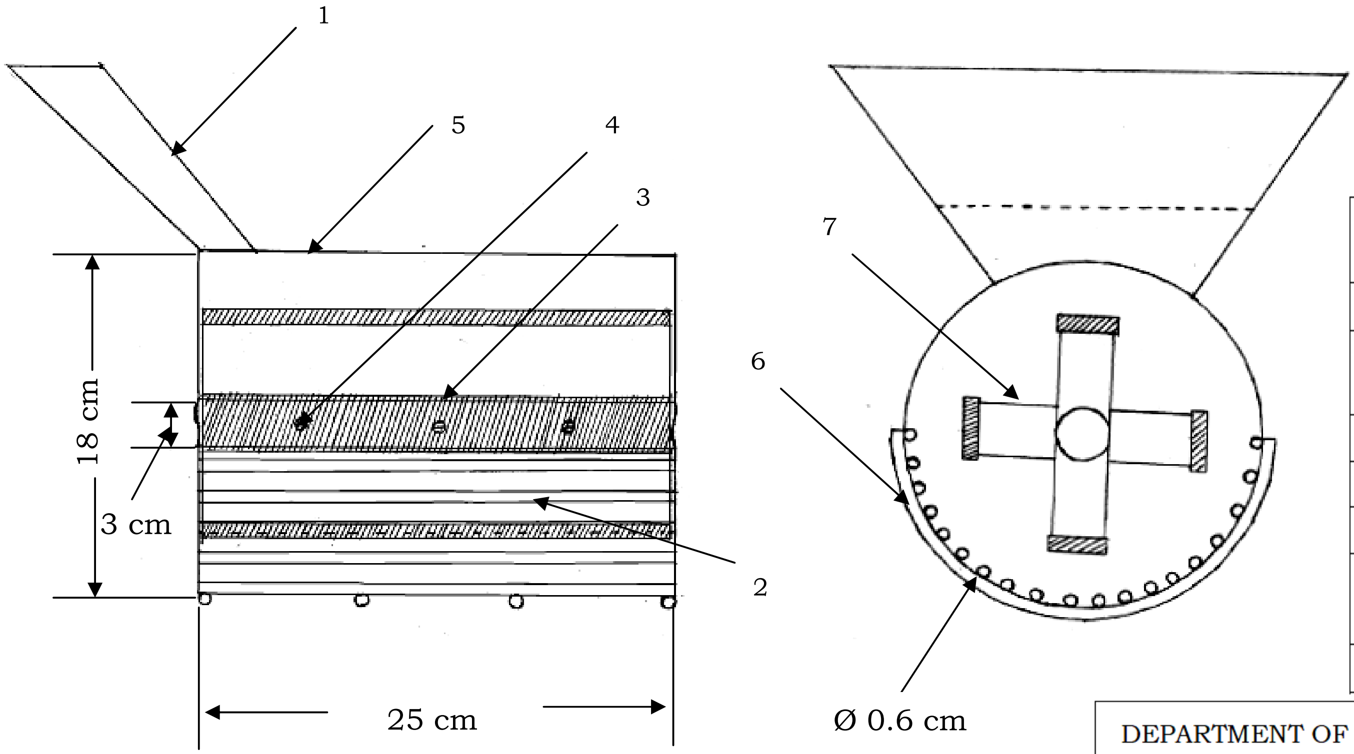
The cylinder was manufactured using M.S. angle flats of size 24.8×1.9 cm. The four flats were welded on the shaft with distance of 1.6 cm in such a way that the angle between two is 90^0 and it forms the shape of a cylinder. Rubber of thickness 0.5cm was fixed on these flats to establish impact to the nuts (Fig 3.2).

3.4.4.4 Perforated concave

The concave was fabricated using 6 mm size mild steel rods. The length of concave was 25cm with slotted opening size of 7.7×1 cm. It was designed by considering average dimensions of nutmegs and kernels. It was designed in such way that kernels should not fall through the slots. It was fabricated using three half round rings, on which 6 mm M.S. rods were welded at a spacing of 1 cm. The clearance between concave and cylinder was maintained 2.1 cm.

3.4.4.5 Outer cover

It was made up of 18 SWG thick M.S. sheet and was bended to semicircular shape of diameter 18 cm and was rigidly fixed to give protection to the cylinder and avoid nutmegs spilling out. It had the provision of attaching a hopper. A flange was attached to it along the length to facilitate cleaning of inner cylinder.



Item no.	Qty	Description
1	1	Hopper
2	31	Iron rods (dia.=6 mm)
3	4	Rubber pads
4	12	Nut-bolts
5	1	Cylinder cover
6	1	Concave (having half circular ring)
7	1	Cylinder

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Fig 3.2 Decortication section of the nutmeg decorticator

Plate 3.3 View of developed nutmeg decorticator and its cylinder

3.4.4.6 Rotor shaft

It was one of the key components of the machine; other parts flats of cylinders and bearings were mounted on the shaft. The standard size and length of the shaft were selected based on the shaft design. The pulley was attached to give drive to shaft from motor.

3.4.4.7 Outlet chute

The outlet was provided at the opposite end of hopper and just over the concave. It was like the door when opened kernels come out of the decorticator through it.

3.5 Testing of decorticator

The developed decorticator was tested as per standard procedures for combination of various treatments as described earlier. Before starting the actual testing, belt tension, direction of rotation of pulley were checked. The clearance between cylinder and the concave were recorded using vernier caliper. The cylinder speed was also recorded using tachometer. After preliminary set up, machine was placed at an angle equal to or greater than angle of repose for nutmegs, so that nutmegs movement took place properly inside the decorticator from inlet to outlet. Then, the motor was started and speed was set at particular rpm using speed cone as per treatment combination planned. Nutmegs were then fed through the hopper continuously. The rotating rasp bar produced two kinds of forces like impact and shearing which caused the out shell of nutmegs to decorticate. Then the outlet door was opened and kernels were collected at the end. The outer shell which was broken was passed through the slots provided in the concave. Two labours were required for these operations one for feeding nutmegs at hopper and other for opening outlet door and collecting nutmegs at outlet. Mass of kernels, broken kernels and shells were recorded (separately), and time of operation to calculate output and efficiency (Plate 3.4).

Plate 3.4 Developed nutmeg decorticator in operation

The procedure was repeated for all the combinations of treatments and data were recorded. The following parameters were recorded during testing:

1) Speed of cylinder (rpm)
2) Mass of nutmegs fed through the hopper (kg)
3) Mass of kernels after decortication (kg)
4) Mass of broken kernels (kg)
5) Mass of un-decorticated nutmegs (kg)
6) Mass of shells (kg)
7) Time of operation (h)
8) Clearance between the cylinder i.e. rubber and concave.
9) Moisture content of nutmegs

With the above data, the following parameters were then computed:

$$\text{Capacity of decorticator } \left(\frac{\text{kg}}{\text{h}}\right)=\frac{\text{Mass of kernels decorticated (kg)}}{\text{time taken (h)}} \quad \text{.............}3.15$$

$$\text{Unshelled nuts (\% by mass)}=\frac{\text{Mass of unshelled nuts (kg)}}{\text{Mass of total nuts fed (kg)}}\times 100 \quad \text{.............}3.16$$

$$\text{Decortication efficiency (\% by mass)}=\frac{\text{Mass of shelled nuts (kg)}}{\text{Mass of total nuts fed (kg)}}\times 100 \quad \text{.............}3.17$$

$$\text{Kernel damage (\% by mass)}=\frac{\text{Mass of broken kernels (kg)}}{\text{Mass of total shelled nuts (kg)}}\times 100 \quad \text{.............}3.18$$

3.6 Statistical analysis

The results of the machine performance for different pre-treated nutmeg decortication were analyzed using Fisher’s Factorial Completely Randomized Design to determine the significant differences among treatments. Levels of significance was used in F-test at (P=0.05) for the statistical conclusion.

3.7 Cost economics

The economics of the developed nutmeg decorticator was determined taking into account the fixed and variable costs (energy consumed, labour, raw materials, etc.).

Experimental Results

IV. EXPERIMENTAL RESULTS

The results of the present study entitled "Design of a Decorticator for Nutmeg (*Myristica fragrans* Houtt.)" conducted at the Post Harvest Technology Scheme, University of Agricultural Sciences, Bangalore are presented under the following headings:

4.1 Physical and mechanical properties of nutmeg and kernel
4.2 Performance evaluation of developed decorticator

4.1 Physical and mechanical properties of nutmeg and kernel

4.1.1 Size

The size of nut and kernel at 14 per cent moisture content (w.b) were higher than the size of nut and kernel at 12 per cent moisture content (w.b) (Tables 4.1 and 4.2). The average dimensions of nuts and kernels at 12 per cent moisture content *viz.,* length, width and thickness were 27.72, 21.61, 20.20 mm, and 23.86, 18.67, 17.12 mm, respectively. While the corresponding values at 14 per cent moisture content were 28.65, 21.83, 20.32 mm, and 24.34, 19.53, 17.83 mm, respectively. The average geometrical diameter of nuts at 12% and 14% moisture contents were 22.92 and 23.31 mm, respectively, and the corresponding values for kernels were 19.79 and 20.37 respectively. The interaction effect between geometrical diameter of nuts at 12 per cent moisture content and 14 per cent moisture content was found to be non-significant. The interaction effect between geometrical diametrical of kernels at 12% and 14% moisture contents were also found to be non-significant.

At 12 per cent moisture content, the average sphericity of nuts and kernels were 0.83 each while the average sphericity of nuts and kernels at 14 per cent moisture were higher and values were also closure (0.814 and 0.83) to value at 12%. The effect of moisture content on the sphericity of nuts and kernels were found to be non-significant.

4.1.2 Shape

By visual observation and standard chart of shapes, the nut and kernel shapes were recorded. The shape of nut and kernel were identical and were ovate shaped.

4.1.3 100 nuts and kernels mass

The mass of 100 nuts and kernels at 12 and 14 per cent moisture content were presented in Table 4.1. The mass of 100 nuts and kernels at 12 and 14 percent moisture content were found to be 5.04, 4.06 and 5.16, 4.32, respectively.

4.1.4 True density

The true density (1012 kg/m^3) of nutmeg at 12 per cent moisture content was found to be lower than the true density of nutmeg at 14 per cent moisture content (1133 kg/m^3). The True density of kernels at 12 per cent moisture content (1109 kg/m^3) was also found to be lower than the true density at 14 per cent moisture content (1197 kg/m^3). The experimental data was recorded in Tables 4.1 and 4.2.

