Study on Engineering Properties of Rudraksha (*Elaeocarpus Ganitrus Roxb.*) for Design and Development of Agricultural Processing Units

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ABSTRACT:-Rudraksha (*Elaeocarpus Ganitrus Roxb.*) exhibits multi-elemental (macro and micro elements) composition by virtue of which it is utilized in production of medicines, cosmetics, spiritual gems and number of activities. The use of Rudraksha is increasing with passage of time and its cultivation is started in plains. Earlier studies were based on pharmaceutical and chemical properties. Its physical and engineering properties were not studied yet which varies largely with climate, soil type and altitude. Present study is based on useful physical and engineering properties of Rudraksha green fruits and beads to extract useful information for design and development of grading system for value addition, conveying and milling units for design and development of processing units to satisfy global requirement of Rudraksha. The texture, tri-axial dimension, frictional properties,density of green fruit and beads of Rudraksha were studied. The tri-axial dimension of Rudraksha green fruit is ranging from 18 mm to 32 mm. The diameter of dry beads of Rudraksha varies from 14.5 mm to 24.5 mm. The angle of internal friction for glass surface ranges from 22.02 to 24.27°, for galvanized iron sheet it ranges between 25.01 to 31.81° and for plywood surface it is found from 28.85 to 34.01.The arithmetic mean of density of Rudraksha beads of large, medium and small size are 0.8 g/cc, 1.15 g/cc and 1.01 g/cc with standard deviation of 6.6 %, 8.4 % and 10.3 % respectively. On the basis of these studies more economic returns can be obtained on grading due to value addition. Frictional properties (angle of repose and angle of internal friction) results in design of storage structures (bunker and silos), conveyors and feed hoppers to regulate flow rates. These studies could change socio-economic status of marginal and small farmers in hilly region as well as in plains.

Keywords: - Rudraksha, Grading, Coefficient of Friction, Conveying, Angle of Internal Friction, Green Fruit, Beads etc.

1.INTRODUCTION

Rudraksha (*Elaeocarpus Ganitrus Roxb.*) is considered as versatile material due to its use in numerous useful work. Presently, 38 varieties of Rudraksha is recognized and cultivated in Nepal, Indonesia, Java, Sri-Lanka, India and some other countries of south–east Asia. In India it is cultivated in Assam, Bihar, Bengal, Himalayan Strips, and Garhwal region, Dehradun, Madhya Pradesh and Maharashtra, Sikkim. Green fruit of Rudraksha is harvested for further utilization as different products to avoid drudgery of peeling. To obtain beads peeled ample is stream washed, dried. Further processing is dependent on utilization (1-4). It is used as Ratna in garland to medicinal drug due to its multi-elemental composition for curing several severe ailments like heart attack and cancer. It is also utilized for medicinal cosmetics to cure sinus and number of skin diseases. It is considered to have very high cosmic force due to its link with eye of Lord Shiva in various old literature of Hindu Mythology. It is grown all around the world under favorable environmental conditions and varies in shape, size and surface strips (facets) extending on its surface (popularly known as Mukhi). It is not only an element to hang in the neck of saints as garland. Roy (1993) found that Rudraksha beads possess inductive and electromagnetic properties and

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controls the human activities through direct action on central nervous system. Macro-nutrients available in Rudraksha beads are Carbon (50.024%), Hydrogen (17.798%), Oxygen (30.4531%) and Nitrogen (0.9461%) and many micronutrients in small proportions are also available in small proportions like Sodium, Alluminium, Potassium, Calcium, Magnesium, Iron, Cobalt, Nickel, Copper, Chlorine, Zinc etc. The multi-elemental composition of Rudraksha makes it suitable for undergoing through various physico-chemical processes to satisfy human requirements through various industries, research centers. Morphological characteristics changes (5-7).

