Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the literatures associated with coconut production, classification and determination of engineering properties, importance of grading, mechanical size graders, electronic and mechanical weight graders and their advantages.

2.1. Coconut and its Importance

Coconut is one of the most valuable crops of the wet tropics and is considered to be among the 20 most important crop plants in the world (Vietmeyer, 1986). It is widely called as *kalpavriksha* which means Tree of Heaven.

The coconut fruit is a fibrous drupe which consists of a thin hard skin called exocarp, a fibrous mesocarp (husk), endocarp (shell) endosperm (kernel), and a cavity filled with liquid (water).Generally when the coconut is immature, the exocorp is green in colour and sometimes bronze. The fruit size and shape varies with respect to type and population. In this context, the shape of the fruit vary from oblate to spherical with weight ranging from 850 to 3700g (1.9‑8.1 lb) when mature (Chan and Elevitch, 2006).

Coconut products derived from the fruit are traded worldwide and generally the products are in the form of copra which is in solid form as well as desiccated form, coconut cream, full nut, coir and activated carbon. The coconut water also traded in the form of fresh, canned or frozen which is considered as local economies among the Asian populations. Along with the above products, charcoal from shell, mature nuts for cooking and food uses, brooms, ropes, and coconut shell products are attracted in overseas markets (Foale, 2003).

The crop is valuable also because of its flexibility within farming systems; intensive farming results in high productivity, but coconut palms can also survive great neglect and still provide products for a farmer to fall back on in times of need (Moore and Howard, 1996).

2.2. Production Status

Worldwide, almost 71000 million nuts are produced from 12.44 million hectare area (Coconut Development Board, 2015). India, Sri Lanka, Indonesia, Philippines, Brazil, Thailand, Mexico, Vietnam and Papua New Guinea are the top coconut producing countries. Among those countries, India is at the top of the list and the cultivation is spread across the coastal track of different states across Tamilnadu, Kerala, Andhra Pradesh, Karnataka, Podicherry, Orissa, West Bengal and Maharashtra and islands such as Andaman and Nicobar.

The average coconut productivity in the country is 10614 nuts per hectare which shares more than Rs. 10000 crores per year to GDP. The statistics of coconut production, area of production and productivity in India is presented in Table 2.1.

Table 2.1 Area and production of coconut in India (2015-16)

	States	AREA (000 Hectares)	Production (Million nuts)	Productivity (Nuts/ha)
1	Kerala	770	7429.39	9641
2	Tamil Nadu	459	6171.06	13423
3	Karnataka	526	5128.84	9744
4	Andhra Pradesh	103	1427.46	13732
5	West Bengal	29	373.58	12658
6	Odisha	50	328.38	6451
7	Gujarat	22	312.68	13706
8	Maharashtra	22	271.24	9775
9	Bihar	14	141.38	9489
10	Assam	19	132.59	6720
11	Chhattisgarh	1	30.54	16508
12	Tripura	7	29.51	4097
13	Nagaland	0	2.67	8091
14	Others	52	388.13	7351
	All India	2088	22167.45	10614

Source: Horticulture Division, Dept. of Agriculture & Cooperation, Ministry of Agriculture & Farmers Welfare, Government of India.

2.3. Botanical Features

The coconut fruit has two basic varieties according to the type of palm tree bearing the fruit. These are the “tall” and “dwarf” coconut trees. The tall variety of coconut is slow growing. The tree produces fruits 6–10 years after planting, and remains productive even after 80–120 years. The fruits of the palm mature in 12 months. The dwarf kind of coconut gives fruit 1–2 years earlier, but grows half of the height than that of the tall variety. Since the tall variety has more oil in the kernel and comparatively larger fruit size this type of fruits are mainly used for oil production. Mostly dwarf coconuts are used for drinking purpose as it has plenty of water. (Foale and Roebeling, 2006).

2.3.1. Coconut diversity

There are different varieties of coconut found in the literature and is presented in Figure 2.1 and these fruits are reported to be of various sizes, colour, shape and husk as well as different cavity and kernel size. The name and origin of these varieties are shown in Table 2.2, from left to right (Bourdeix, 2005).