4.1.5 Bulk density

The bulk density of nutmegs and kernels significantly varied with moisture content. The bulk density of nutmegs and kernels at 12 per cent moisture content were found to be 495 and 667 kg/m^3, respectively, where as corresponding values at 14 per cent moisture content were 532 and 689 kg/m^3, respectively (Tables 4.1 and 4.2).

4.1.6 Porosity

The porosity of nutmegs and kernels at different moisture content were presented in Tables 4.1 and 4.2. The data showed no significant variation between porosity at 12 per cent and 14 per cent moisture content. The porosity of nuts and kernels at 12 per cent moisture content were found to be 51.02 and 38.92 per cent, respectively, whereas corresponding values at 14 per cent moisture content were found to be 52.70 and 42.13 per cent, respectively.

4.1.7 Frictional properties

4.1.7.1 Angle of repose

The angle of repose of nutmegs and kernels at 12 and 14 per cent moisture content were expressed in the Tables 4.1 and 4.2. The angle of repose of nutmegs and kernels at 12 per cent moisture content were found to be 51.78^0 and 52.51^0, respectively. The corresponding values at 14 per cent moisture content were found to be 50.07^0 and 50.54^0, respectively.

4.1.7.2 Co-efficient of static friction

The co-efficient of friction on the different surface of materials like wood (ply-wood), galvanized iron sheet, rubber and glass were measured using standard techniques and procedures; analyzed statistically and presented in Table 4.3. The data showed that no significant difference between frictional properties of nutmegs and kernels at 12 per cent and 14 per cent moisture content.

4.1.7.3 Compressive strength

The data on compressive strength of nutmeg and kernel presented in Tables 4.1 and 4.2. The compressive strength of nutmeg varied significantly with moisture content but there was no significant difference of compressive strength of kernels at 12 and 14 per cent moisture content. The average compressive strength of nutmeg (244.38 N) at 12 per cent moisture content was significantly lower than the average compressive strength of nutmeg (385.79 N) at 14 per cent moisture content. The compressive strengths of kernel were 629.20 and 893.19 N at 12 and 14 per cent moisture content, respectively.

Table 4.1: Physical properties of nutmeg

Moisture content (w.b)	**Geometrical mean diameter, mm**	**Sphericity**	**100 nuts mass, g**	**True density, kg/m³**	**Bulk density, kg/m³**	**Porosity, %**	**Angle of repose, degree (⁰)**	**Compressive strength, N**
12 %	22.92	0.827	5.04	1012	495	51.02	51.78	244.38
14 %	23.31	0.810	5.16	1133	532	52.70	50.07	385.79
F-Test	NS	NS	NS	*	*	NS	*	NS
S. Em ±	0.458	0.115	0.139	35.241	4.988	1.612	0.283	3.287
CD at 5%	1.360	0.413	0.332	114.927	16.267	5.257	0.980	12.905

Table 4.2: Physical properties of kernel

Moisture content (w.b)	**Geometrical mean diameter, mm**	**Sphericity**	**100 nuts mass, g**	**True density, kg/m³**	**Bulk density, kg/m³**	**Porosity, %**	**Angle of repose, degree (⁰)**	**Compressive strength, kgf**
12 %	19.79	0.83	4.06	1109	677	38.92	52.51	629.20
14 %	20.37	0.83	4.32	1197	689	42.13	50.54	893.19
F-Test	NS	NS	NS	*	*	NS	*	NS
S. Em ±	0.508	0.0064	0.108	29.844	1.161	1.44	0.283	8.58
CD at 5%	1.508	0.0201	0.375	97.327	3.789	4.6993	0.980	33.684

Note: * Indicates significance NS- Indicates non-significance

Table 4.3: Co-efficient of friction of nutmeg

Moisture content (w.b)	Friction surfaces			
	Wood	**Galvanized iron sheet**	**Rubber**	**Glass**
12 %	0.3277	0.2768	0.3689	0.3057
14 %	0.3463	0.3021	0.3841	0.3278
F-Test	NS	NS	NS	NS
S. Em ±	0.0075	0.0081	0.0089	0.0132
CD at 5%	0.0293	0.0321	0.0351	0.0520

Note: NS- indicates non-significance

4.2 Performance evaluation of developed decorticator

The prototype decorticator developed was tested for its performance. The tests were conducted for different pre-treatments of nutmegs. For each trial 0.5 kg pre-treated or raw nutmegs were used. The prototype machine was operated for three treatments of two moisture contents at two cylinder speeds. The clearance (2.1cm) of the decorticator was constant for each pre-treatment.

The results in respect of effect of different moisture content, pre-treatments and speeds on decortication efficiency (%), total recovery of kernels (%), breakage (%), whole kernels (%), unshelled kernels (%) and capacity (kg/h) of machine have been presented in Table 4.4. It showed significant differences between treatments. From the statistical analysis, it was found that decorticator had best performance when it operated at a speed of 450 rpm and fed with roasted nuts of 14 per cent moisture content. Second best performance was found when decorticator fed with raw nuts having 12 per cent moisture content and operated at a speed of 450 rpm. There was no significant difference between these two treatments but roasting is time, labour and energy consuming process. Therefore, the decortication process of roasted nuts was found to be costlier than decortication of raw nuts.

4.2.1 Effect of pre-treatments and speeds on decorticator performance

The results on effect of three different pre-treatments to nutmegs on decorticator performance at 300 and 450 rpm were presented in Tables 4.5 and 4.6.

At 12 per cent moisture content, raw, steamed and roasted nutmegs were fed to the decorticator and operated at 300 and 450 rpm. The decorticator performance in terms of efficiency, total recovery, breakage, whole kernel percentage, unshelled nuts and capacity were recorded (Tables 4.5 and 4.6). It showed that when

Table 4.4: Performance of developed nutmeg decorticator

Moisture content (w.b)	Pre-Treatment	Speed of rotor, rpm	Efficiency, %	Total recovery, %	Broken, %	Whole kernels, %	Unshelled kernels, %	Capacity, kg/h
12%	Raw	300	97.70	64.92	2.70	62.22	2.30	45.00
		450	98.11	67.00	3.08	63.92	1.89	56.59
	Steamed	300	84.20	60.00	2.50	57.50	15.80	31.58
		450	99.20	67.60	7.00	60.60	0.80	38.30
	Roasted	300	96.00	67.70	3.80	63.90	4.00	40.00
		450	97.34	69.91	2.66	67.25	2.66	45.09
14%	Raw	300	86.95	57.23	4.62	52.61	13.05	32.01
		450	94.52	61.83	3.49	58.35	5.48	36.14
	Steamed	300	83.40	50.00	9.80	40.20	16.60	31.03
		450	94.82	62.65	6.08	56.57	5.18	39.29
	Roasted	300	64.38	42.60	2.19	40.42	35.63	33.23
		450	88.05	57.67	2.09	55.58	11.95	43.03
	F-Test		*	*	*	*	*	*
	S. Em ±		0.016	0.231	0.036	0.295	0.054	0.962
	CD at 5%		0.048	0.713	0.110	0.908	0.165	2.965

Note**:** * Indicates significance

Table 4.5 Effect of pre-treatment and speed on performance of nutmeg decorticator at 12 % moisture content (w.b)

Pre-Treatment	Speed of rotor, rpm	Mass of sample, kg	Mass of whole kernels, kg	Mass of broken kernels, g	Mass of unshelled nuts, g	Mass of shells, kg	Efficiency, %	Total recovery, %	Broken, %	Whole kernels, %	Unshelled kernels,%
Raw	300	0.500	0.311	13.5	11.5	0.164	97.70	64.92	2.70	62.22	2.30
	450	0.500	0.322	15.5	9.5	0.157	98.11	67.00	3.08	63.92	1.89
Steamed	300	0.500	0.288	12.5	79.0	0.121	84.20	60.00	2.50	57.50	15.80
	450	0.500	0.303	35.0	4.0	0.158	99.20	67.60	7.00	60.60	0.80
Roasted	300	0.500	0.320	19.0	20.0	0.142	96.00	67.70	3.80	63.90	4.00
	450	0.488	0.329	13.0	13.0	0.134	97.34	69.91	2.66	67.25	2.66

Pre-Treatment	Speed of rotor, rpm	Mass of sample, kg	Time taken for decortications, sec	Capacity, kg/h
Raw	300	0.500	40	45.00
	450	0.500	32	56.59
Steamed	300	0.500	57	31.58
	450	0.500	47	38.30
Roasted	300	0.500	45	40.00
	450	0.488	39	45.09

Table 4.6 Effect of pre-treatment and speed on performance of nutmeg decorticator at 14 % moisture content (w.b)

Pre-Treatment	Speed of rotor, rpm	Mass of sample, kg	Mass of whole kernels, kg	Mass of broken kernels, g	Mass of unshelled nuts, g	Mass of shells, kg	Efficiency, %	Total recovery, %	Broken, %	Whole kernels, %	Unshelled kernels, %
Raw	300	0.50	0.262	23.0	65.0	0.148	86.95	57.23	4.62	52.61	13.05
	450	0.50	0.293	17.5	28.0	0.164	94.52	61.83	3.49	58.35	5.48
Steamed	300	0.50	0.201	49.0	83.0	0.167	83.40	50.00	9.80	40.20	16.60
	450	0.50	0.284	30.5	26.0	0.162	94.82	62.65	6.08	56.57	5.18
Roasted	300	0.48	0.194	10.5	171.0	0.105	64.38	42.60	2.19	40.42	35.63
	450	0.50	0.279	10.5	60.0	0.153	88.05	57.67	2.09	55.58	11.95

Pre-Treatment	Speed of rotor, rpm	Mass of sample, kg	Time taken for decortications, sec	Capacity, kg/h
Raw	300	0.50	56	32.01
	450	0.50	50	36.14
Steamed	300	0.50	58	31.03
	450	0.50	46	39.29
Roasted	300	0.48	52	33.23
	450	0.50	42	43.03

steamed nutmegs fed to decorticator and operated at a cylinder speed of 450 rpm gave higher efficiency of 99.20% but in this case breakage percentage (7%) was also higher compared to other pre-treatment and speed combination. The next best performance (efficiency-97.34% and breakage-2.66%) observed when roasted nutmegs fed to decorticator rotating at speed of 450 rpm. But no significant difference found on the performance of decorticator when fed with raw nuts (efficiency-98.11% and breakage-3.08%) and performance of decorticator when fed with roasted nuts at 450 rpm. The capacity of decorticator was found higher (56.59 kg/h) in case of raw nutmegs feeding at a speed of 450 rpm.