2.MATERIALS AND METHODS

2.1 TEXTURE

The texture of Rudraksha green fruit is smooth or plain. The kernel obtained after removal of uppermost layer resembles to vesicular and amygdaloidal texture of vesicular basalt rocks formed due to escape of gases from molten magma through due to volcanic eruptions. Similar to the rock vesicles are found all around the surface of Rudraksha kernel but these vesicles are empty compared to vesicular basalt rock in which vesicles are filled with minerals. So, the texture of Rudraksha kernel is said to be vesicular. Texture is very important property of a material which influences number of properties of a material. Surface roughness, coefficient of friction (static and dynamic friction), angle of repose etc which is used in design of storage structures (storage bins & silos), design of suitable hopper for feeding during milling and developing a conveyance system for movement of grains from one place to another place. The textural properties are analysed generally with the help of texture analyser which shows hardness of shell and magnitude of impact force to break the shell. The kernel is placed at impact platform in different orientation with varying dimensions. The beads of different shape and size are tested by applying increasing magnitude of forces and the magnitude of force should be noted carefully at the time of break.

Fig.1.a. Vesicular basalt rock

Fig.1.b. Micrograph of Rudraksha bead

2.2 TRI-AXIAL DIMENSIONAL AND SPHERICITY

To determine grain size distribution of green fruit of Rudraksha to know the range of green fruit size and find its sphericity used in design consideration of hopper and discharging chute due to its direct influence on frictional properties. Randomly selected fifteen samples of large, medium and small green fruit of Rudraksha from pile of freshly harvested Rudraksha green fruit.Tri - axial dimension is taken with the help of Vernier Caliper of sensitivity 0.01 mm. First of all largest dimension was designated as 'a', dimension perpendicular to it was designated as 'b' and dimension mutually perpendicular to a and b was designated as 'c'. Tri-axial dimensional analysis can also helps us for primary classification of green fruit as well as beed into large, medium and small for value addition during marketing, design of sieve orifice and design of suitable conveyance system for various stages of processing (9-10). The sphericity of material is calculated from the equation (i) as shown below

Sphericity $= \frac{(a*b*c)^{\frac{1}{3}}}{a}$………………………………………….. 2.2. (i)

2.3 DETERMINATION OF COEFFICIENT OF FRICTION AND ANGLE OF INTERNAL FRICTION:-

2.3.1 Inclined Angle Apparatus:-To determine optimum slope to be provided in conveyance system for movement of raw green fruit through conveyor, hopper and design of suitable storage structure based on it.The coefficient of friction for different slope is determined with the help of Inclined Angle Apparatus which is a set of a 60 cm long adjustable platform for changing the surface by changing base plate fitted on it with clip. It is provided with a wooden pan of 128.20g and steel pan of 28.79g with Hooke and string arrangements. The selected samples of large green fruit of Rudraksha is being weighed, kept in wooden pan and positioned at the end of sliding platform with changeable upper surface. On the other side, the steel pan is suspended in the air and weights are being applied with increasing their magnitude by a smaller unit so that we can observe the slide of wooden pan towards upper side. The ratio of vertical weights to horizontal weigh is termed as coefficient of friction and the corresponding angle is called internal angle of friction. This angle plays very significant role in design of conveyor system, storage structures, handling equipments.

Fig.2.3. a. Inclined Angle Apparatus **Fig.2.3.b**.Reading of Inclined Angle Apparatus

2.3.2 CONICAL FUNNEL METHOD: - The Rudraksha beads are filled in conical funnel or any other tapered bottle and allowed to fall slowly by adjusting the proper clearance from surface at which coefficient of friction is to be determined. The experiment is replicated three to five times or more and horizontal as well as vertical dimensions are noted as vertical height (H) and horizontal expansion(L)of bead in stable state are noted. The angle of internal friction or angle of repose is measured as

$\alpha = \tan^{-1}\{\frac{2*H}{L}\}$…………………………………………………………2.3(ii)

2.4 DENSITY AND SPECIFIC GRAVITY

The mass of a substance present in unit volume is termed as density. The density in its natural state is called bulk density and density of dry matter of a body contained in it is termed as dry density. Generally bulk density is measured by liquid displacement method and dry density is determined by exposing given sample under oven drying. Specific gravity is also determined using pycnometer method, 500 ml flask and some other similar analytical techniques. The density or specific gravity of Rudraksha is determined to determine its property for gravimetric separation, deciding the optimum speed of motor during grading, speed of conveyor and type of conveyor used for feeding and spacing of pulley to support them on track. Density is the ratio of its mass to its volume at natural conditions.