Table 2.2 Simplified classification of coconuts

Positions	Variety	Origin
Top row	Papua Yellow Dwarf	Papua New Guinea
	Tahiti Red Dwarf	French Polynesia
	Madang Brown Dwarf	Papua New Guinea
	Cameroon Red Dwarf	Cameroon
	Spicata Tall	Samoa
	Rotuman Tall	Fiji
	Rennell Tall	Solomon islands
Middle row	Niu Afa Tall	Samoa
	Comoro Moheli Tall	Comoro island
	Sri Lanka Tall	Sri lanka
	West African Tall	Côte d'Ivoire, West Africa
	Tuvalu Tall	Tuvalu
	West African Tall	Côte d'Ivoire, west Africa
	Miccro Laccadives Tall	India
Bottom row	Vanuatu Tall	Vanuatu
	Malayan Yellow Dwarf	Malaysia
	Malayan Tall	Malaysia
	Tagnanan Tall	Philippines
	Tampakan Tall	Philippines
	Kappadam Tall	India

Source : (Bourdeix, R. 2005)

2.4. Marketing of Coconuts

Marketing of coconut consist of a series of activities from production to its end use. Siddarameswara (2015) reported that in marketing of coconut, sellers and buyers have mutual coordination in each other's activities, where goods and services from producers move through certain channels by conscious application of marketing tools. Intermediate channels play a major role in both assembling and equalization functions in marketing of coconuts. Coconut farmers who depend on direct channel are those who have comparatively better financial base than other categories of farmers, provided with infrastructure facilities and nearness. Fig. 2.2 shows the distribution of the matured coconuts from the field to the consumers.