The raw, steamed and roasted nutmegs at 14 per cent moisture content were fed to the decorticator operating at 300 and 450 rpm. The decorticator performance in terms of efficiency, total recovery, breakage, whole kernel percentage, unshelled nuts and capacity were recorded (Tables 4.5 and 4.6). The Table 4.5 showed that steaming pre-treatment was the best for decortication, but showed higher breakage. The feeding of raw nuts to decorticator operating at cylinder speed of 450 rpm found to had best overall performance (efficiency-94.52% and beakage-3.49%). The capacity of decorticator was higher for raw nutmegs feeding.

4.2.2 Effect of moisture content and pre-treatment on decorticator performance

The results of effect of two different moisture content and three different pre-treatments were presented in Tables 4.7 and 4.8.

When the decorticator operated at a speed of 300 rpm for 12 and 14 per cent moisture content of nutmegs and three different pre-treatments (raw, steaming and roasting), the best overall performance was observed for the nuts at 12 per cent moisture content. This combination of treatment had an efficiency of 97.70 per cent with lower breakage (2.70 %) compared to other combination.

Table 4.7 Effect of moisture content and pre-treatment on performance of nutmeg decorticator operating at 300 rpm

Moisture content (w.b)	Pre-Treatment	Mass of sample, kg	Mass of whole kernels, kg	Mass of broken kernels, g	Mass of unshelled nuts, g	Mass of shells, kg	Efficiency, %	Total recovery, %	Broken, %	Whole kernels, %	Unshelled kernels,%
12 %	Raw	0.50	0.311	13.5	11.5	0.164	97.70	64.92	2.70	62.22	2.30
	Steamed	0.50	0.288	12.5	79.0	0.121	84.20	60.00	2.50	57.50	15.80
	Roasted	0.50	0.320	19.0	20.0	0.142	96.00	67.70	3.80	63.90	4.00
14 %	Raw	0.50	0.262	23.0	65.0	0.148	86.95	57.23	4.62	52.61	13.05
	Steamed	0.50	0.201	49.0	83.0	0.167	83.40	50.00	9.80	40.20	16.60
	Roasted	0.48	0.194	10.5	17.1	0.105	64.38	42.60	2.19	40.42	35.63

Moisture content (w.b)	Pre-Treatment	Mass of sample, kg	Time taken for decortication, sec	Capacity (projected), kg/h
12 %	Raw	0.50	40	45.00
	Steamed	0.50	57	31.58
	Roasted	0.50	45	40.00
14 %	Raw	0.50	56	32.01
	Steamed	0.50	58	31.03
	Roasted	0.48	52	33.23

Table 4.8 Effect of moisture content and pre-treatment on performance of nutmeg decorticator operating at 450 rpm

Moisture content (w.b)	Pre-Treatment	Mass of sample, kg	Mass of whole kernels, kg	Mass of broken kernels, g	Mass of unshelled nuts, g	Mass of shells, kg	Efficiency, %	Total recovery, %	Broken, %	Whole kernels, %	Unshelled kernels,%
12 %	Raw	0.50	0.322	15.5	9.5	0.157	98.11	67.00	3.08	63.92	1.89
	Steamed	0.50	0.303	35.0	4.0	0.158	99.20	67.60	7.00	60.60	0.80
	Roasted	0.49	0.329	13.0	13.0	0.134	97.34	69.91	2.66	67.25	2.66
14 %	Raw	0.50	0.293	17.5	27.5	0.164	94.52	61.83	3.49	58.35	5.48
	Steamed	0.50	0.284	30.5	26.0	0.162	94.82	62.65	6.08	56.57	5.18
	Roasted	0.50	0.279	10.5	60.0	0.153	88.05	57.67	2.09	55.58	11.95

Moisture content (w.b)	Pre-Treatment	Mass of sample, kg	Time taken for decortication, sec	Capacity (projected), kg/h
12 %	Raw	0.50	32	56.59
	Steamed	0.50	47	38.30
	Roasted	0.49	39	45.09
14 %	Raw	0.50	50	36.14
	Steamed	0.50	46	39.29
	Roasted	0.50	42	43.03

T_1N_1 	T_1N_2 
T_2N_1 	T_2N_2 
T_3N_1 	T_3N_2 

Where, T1, T2, T3 – without pre-treatment (raw), with pre-treatments (steaming and sand roasting)

N1, N2 – speeds of rotor pulley (300 and 450 rpm)

Plate 4.1 Performance of decorticator at 12 % moisture content

T_1N_1 	T_1N_2 
T_2N_1 	T_2N_2 
T_3N_1 	T_3N_2 

Where, T1, T2, T3 – without pre-treatment (raw), with pre-treatments (steaming and sand roasting)

N1, N2 – speeds of rotor pulley (300 and 450 rpm)

Plate 4.2 Performance of decorticator at 14 % moisture content

When the decorticator operated at a speed of 450 rpm for nutmegs at 12 and 14 per cent moisture content and three different pre-treatments (raw, steaming and roasting), the best overall performance was observed when nuts had 12 per cent moisture content and fed to decorticator without any pre-treatment. This combination of treatment (raw nutmeg having 12 per cent moisture content fed to decorticator operating at 450 rpm) had higher efficiency of 98.11 with lower breakage (3.08 %) than other pre-treatments combination.

4.3 Economics

The economics of the developed prototype decorticator and the cost incurred to decorticate one kilogram of nutmeg was determined taking into account the fixed and variable costs. The details are presented in Appendix II.

The cost incurred for developing the prototype decorticator was ₹ 6034/– which included the motor cost, material cost and fabrication cost i.e. labour charges. The total operational cost of the decorticator was 42.112 ₹/h which included the fixed cost and variable cost. The fixed cost consisted of depreciation (10%), interest (12%) and cost of maintenance (2%). While the variable cost included electricity charges at 4.50₹/h/kW. Taking the above variables and fixed costs, it required ₹ 0.79/– to decorticate 1 kg of nutmeg to get kernels.

Discussion

V. DISCUSSION

The results obtained in the investigation are critically discussed under the following headings:

- 5.1 Physical and mechanical properties of nutmegs and kernels at 12 and 14 per cent moisture contents
- 5.2 Development of a prototype decorticator for nutmegs
- 5.3 Performance evaluation of prototype decorticator for decortication of nutmegs
- 5.4 Economics of decortication process of nutmegs

5.1 Physical and mechanical properties of nutmegs and kernels at 12 and 14 per cent moisture contents (w.b.)

The physical and mechanical properties of nutmegs and kernels were studied, as these properties are necessary for development of a decorticator for nutmeg (Tables 4.1 and 4.2). It could be seen from the tables that there was no significant difference observed among the nutmegs at 12 and 14% moisture content (w.b.), and kernels at 12 and 14% moisture content with respect to geometrical mean diameter, sphericity, 100 nuts/kernels mass, porosity and compressive strength. However significant differences were observed with respect to true density, bulk density and angle of repose.

It was observed that the size of nutmegs and kernels at 14% moisture content was found to be higher than at 12% moisture content. The geometrical mean diameter of nutmeg at 14% moisture content (23.31mm) was reduced when its moisture content decreased to 12% (22.92mm) but statistically no significant difference attributed. The geometrical mean diameter decreases due to evaporation of moisture from the nutmeg. Similar thing happened with kernels, initially kernels at 14% moisture content were attached to the shell and had large geometrical mean diameter (20.37mm) which reduces after drying to 12% moisture content (19.79mm) and the kernels detached from the respective shell due to shrinkage after moisture evaporation (Figs. 5.1 and 5.2).