Bulk density (B.D) $=\frac{Total\ mass\ of\ \ Sample}{Total\ volume\ of\ sample}$…………………………………2.4(i)

Dry density (D.D) $=\frac{Total\ mass\ of\ oven\ dried\ \ Sample}{Total\ volume\ of\ oven\ dried\ sample}$………………………..2.4(ii)

Specific Gravity (G) = $\frac{Mass\ of\ a\ particular\ volume\ of\ Sample}{Mass\ of\ same\ volume\ of\ water\ molecule}$…………………2.4(iii)

2.5 MORPHOLOGY:-The morphology of Rudraksha bead is very important parameters which convey number of useful information regarding external as well as internal characteristics. The number of facets (Mukhi) present on the outermost surface is same in number to the number of chamber present inside and voids spaces available inside a bead. It is useful to understand many useful thermal, electrical and mechanical properties of bead. Morphology reflects shape and textural properties simultaneously. It also decides thermal diffusivity for flow of heat during heat treatment and rupture produced on application of forces.

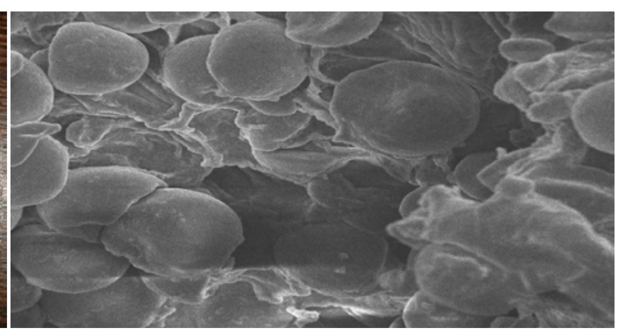

Figure. 2.5.a. Morphology of Rudraksha Bead**Figure. 2.5.b.** Void spaces inside the Bead

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3. Results and Discussion: -

3.1 TEXTURAL ANALYSIS: - The study of texture provides us information regarding hardness or firmness of material. It characterizes compressive strength by application of impact force. The t texture of Rudraksha green fruit is very soft and the texture of dry bead is very high. The magnitude of impact force is applied in various planes on a platform in compression testing machine ranging from 1020 N to 3020 N. The hardness is increasing with increase in dimensions of bead

3.2 TRI-AXIAL DIMENSIONAL ANALYSIS: - The diameter of freshly harvested Rudraksha green fruit varies from 16 mm to 32 mm. The variability in its dimension propels its classification into different classes on the basis of particle size distribution. So, based on observation from above tables, three classes are prepared on the basis of average of largest dimension. It will help us in value addition during marketing of raw harvested fruits. Above study is also helpful in developing a suitable manual or motorized grading unit to classify the fruit into various grades before undergoing to peeling and milling. It will be helpful in deciding clearance in milling machine. The average sphericity of fruits not varies largely from one another but they are showing variability from smaller to larger.

Table 3.1 Dimension of Various Grades of Green Fruits of Rudraksha

Sl. No.	Class	Average diameter(mm)
1	Small	<22mm
2	Medium	22-26 mm
3	Large	> 26 mm

Similarly the average diameters of large, medium and small beads of Rudraksha are found 23 mm, 20 mm and 18 mm.

Fig.3.2. a. Variation in size of beads

Table 3.2.Variation in mean thickness of pulp layer over bead for large, medium and small:-