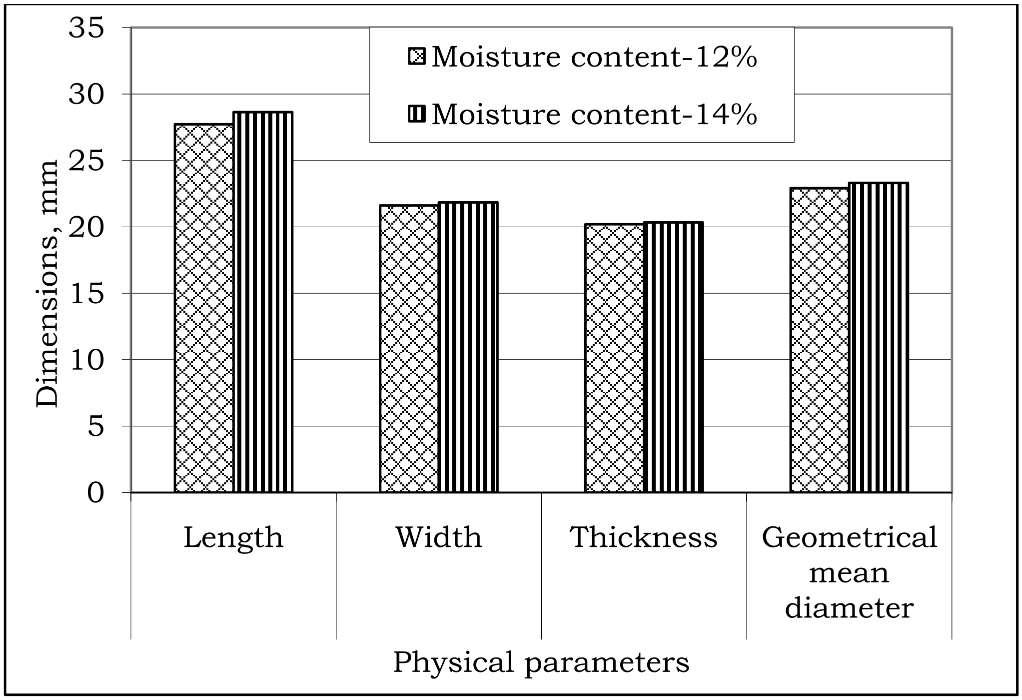

Fig. 5.1 Physical properties of Nutmeg

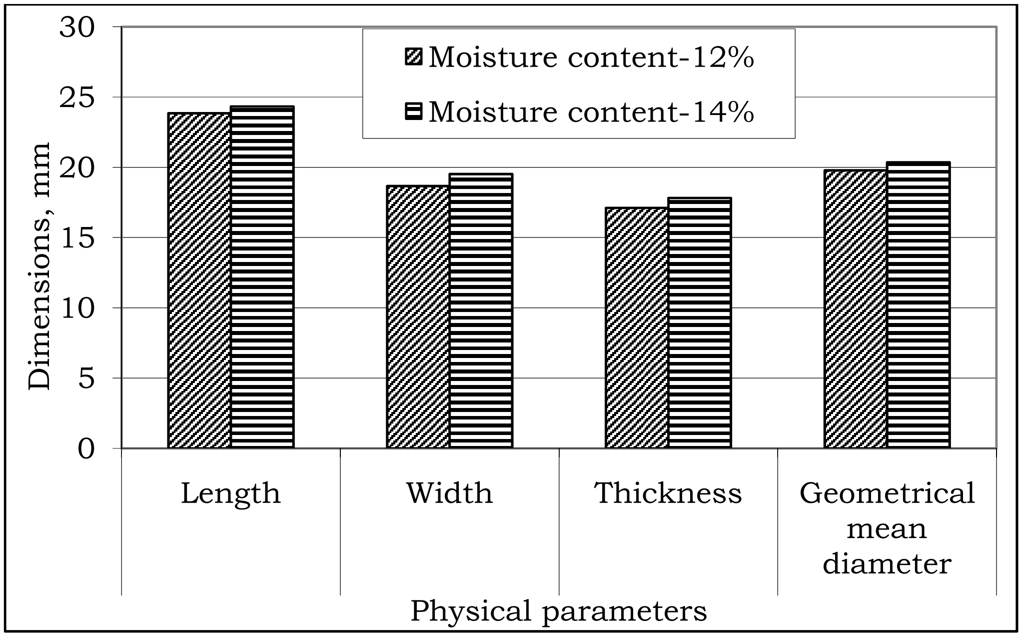

Fig. 5.2 Physical properties of Kernel

The sphericities of nutmeg and kernel at 12 and 14 % moisture content were almost same and hence no significant differences found, and the data were presented in Tables 4.1 and 4.2 (Fig. 5.3).

The coefficients of friction of nutmeg at 12 and 14 % moisture content were presented in Table 4.3. There was no significant difference observed among nutmegs at two different moisture contents with respect to different frictional surfaces of materials. But the nutmegs at 14 % moisture content had slightly higher coefficient of friction (0.3021) than at 12 % moisture content (0.2768) which may be due to higher moisture content. As moisture content reduced the surface become hard and smooth due to high oil content. As oil content at surface increased the friction between the surfaces get reduced thus causing reduction in coefficient of friction (Fig. 5.4).

The mass of nutmeg as well as kernel reduced due to reduction in moisture content from 14 per cent to 12 per cent. The mass of nutmeg and kernel were higher at 14 per cent moisture content (5.16 and 4.32g, respectively) and lower at 12 per cent moisture content (5.04 and 4.06g, respectively) (Tables 4.1 and 4.2) (Fig. 5.5).

The true density of nutmeg and kernel had a significant effect with respect to moisture content. At 14 per cent moisture content the true density (nutmegs-1133kg/m^3 and kernels-1197kg/m^3) was higher compared to 12 per cent moisture content (nutmegs-1012kg/m^3 and kernels-1109kg/m^3). It was observed that nutmeg size was higher at high moisture content and lower at low moisture content (Fig. 5.6).

The effect of moisture content on bulk density was significant because larger sized nuts had more pore space among them compared to smaller sized increasing the volume. At higher moisture, the mass of nutmegs and kernels was high resulting in higher bulk density (Tables 4.1 and 4.2).

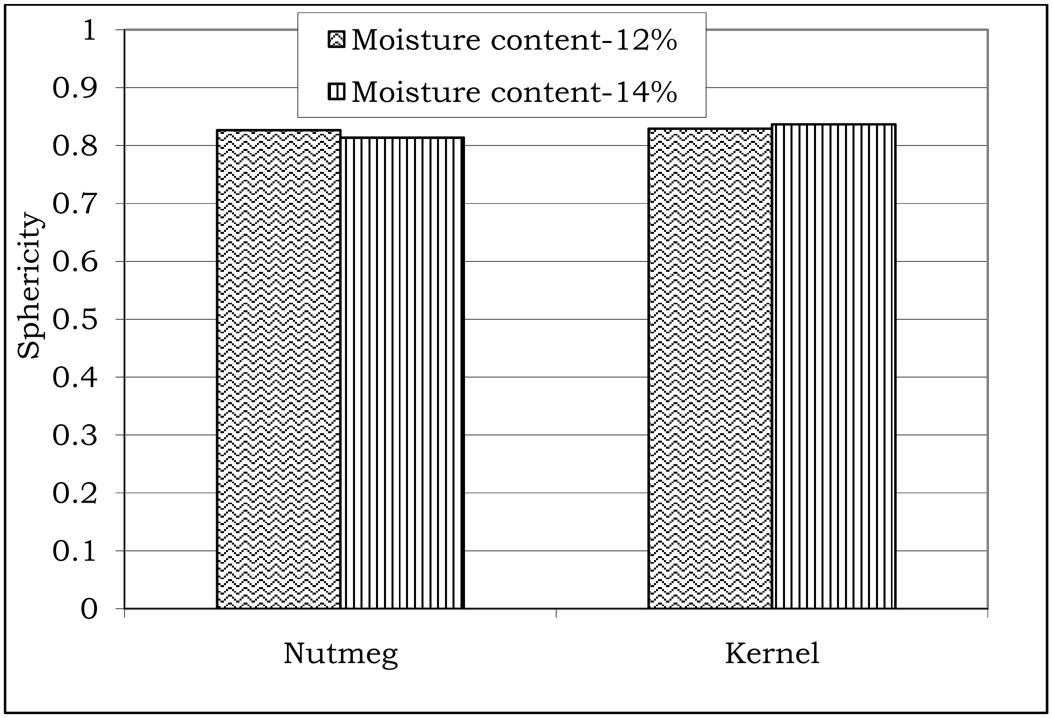

Fig. 5.3 Sphericity of nutmeg and kernel at different moisture contents

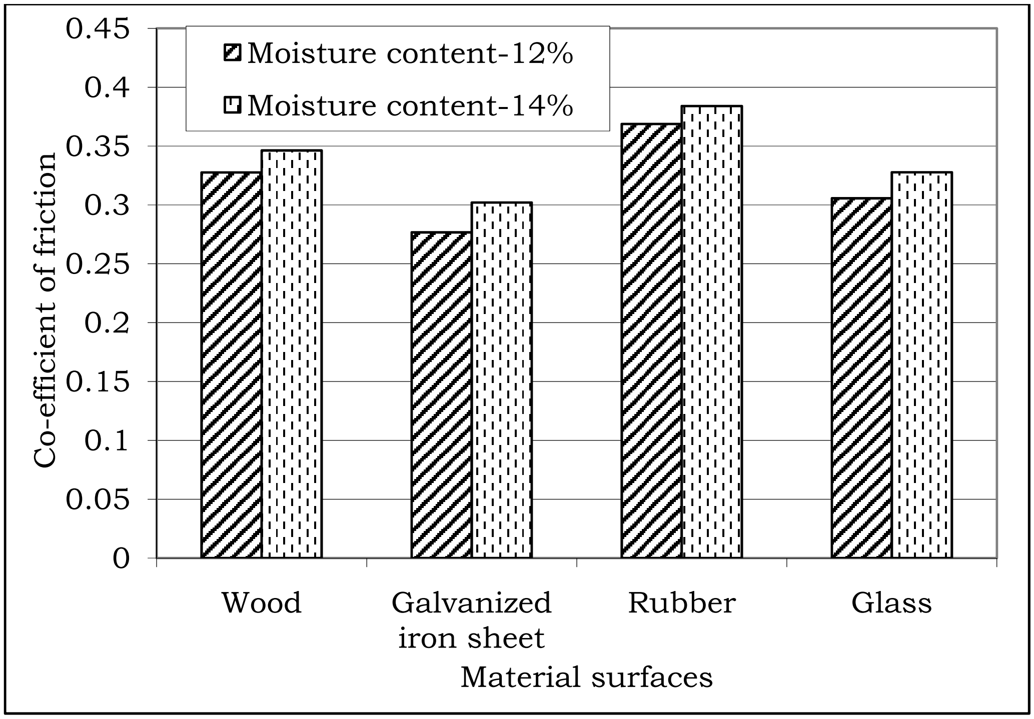

Fig. 5.4 Coefficient of friction of nutmeg on different surfaces

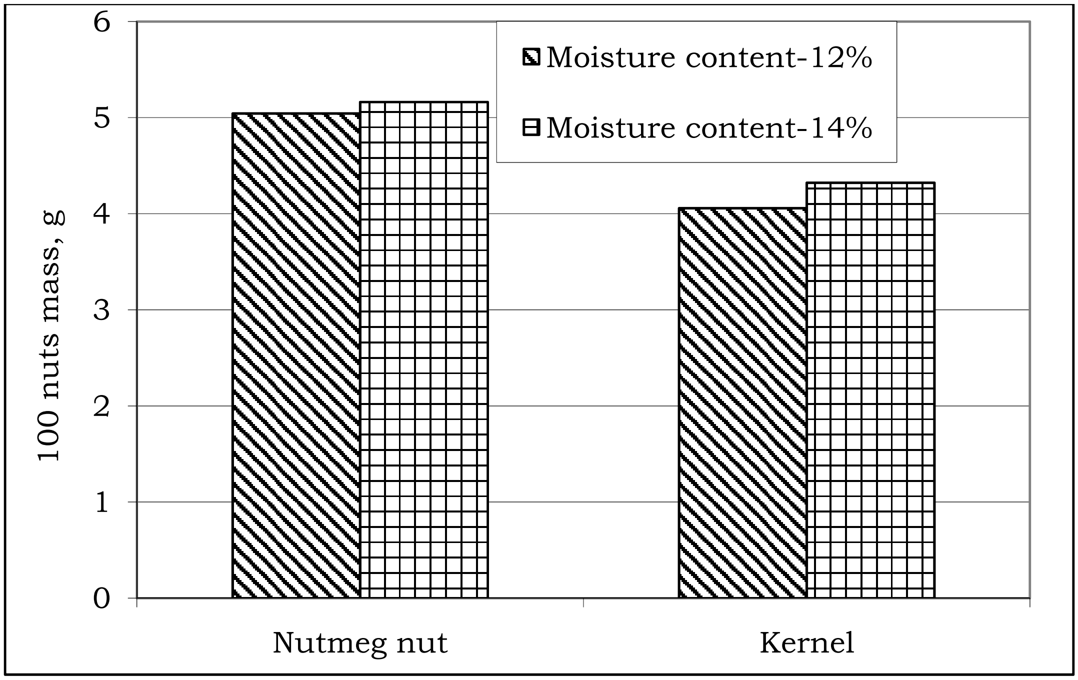

Fig. 5.5 100 seed mass of nutmeg and kernel

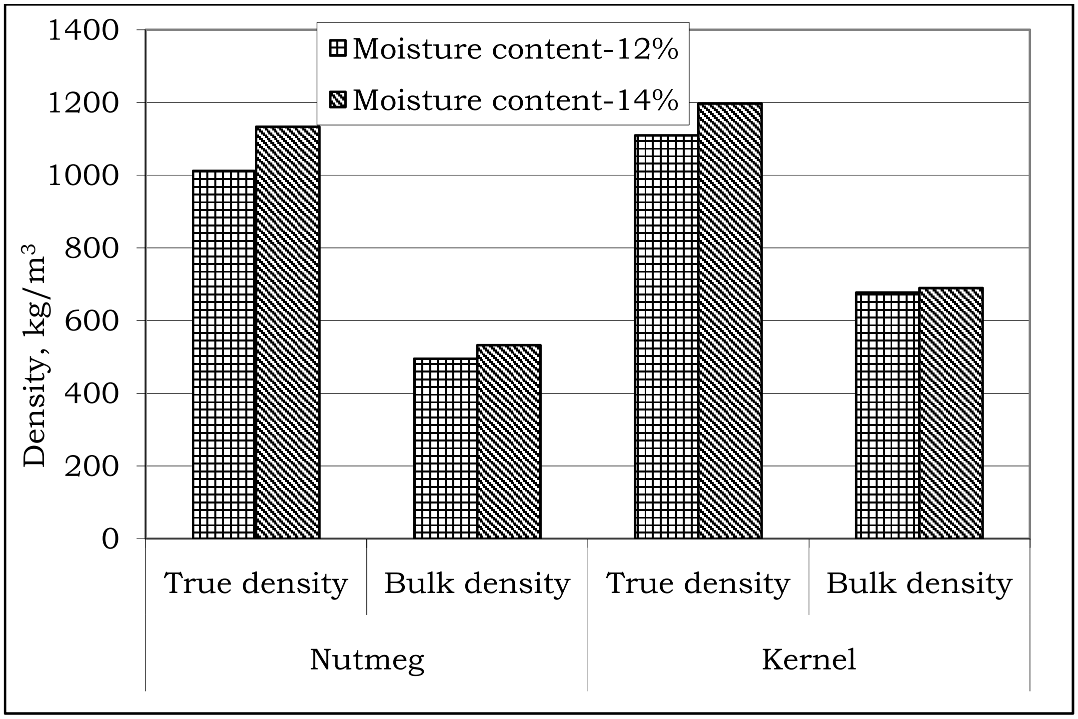

Fig. 5.6 Densities of nutmeg and kernel

The moisture content had no significant effect on porosity however its value was high at 14 % moisture content and low at 12 % moisture content for nutmegs as well as its kernels. The difference in the value may be due to variation in the size of nuts or kernels. The size of nuts and kernels were higher at 14 per cent moisture compared to 12 per cent moisture content.

The angle of repose was higher for kernels compared to nutmegs due to smaller size. There was significant difference between angle of repose of nutmegs at 12 and 14 per cent moisture content and angle of repose of kernels at 12 and 14 per cent moisture content (Fig. 5.7).

The compressive strength of nutmegs was higher at 14 per cent moisture content compared with compressive strength at 12 per cent moisture. The similar relation also observed for kernels. Further, there was no significant difference between compressive strengths at two different moisture contents. Higher average compressive strength of nutmeg at 14 per cent moisture was 385.79 N and that of kernel was 893.19 N (Fig. 5.8).

5.2 Development of prototype decorticator for nutmegs

As mentioned in chapter III (MATERIAL AND METHODS), the prototype decorticator was fabricated in the workshop of Post Harvest Technology Scheme, University of Agricultural Sciences, Bangalore. The machine parameters were standardized by taking various trials at different speeds, pre-treatments and different clearances. The decorticator was then analyzed for two cylinder speeds, three different pre-treatments to nutmeg at two moisture content and 2.1cm clearance between cylinder and concave. The machine parameters for raw nutmegs at 12% moisture content and cylinder speed of 450 rpm found to be optimum. This combination gave higher decortication efficiency and recovery with minimum breakage of kernels.

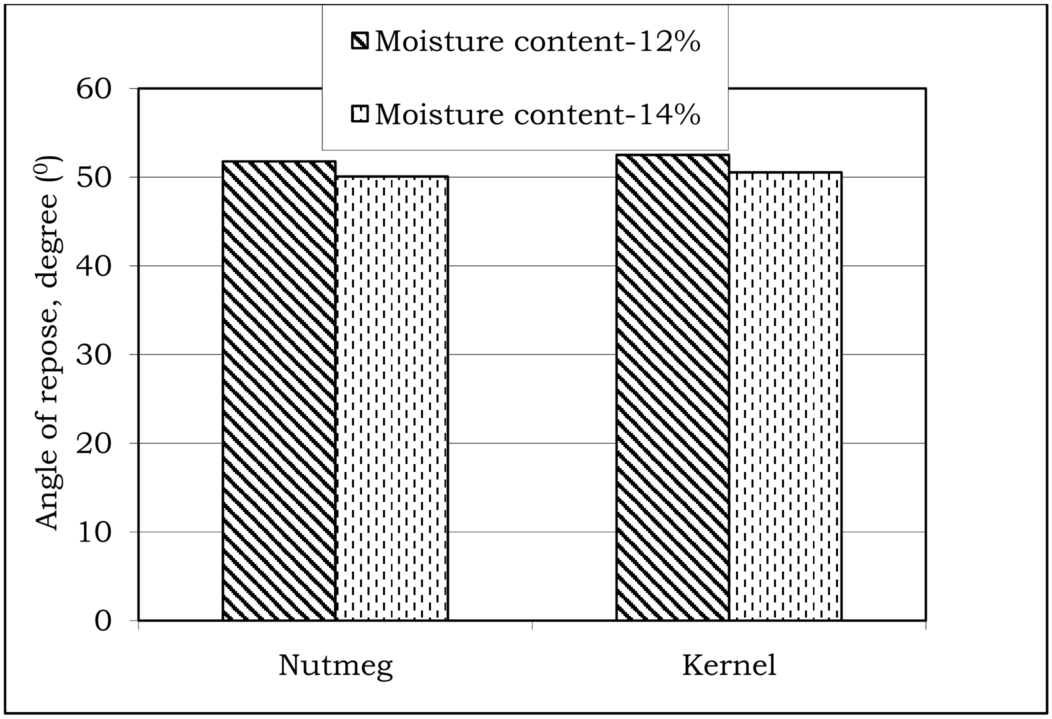

Fig. 5.7 Angle of repose of nutmegs and kernels

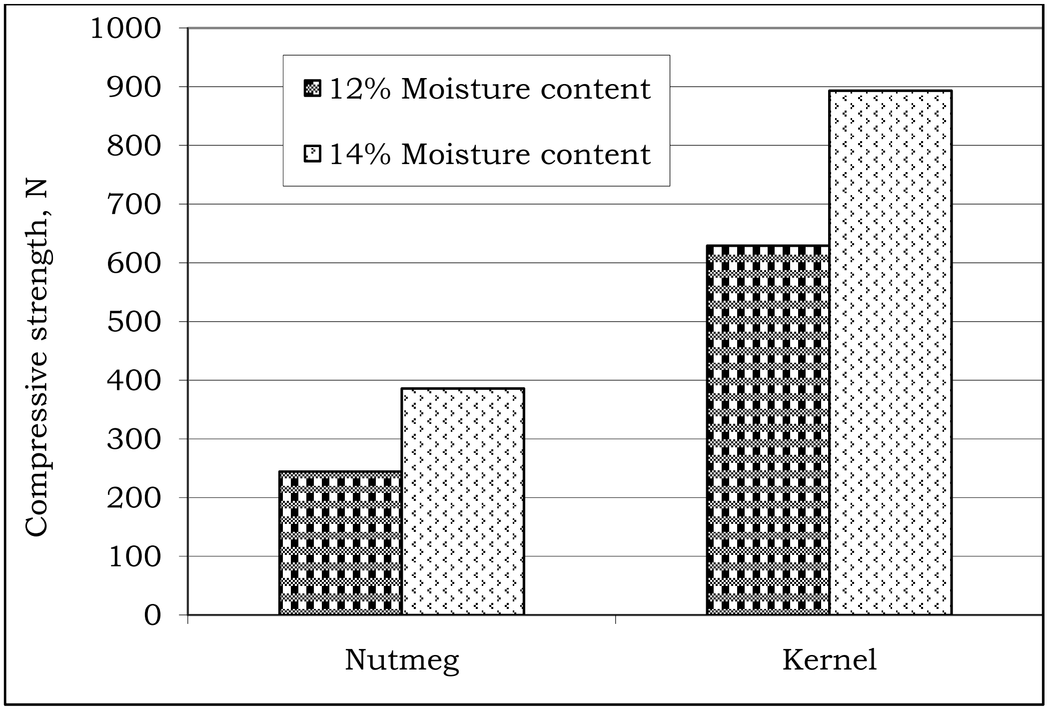

Fig. 5.8 Compressive strength of nutmeg and kernel at different moisture contents

5.3 Performance evaluation of prototype decorticator

5.3.1 Decortication efficiency

The decortication efficiency of nutmegs (99.20 per cent) were found significantly higher for the steamed nutmegs of 12 per cent moisture content fed to the decorticator running at the cylinder speed of 450 rpm compared to other combination of parameters. It might be due to the steaming at high pressure which expanded the shell, softened the nuts due to penetration of steam into the shell and air-curing followed by steaming which made shell ultimately harden. However after shelling, kernels became blackish leading to fewer buyers in the market. The cost of processing was higher compared to processing with raw nutmegs. There was significant effect of pre-treatment and cylinder speed on decortication efficiency. Higher decorication efficiencies were observed at the cylinder speed of 450rpm compared to running at 300rpm. Considering some negative effects in decortication of nutmeg by steaming, the second best efficiency (98.11 per cent) was observed when combination of raw nuts of 12 per cent moisture content were fed to the decorticator running at 450rpm. This combination had lower cost of processing (Fig. 5.9).