Sl. No.	Mean Diameter of Large(mm)		Mean Diameter of Medium(mm)		Mean Diameter of Small(mm)	
	Green Fruit	Dried Bead	Green Fruit	Dried Bead	Green Fruit	Dried Bead
1	29.0	21.16	24.50	19.09	21.94	17.53
2	26.7	21.21	21.94	19.06	19.26	17.27
3	25.8	20.25	23.24	18.87	19.42	17.33
4	24.2	20.37	20.85	18.89	19.59	18.51
5	23.2	20.24	21.97	18.85	19.24	18.17
6	23.1	20.78	21.89	17.79	20.98	18.23
7	25.4	20.64	23.21	17.57	19.39	17.88
8	26.0	20.55	22.28	18.07	20.98	17.66
9	25.1	21.60	22.58	17.33	19.29	17.82
10	27.2	20.83	21.99	17.31	20.98	17.86
11	26.1	20.26	20.60	16.39	20.32	16.38
12	23.2	20.29	20.27	16.80	19.66	17.48
13	26.0	19.63	22.31	16.51	21.47	17.24
14	27.9	20.78	22.28	16.39	22.28	15.95
15	27.7	20.14	23.24	16.37	17.73	16.41

Above plot reveals that the mean diameter of green fruit is larger than the beed obtained on peeling the pulp significantly. The mean thickness of green layer is about 5.18 mm. The thickness of pulp layer ranges from 2.35 mm to 7.39 mm. The beed diameters are not directly proportional to corresponding green fruit diameters.

Above plot for medium green fruit and beed mean diameters reveals that the mean diameter of green fruit is larger than the beed obtained on peeling the pulp significantly in medium size also. The mean thickness of green layer is about 4.52 mm ranging from 1.96 to 6.86. The beed diameters are independent of corresponding green fruit diameters in medium size green fruit also.

The above plot reveals that the thickness of pulp layer around the beed is minimum for small size green fruit of Rudraksha. The mean thickness for pulp is 2.52 mm in small green fruit for a range of 1.07 mm to 4.41 mm.

(d) Variation in sphericity of green fruits of Rudraksha

Sl. No.	Sphericity of large	Sphericity of medium	Sphericity of small
1	0.9048	0.9074	0.9140
2	0.9207	0.9140	0.8676
3	0.9211	0.9294	0.8826
4	0.9296	0.8687	0.9330
5	0.8921	0.9550	0.8649
6	0.8566	0.9122	0.9120
7	0.9083	0.9283	0.9235

8	0.8958	0.9282	0.9120
9	0.9363	0.9031	0.8769
10	0.9082	0.8659	0.9120
11	0.8992	0.8582	0.9238
12	0.9064	0.8445	0.9362
13	0.9273	0.9142	0.8260
14	0.8986	0.9282	0.9282
15	0.9220	0.9294	0.8865

The shape of large green fruit of Rudraksha is more uniform compared to medium and small green fruits. As plot reveals the variability in shape of small green fruit is maximum whereas the mean sphericity for all three groups is almost same.

(e) **Variation in sphericity of dried beads of all grades: -**

Sl. No.	Sphericity of large	Sphericity of medium	Sphericity of small
1	0.8780	0.8600	0.8988
2	0.8988	0.8666	0.8993
3	0.8882	0.8738	0.8667
4	0.8856	0.8664	0.8730
5	0.8649	0.8728	0.8819
6	0.9275	0.8895	0.9023
7	0.8785	0.8700	0.8637
8	0.8935	0.8989	0.9010
9	0.8817	0.8667	0.9001
10	0.8699	0.9014	0.9208
11	0.8808	0.8908	0.9000
12	0.8821	0.8797	0.8738
13	0.8963	0.8877	0.9098
14	0.9033	0.8908	0.8861
15	0.8914	0.9097	0.9220

The mean sphericity in all three classes of dried beed has insignificant variability. The sphericity and variability of large beed is found highest individually. The mean sphericity is found maximum for small sized beed. The medium size beed is found more uniform and shows minimum variability.

3.3 DETERMINATION OF COEFFICIENT OF FRICTION AND ANGLE OF INTERNAL FRICTION:-

The coefficient of friction shows increasing trend from glass surface minimum, galvanized iron sheet as medium and plywood surface maximum as shown by following tables:-

3.3.1 ANGLE OF INTERNAL FRICTION FOR RUDRAKSHA USING CONICAL FUNNEL METHOD

Table 3.3.a.1For Ply-wood Surfacefor Galvanized Iron Surface

Sl. No.	Height of Hip(H) (cm)	Horizontal Expansion(L) (cm)	Angle of Internal Friction [$\alpha = \tan^{-1}(2H/L)$] in degrees
1	5.4	17	32.4
2	6.3	19.9	32.34
3	5.6	17.7	32.32
4	5.4	19.6	28.85
5	5.4	16	34.01

The static angle of internal friction varies from 28.8 ° to 34 ° with an average value of 32 ° and standard deviation of 1.89 °. The angle of internal friction get increased due to mutual roughness characteristics of both surface as they have relatively coarser surface.