5.3.2 Total kernel recovery

Different pre-treatment had significant effect on kernel yield (Table 4.4). Higher kernel recovery observed in case of roasting treatment. The treatment combination such as feeding of roasted nutmegs at cylinder speed of 450 rpm gave higher kernel recovery (69.91 per cent) compared to other combinations. The main negative factor was reduction in the essential oils content of kernels due to volatility and may evaporate at higher temperatures due to low boiling point (Fig. 5.10).

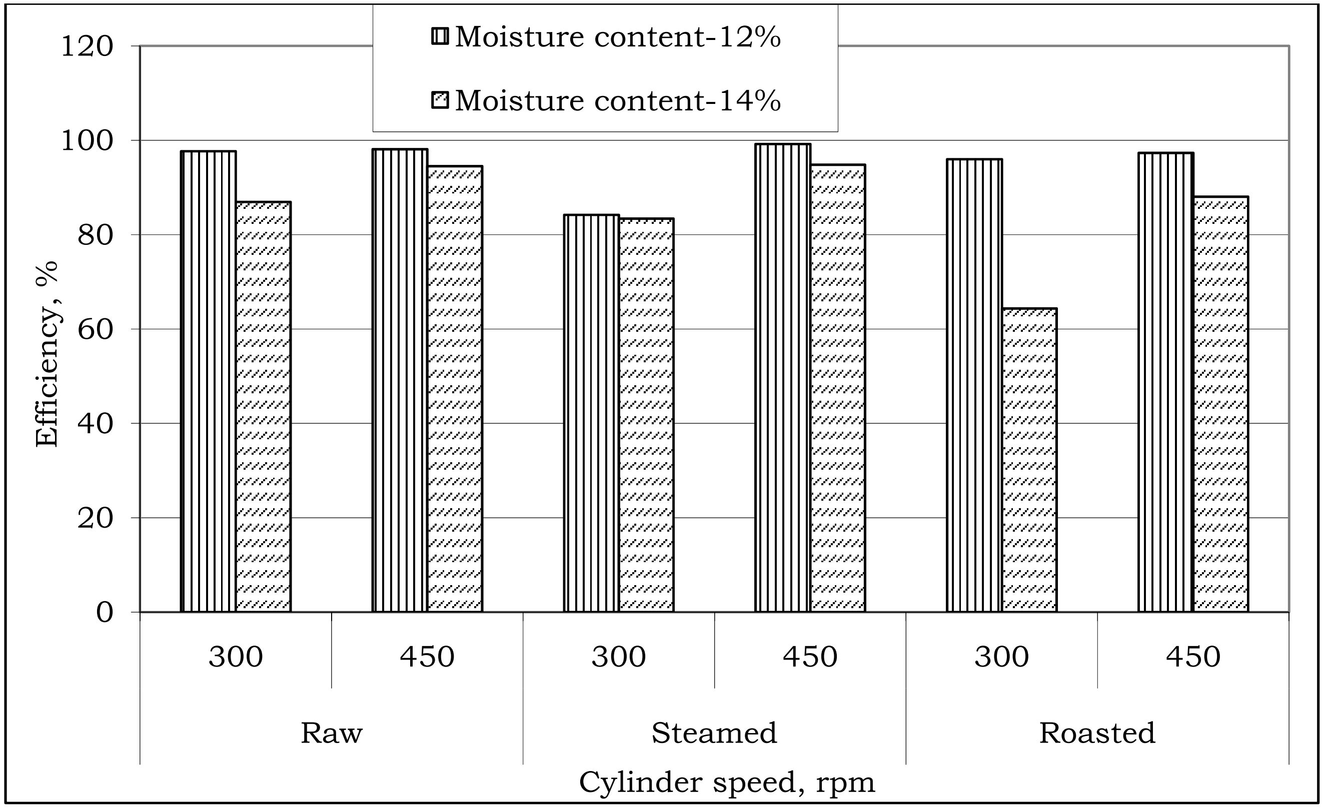

Fig. 5.9 Efficiency of decorticator at 12 and 14% moisture content

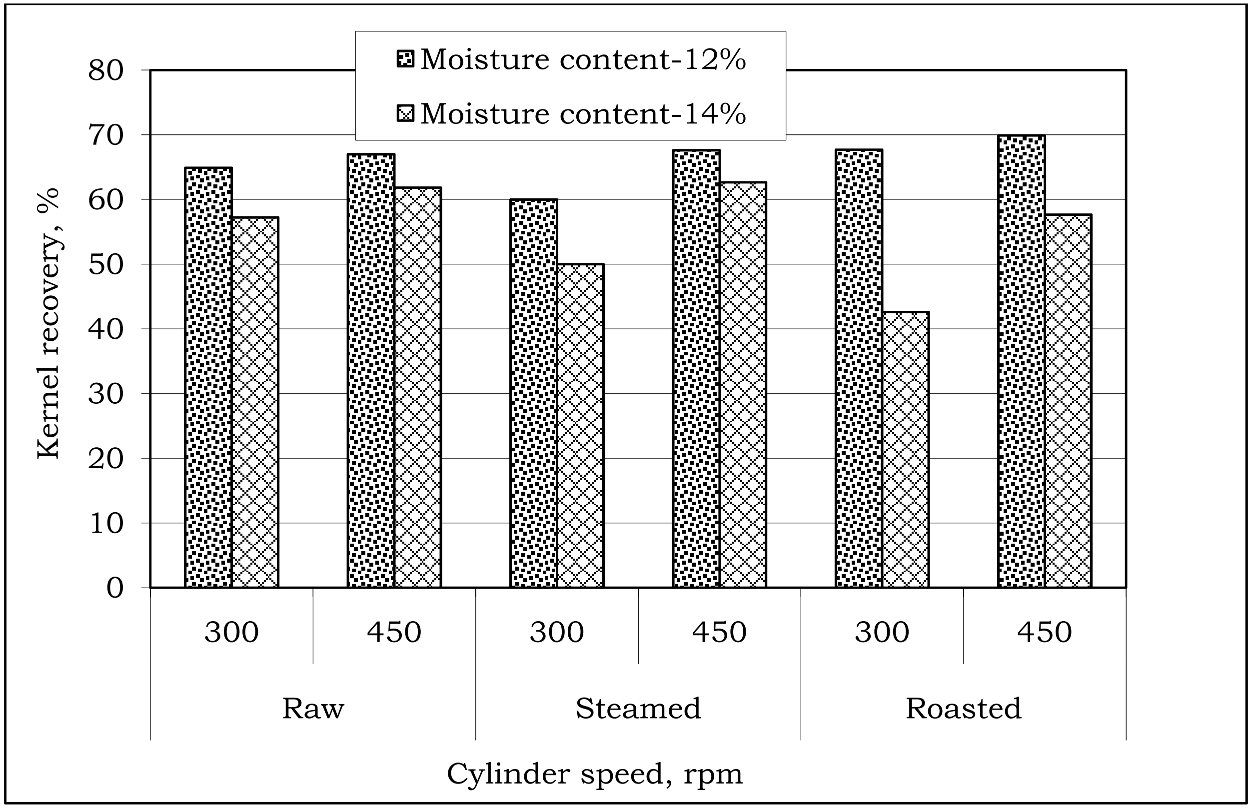

Fig. 5.10 Kernel recovery at 12 and 14% moisture content

5.3.3 Percentage of broken kernels

The percentage of broken kernels was found to be lower when roasted nutmegs at 14 per cent moisture content were processed at cylinder speed of 450 rpm. Due to removal of moisture content from kernel, it became harder than its shell. The lower percentage of broken kernels was 2.09 per cent and higher percentage was 9.80 per cent suggesting significant effect of pre-treatment and cylinder speed on the breakage of kernels (Fig. 5.11).

5.3.4 Percentage recovery of whole kernels

The whole kernel recovery was significantly affected by the pre-treatment and cylinder speed at two different moisture contents. Higher percentage of whole kernels (67.25 per cent) was observed when roasted nutmegs at 14 per cent moisture content were processed by the decorticator running at 450 rpm (Fig. 5.12).

5.3.5 Decorticator capacity

The capacity of nutmeg decorticator was found significantly different for each different pre-treatment and cylinder speed combination at two different moisture contents. Higher capacity of decortication (56.59kg/h) was observed when raw nutmeg at 12 per cent moisture (without any pre-treatment for shell softening) were processed by the decorticator running at cylinder speed of 450 rpm. This was perhaps due to the fact that the duration of decortication process was minimum. Steaming and roasting softens the nutmeg shell. However it needed higher shear stress while roasting needed higher impact strength than shearing which increased decortication duration than raw nutmeg processing (Fig. 5.14).

By analysing all factors such as percentage of breakage, whole kernels, efficiency, unshelled kernels and capacity, it was found that the roasting treatment at 12 per cent moisture content and cylinder speed of 450 rpm gave the best results.

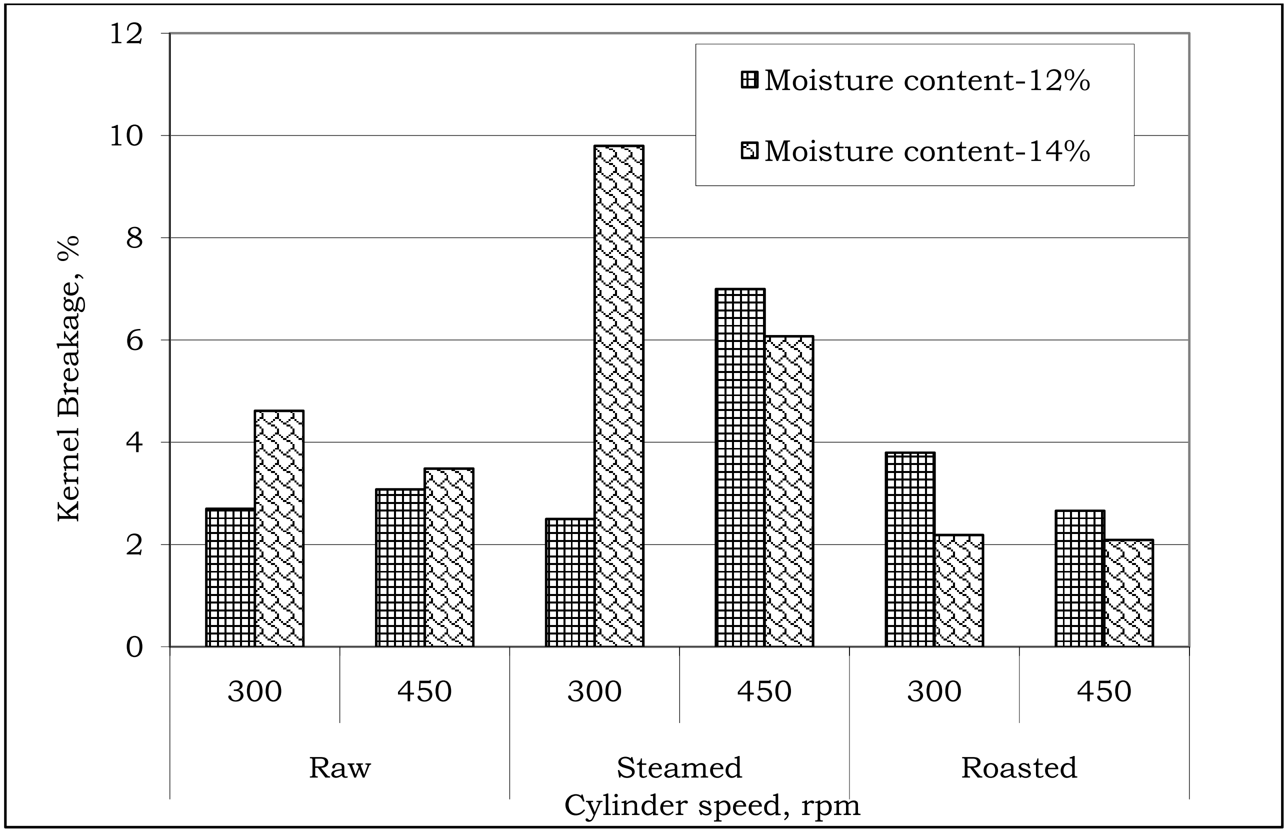

Fig. 5.11 Percentage of kernel breakage at 12 and 14% moisture content

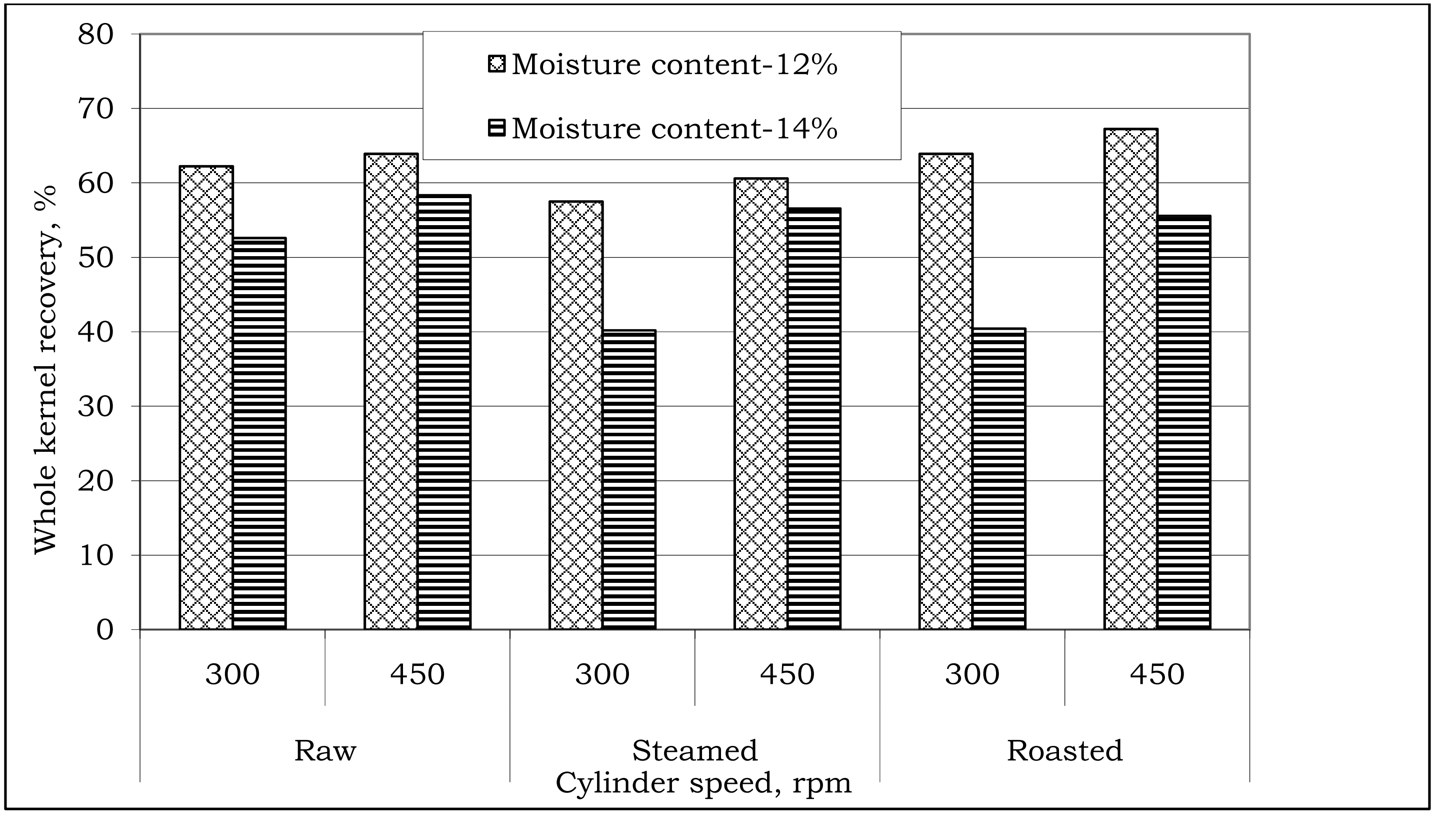

Fig. 5.12 Whole kernel recovery at 12 and 14% moisture content

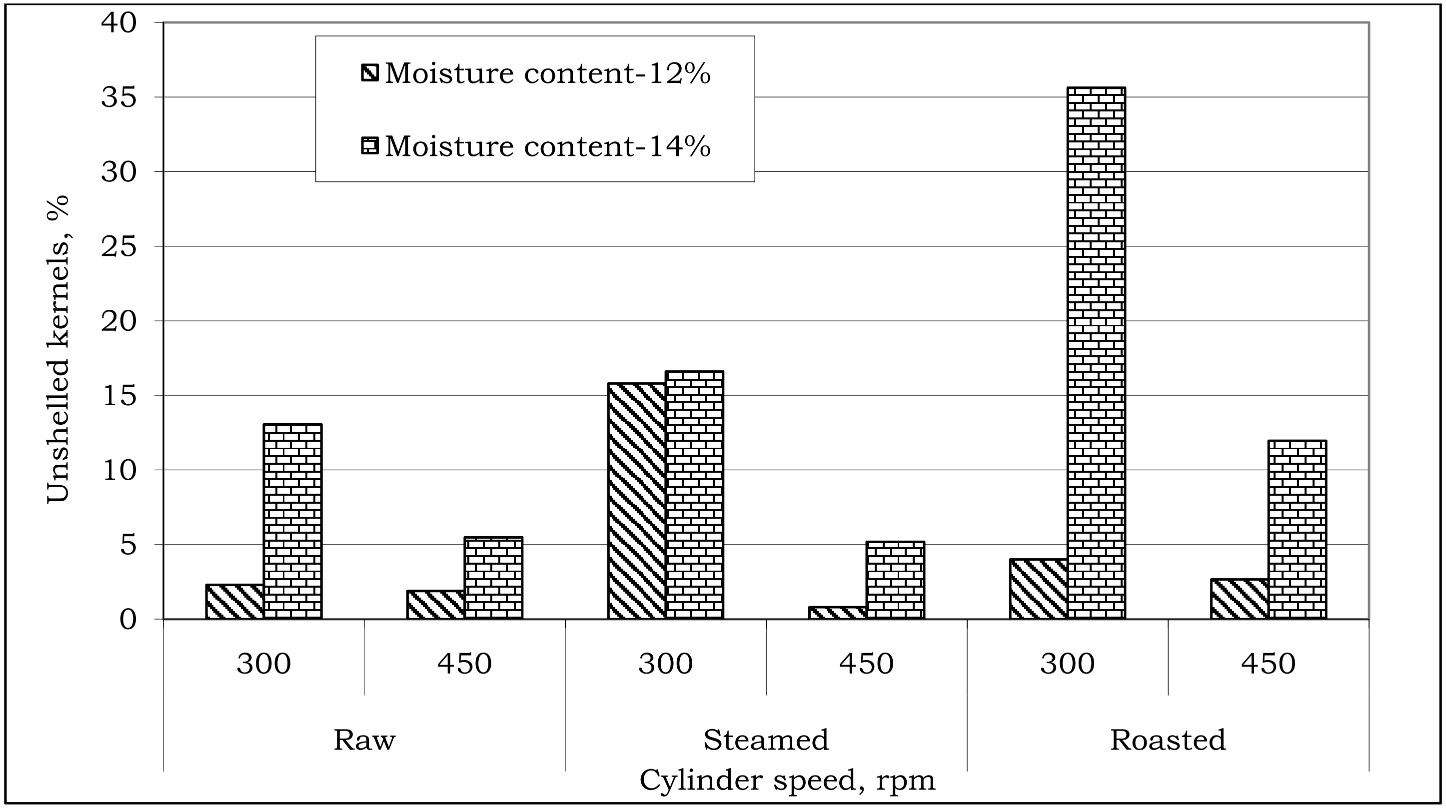

Fig. 5.13 Percentage of unshelled nutmegs at 12 and 14 % moisture content

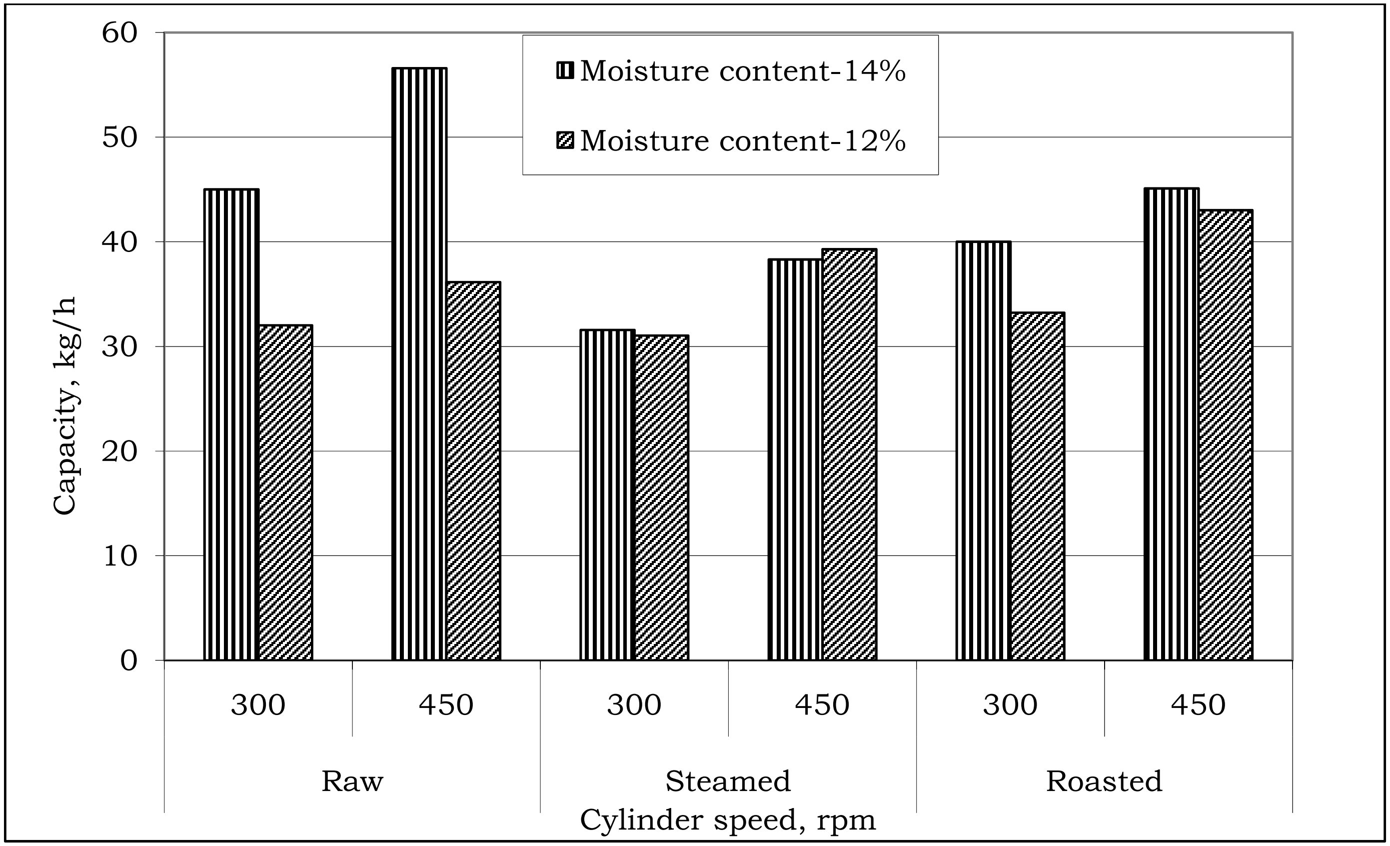

Fig. 5.14 Capacity of decorticator at 12 and 14% moisture content

5.4 Economics of decortication process

The cost incurred in decorticating one kilogram of raw nutmeg of 12 per cent moisture content to process into kernels using the developed prototype decorticator was only ₹ 0.79/– which was comparatively lower than manual decortication process. The electricity and labour costs accounted to 96.91 per cent of the total operational cost.

Summary

VI. SUMMARY

Nutmeg (*Myristica fragrans* Houtt.) is an important tree spice. Nutmeg and Mace are two different parts of same fruit of the nutmeg tree, *Myristica fragrans* Houtt. Nutmeg tree is indigenous to the Banda Islands in the Moluccas of Indonesia or Spice Islands. The species of genus *Myristica* are distributed from India and South-East Asia to North Australia and the Pacific Island. It is also grown on small scale in India, Sri Lanka, Chain, Malaysia, Western Sumatra, Zanzibar, Mauritius and the Solomon Island. In India, Nutmeg is mainly cultivated in Thrissur, Ernakulam and Kottayam districts of Kerala and part of Kanyakumari and Tirunelveli districts of Tamil Nadu (Sincair, 1958). Also, production of nutmeg is estimated to be 2,500-2,600 tonnes only from an area of about 13709 ha (Joseph, 2010).

Though the process of decortication of nutmegs to separate kernels is done manually using a hammer or mechanically by a cracking device. Seed coat is cracked and removed by impact. There is good scope for development of new machine (decorticator) as traditional process is time and labour consuming. Hence, this study entitled “Development of Decorticator for Nutmeg (*Myristica fragrans* Houtt.)” was undertaken with specific objectives and the results of the investigation are summarized below.

The physical properties of nutmegs and their kernels at two different moisture contents were studied by using standard procedures given by Mohesnin (1970). When the recorded data analyzed statistically, it was observed that the physical properties like geometrical mean diameter, sphericity, 100 nuts mass, porosity and mechanical property like compressive strength of nutmegs and kernels had no moisture content effect on them, respectively. But some physical parameters such as true density, bulk density and angle of repose of nutmegs and kernels had some effect of moisture content and some significant differences observed between their readings. Non-significant differences were observed in case of frictional properties of nutmeg for different materials with respect to moisture content.

The developed prototype decorticator was tested using nutmegs with different treatment combinations for variation in moisture content of nutmeg seeds, variation in rotational speed of cylinder and variation in shell softening treatment given to nutmegs such as raw feeding, roasting and steaming.

1. Nutmegs at 12 % moisture content steamed for shell softening process and fed to the decorticator rotating at 450 rpm, gave higher decortication efficiency (99.20%) than other combinations.
2. Higher kernel recovery observed when nutmegs having 12 % moisture content and fed to decorticator running at cylinder speed of 450 rpm.
3. Maximum whole kernel recovery with minimum kernel breakage was observed when roasted nutmegs with 12 % moisture content fed to the decorticator at 450 rpm.
4. The capacity of decorticator was observed higher when raw nutmeg at moisture content 12 % were fed to decorticator running at speed 450 rpm.