Table 3.3. a. 2.For Galvanized Iron Surface

Sl. No.	Height of Hip(H) (cm)	Horizontal Expansion(L) (cm)	Angle of Internal Friction [$\alpha = \tan^{-1}(2H/L)$] in degrees
1	4.2	18.0	25.01
2	5.0	18.0	29.05
3	5.3	22.8	30.4
4	5.8	18.7	31.81
5	5.0	18.8	28.00

The static angle of internal friction varies from 25 ° to 32 ° with an average value of 28.8 ° and standard deviation of 2.58 °. From observation table reveals that the similarity in frictional properties is around 90% level of significance.

Table 3.3. a. 3. ForGlass Plate Surface

Sl. No.	Height of Hip(H) (cm)	Horizontal Expansion(L) (cm)	Angle of Internal Friction [$\alpha = \tan^{-1}(2H/L)$] in degrees
1	4.0	18.2	23.72
2	4.6	20.4	24.27
3	3.8	18.8	22.02
4	4.2	19.6	23.19
5	3.9	19	22.31
6	3.6	18.4	21.37

The angle of internal friction varies from 22° to 24.27° with an average value of 22.8°and standard deviation of 1.1°. It reveals minimum force of attraction between surface and material. The variation is only around 5%.

3.3.2 Table 3.3.a. Coefficient of friction on glass plate for large, medium and small green fruit on Glass Surface

Slope	Large size on glass plate(μ)	Medium size on glass plate(μ)	Small size on glass plate(μ)
0	0.331	0.336	0.344
5	0.401	0.368	0.381
10	0.434	0.409	0.417
15	0.497	0.439	0.441
20	0.542	0.467	0.475
25	0.590	0.513	0.518
30	0.640	0.556	0.559

The coefficient of friction at level surface is minimum for larger green fruit due to poor inter-granular arrangement. The coefficient of friction is maximum for large green fruit due to greater mass(moment of inertia) more surface area in contact during dynamic state and maximum variation in dimensional properties causing irregularity in spherical shape whereas it is minimum in case of medium size green fruit due to minimum variability in tri-axial dimensions and more pronounced spherical shape as shown in **Fig. 3.3.a** .

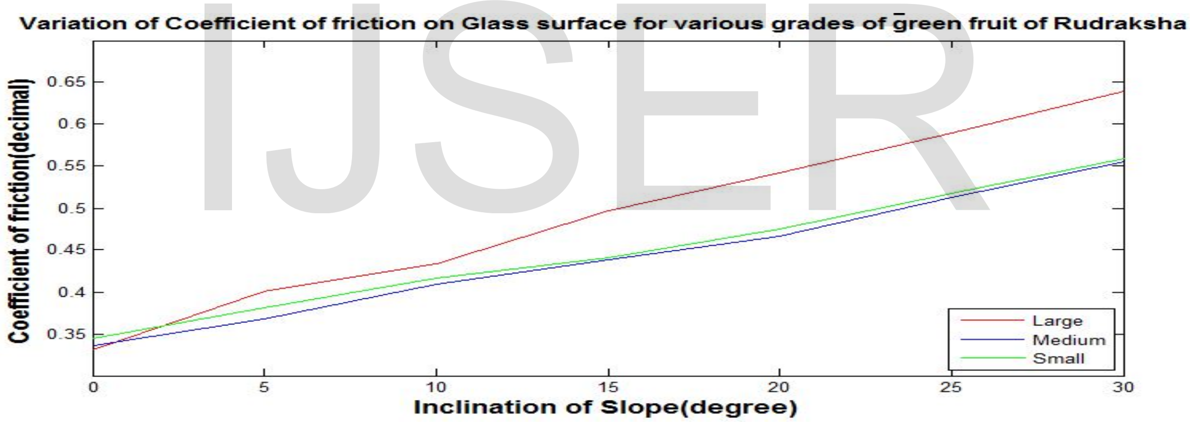

Fig. 3.3.a. Variation in coefficient of friction on Glass surface for different grades of Green fruit

The coefficient of friction shows a little variation among various grades of green fruit at level surface. Large and medium grades shows almost similar frictional coefficient whereas small green fruit exihibits maximum coefficient of friction in diffent angle of inclination as shown in **Fig. 3.3.b**.

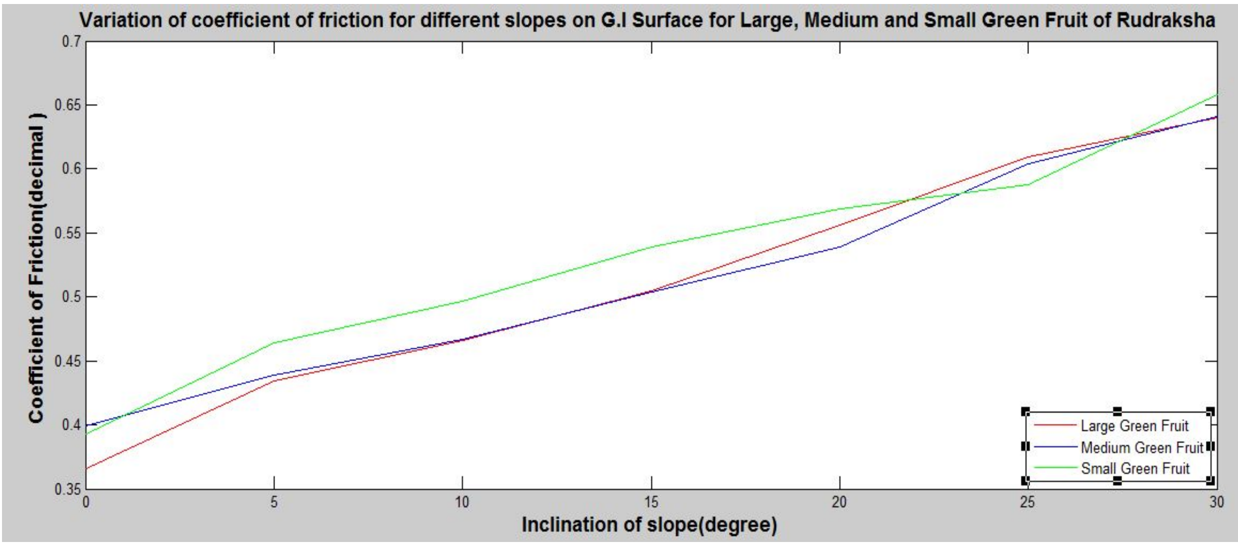

Fig. 3.3.b. Variation of coefficient of friction for different grades of green fruit on G.I Surface

The magnitude of coefficient of friction is highest in case of plywood surface due to predominant roughness of surface causing friction. The coefficient of friction shows same trend for all three selected material at level surface. Medium size green fruit of Rudraksha exhibits maximum friction properties due to better sphericity and higher degree of inter-granular overlapping. Small green fruit exhibits greater magnitude of coefficient of friction due to compact packing and low porosity as shown in **Fig. 3.3.c**.