By considering the performance of each pre-treatment, the total duration of decortication, labour and energy requirement, it was observed that feeding raw nutmeg of 12 % moisture content to the decorticator rotating at 450 rpm cylinder speed gave the best decortication performance.

The cost of the developed prototype power operated nutmeg decorticator was ₹6034/–, which includes the motor, material, and fabrication costs. The operational cost of the decorticator was ₹44.112/h, which included the fixed and variable costs. The cost incurred to decorticate 1 kg of raw nutmegs at 12 % moisture content to produce kernels was ₹ 0.79, only.

FUTURE LINE OF WORK

1. There is a need to conduct studies on storage of nutmeg kernels with respect to bio-chemical changes (changes in essential oil content during storage), and packaging studies to export nutmeg.
2. There is need to create awareness among farming communities and industries on adoption developed nutmeg decorticator for decortication of nutmegs.

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Appendices

APPENDIX-I

Specification and cost of developed prototype decorticator for decortication of nutmegs

Sr. no.	Material	Size	Quantity	Total cost of materials (₹)
1.	Mild steel angle	3.5 × 3.5 cm	20 kg	700
2.	Mild steel flats	1.9 cm	2 kg	70
3.	6 mm round rod	0.6 cm	2 kg	50
4.	Mild steel sheet	18 gage	0.5 kg	100
5.	Mild steel shaft	2.5 cm	2 kg	150
6.	Sealed bearings and cover	2.5 cm	2	300
7.	Pulley (big)	25 × 2.54 cm	1	250
8.	Speed cone	1:1.5	1	200
9.	Electric motor	0.5 hp	1	2000
10.	V-belt	-	1	90
11.	Tyre Rubber	30 × 30 cm	-	150
12.	Miscellaneous	-	-	250
13.	Total cost	-	-	4310
14.	Labour cost (40%)	-	-	1724
	Total cost of machine	-	-	**6034**

APPENDIX-II

COST ECONOMICS OF NUTMEG DECORTICATOR

1. **Fixed cost**
    a. Material cost + fabrication cost (C) = ₹ 6034
    b. Salvage value (S) @ 10 % of total cost of decorticator = ₹ 603.4
    c. Annual use (U) (Expected operational hours) = 700 h
    d. Expected life of decorticator (L), years = 10 years

i. Depreciation (D)

$$D=\frac{C-S}{UL}$$

$$=₹\ 0.776/h$$

ii. Interest on capital investment @ 12 % per annum on fixed price (I)

$$I=\frac{C+S}{2U}\times 0.12$$

$$=₹\ 0.569/h$$

iii. Repair / maintenance cost @ 2 % (R)

$$R=\frac{C}{UL}\times 0.02$$

$$=₹\ 0.017/h$$

Total fixed cost (D + I + R) = 0.776+0.569+0.017 = ₹ 1.362/h

2. **Operational cost/Variable cost**

i. Power consumption = 1.5 kW/h

(Energy cost @ 3.40/units) (P) = ₹ 5.25/h

ii. Labour cost @ ₹ 150 per day (8 hours) per person

(2 men are required = 2×18.75) (b) = ₹ 37.50/h

Total variable cost (P + b) = 5.25+37.5 = ₹ 42.75/h

Total cost of operation (A) = Total fixed cost + Total variable cost

= ₹ (1.362+42.75)/h

= ₹ 44.112/h

When the decorticator was performing at high decortication efficiency and having a maximum whole kernel recovery of nutmeg kernels, the average throughput of machine was 56.59 kg/h.

One kilogram of nutmegs costs ₹ 0.79 for decortication process to produce kernels.

Cost analysis for decortications of 1 kg nutmeg

Cost of nutmeg	= ₹ 250/kg
Transportation cost	= ₹ 2/kg
Labour cost	= ₹ 0.66/kg
Decortications cost	= ₹ 0.79/kg
Total cost	**= ₹ 253.45/kg**

Benefit from 1 kg nutmegs

The optimum overall performance of decorticator was found when decorticator was running at 450 rpm and fed with raw nutmegs of 12 % moisture content. By using the developed decorticator, 1 kg of nutmegs yielded about 643 g of whole kernels and 31 g of brokens.

The sale price of 1 kg of nutmeg kernels is about ₹ 450/kg while sale price of broken kernels is about ₹ 400/kg.

The cost details presented here under

Cost of the whole kernels	= ₹ 289.35/kg
Cost of the broken kernels	= ₹ 12.4/kg

Total benefit = ₹ 301.75/h

Cost benefit ratio = 253.45:301.75

Cost benefit ratio = 1:1.19