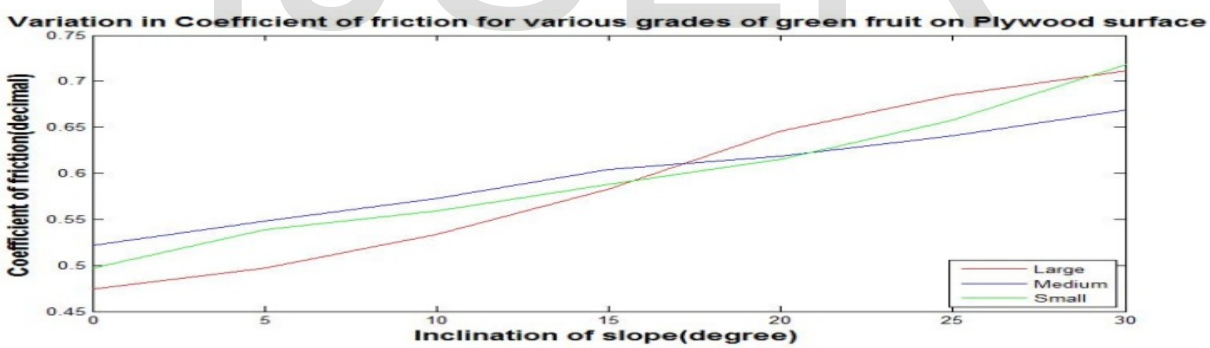

Fig 3.3. c. Variation of coefficient of friction for green fruit on Plywood Surface

3.4 DENSITY, SPECIFIC GRAVITY OF GREEN FRUITS &BEADS :-

The density or specific gravity is common parameter for property to float on the surface of water. It is helpful in studying various grading and separation mechanism. Determination of pulley spacing in design of conveyor and selection of suitable type of conveyor for movement of material from one processing unit to other unit for various unit operations.

The arithmetic mean of density of randomly selected 15 sample of each group (large, medium and small) Rudraksha green fruit are 2.78 g/cc, 3.37 g/cc and 3.42 g/cc with standard deviation of 17.5%, 15.6 % and 15.6 % respectively. The magnitude of density justify the sinking of all grades of green fruit of Rudraksha in water.

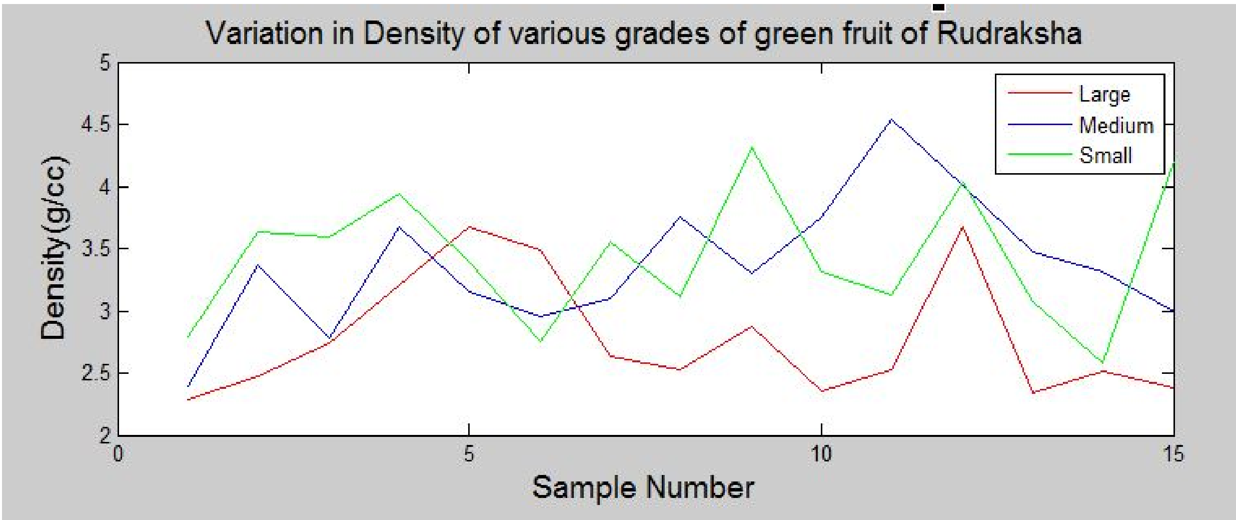

Fig. 3.4.a. Variation in density of various grades of Green fruits

The arithmetic mean of density of Rudraksha beads of large, medium and small size are 0.8 g/cc, 1.15 g/cc and 1.01 g/cc with standard deviation of 6.6 %, 8.4 % and 10.3 % respectively. Though, all grades of dry Rudraksha beads are also sinking in water. Sinking of medium and small are reasonable but sinking of large may be due to surface texture and shape factor which makes it unfit for displacement of more water than its volume to satisfy floating conditions as shown in Fig. 3.4.a.

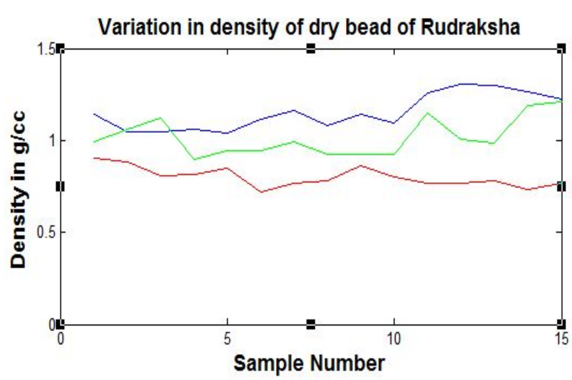

Fig.3.4. b. Variation in density of dry beads of Rudraksha

4. CONCLUSION:

The study of various engineering properties give the following conclusions-

(i)The texture of green fruit of Rudraksha is smooth or plain whereas the surface of dry bead is very undulating. Freshly harvested green fruit can be easily peeled with hand but the bead is not broken using hammer. Its compressive strength varies from 1040 N to 3020 N which signifies its hardness. It cannot be crushed easily using hammer. So, it undergoes either chemical treatment or thermal treatment before crushing.

(ii) The dimension of Rudraksha green fruit is ranging from 18 mm to 32 mm. The beads obtained on peeling green fruit also vary in dimensions. The variation in dimensional properties of Rudrakshapropel us for grading of freshly harvested Rudraksha into three grades as presented in table and it will lead to good aesthetic during marketing and value addition. So, there is need to develop suitable grading system. The type of grading system will depend on the amount of production and availability of resources. So, it necessitates the development of suitable grading system (hand operated or motorized) with two sieve set of diameters 22 mm and 26 mm with suitable slope. The diameter of dry beads of Rudraksha varies from 14.5 mm to 24.5 mm with an average value of 18 mm for small, 20 mm for medium and 23 mm for large. So, for mechanization separate grading system can be developed for fast grading to feed under various operations in different industries. The dimensional properties also have influence on the motion of grains and free flowing mechanisms.The mean sphericity in all three classes of dried beed has insignificant variability. The sphericity and variability of large beed is found highest individually. The mean sphericity is found maximum for small sized beed. The medium size beed is found more uniform and shows minimum variability.

(iii) The coefficient of friction is associated with angle of internal friction or angle of repose which helps us in predicting stability of slope in design of conveyor or design of hopper for regulating feed rate. The coefficient of friction for different slopes is determined for all three surfaces. The angle of internal friction for glass surface is ranges between 22.02 to 24.27°, for galvanized iron sheet is between 25.01 to 31.81° and plywood surface is found from 28.85 to 34.01°. Though plywood is found with highest internal angle of friction or angle of repose but it has low workability in various conditions especially in water and high temperature. So, we will select G.I sheet due to high heat capacity and molding ability.

(iv) The density or specific gravity is common parameter for property to float on the surface of water. The density of green fruit of Rudraksha varies from 2.53 to 5.29 g/cc whereas the density of dried bead found 0.721 g/cc to 1.309 g/cc. The green fruit is sinking in water, it is understood from the study but the sinking of dried seeds of density less than 1g/cc may be due to uneven distribution of mass of bead due to location of seed in a particular chamber among many. It may be also concluded that the contact area is getting minimized due to irregular surface and displacement of lesser volume of water by respective bead. Chemical composition of bead indicates towards floating of bead as it has Carbon (50.024%), Hydrogen (17.798%), Oxygen (30.4531%) and Nitrogen (0.9461%) and many micronutrients in small proportions are also available in small proportions like Sodium, Alluminium, Potassium, Calcium, Magnesium, Iron, Cobalt, Nickel, Copper, Chlorine, Zinc etc.

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