Fig. 2.1. A simplified classification of coconut

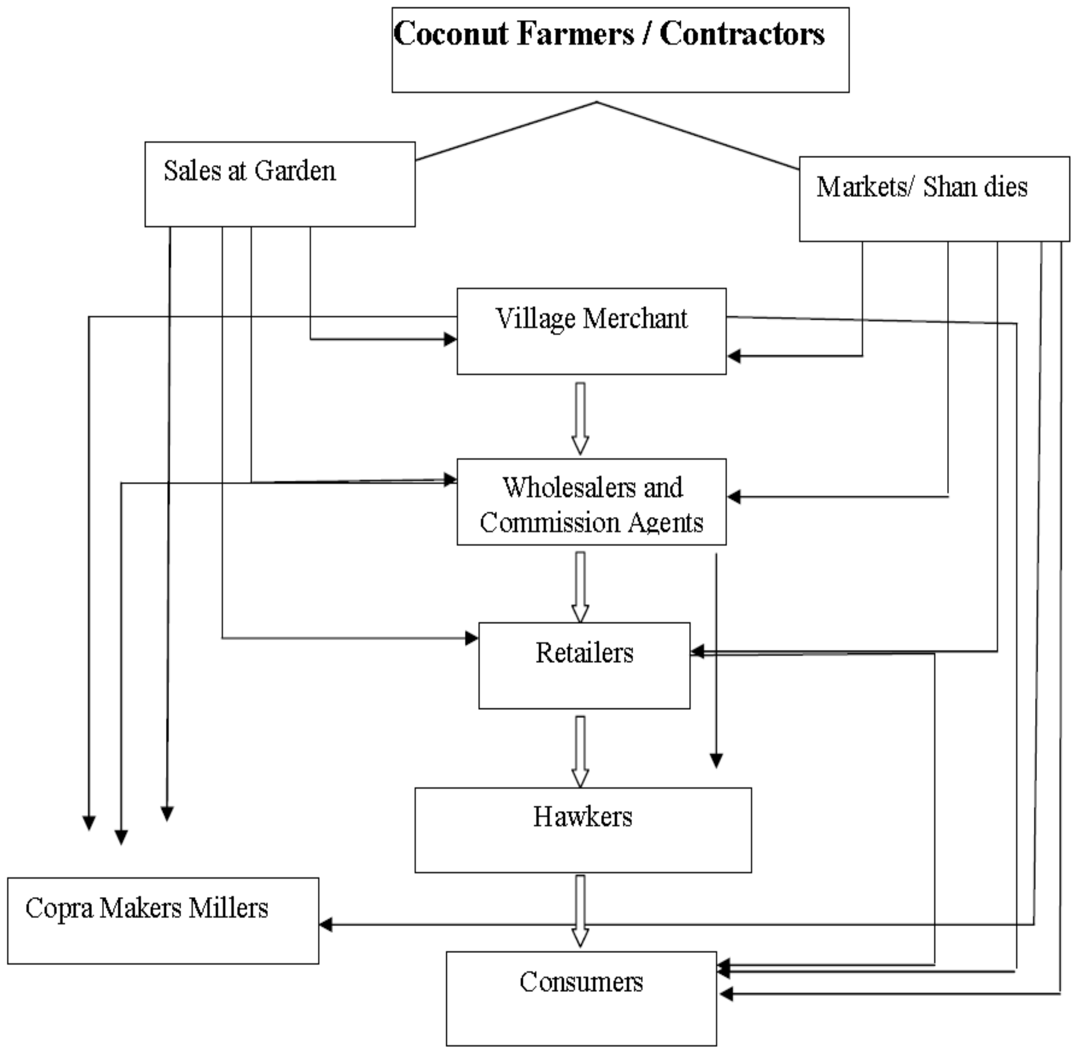

Fig. 2.2. Distribution of matured coconuts

2.5. Grading of Coconut

Grading of coconut for fresh consumption is done visually by the size of de-husked coconut. According to the coconut grading and marking rules, 1976. The grade designation of dehusked coconut-in-shell is given in Table 2.3.

Table 2.3 Grading of coconuts in shell

Grades	Size[#] (Diameter, mm)	Colour	Description
Extra special	>110	Brown	The coconuts shall be well developed, matured and husked[**] with or without water. These shall be free from bad smell, damage and blemish due to fungus and insect infestation and dark brown colour at the top. When struck at the shell with finger or metal it shall give the characteristic metallic sound without any dull note.
Special	100 - 110	brown & white	
Standard	90 - 100	brown & white	
General Non specified ***	< 90	Mixed	

To find out the size, the nuts should be husked and the size should be measured by passing the nuts in the iron rings made to the size required.

**The husk not exceeding 10% of the weight of the nuts is permissible.

***Packing under "non-specified" grade will be allowed only against a specific order from the foreign buyer indicating the quality and quantity of the products desired.

2.6. Engineering Properties

Engineering properties of fruit crops are essential for the design and operation of various equipments. Basic knowledge on these properties of crop products is of great importance and help the engineers, food scientists and processors for efficient design of equipment (Sahay and Singh, 1994).

2.6.1. Physical properties

It is well known that the physical properties required for designing a grading equipments are size, shape, bulk density and true density. These properties are reviewed and presented here.

2.6.1.1. Size

The importance of these axial dimensions in determining aperture size of machines, particularly in separation of materials has been discussed by Mohsenin (1986) and Omobuwajo *et al.,* (1999). These dimensions may be useful in designing the machine components

Length, width, and thickness of the fruit were considered designing a mechanical harvester for apricot (*Hacthaliloglu* L.), Erdogan *et al*. (2003). It was reported that the axial dimensions are significant in determining aperture size of machines.

Aydin (2002) investigated some physical properties of almond nut and kernel as a functions of moisture content. The average length, width, thickness, geometric mean diameter, unit mass and volume of nuts were 25.49, 17.03, 13.12, 18.13 mm, 2.64 g and 2.61 cm^3, respectively. Corresponding values for kernel were 21.19, 14.34, 6.38, 11.42 mm, 0.69 g and 0.71 cm^3 respectively.

Bahnasawy *et al.,* (2004) investigated equatorial and polar diameter of different Egyptian varieties of onion (Giza 6 (white), Beheri (red) and Giza 20 (yellow)). It was found that the equatorial and polar diameters are varied in the range of 5.12± 0.33 to 6.20± 1.5 cm for all varieties with coefficient of variation (CV) of 11–25%.

Owolarafe and Shotonde (2004) reported the average length, width and thickness of fresh okra fruit as 54.60, 28.60 and 26.70 mm, respectively.

The linear dimensions (length and diameter) of the four orange varieties (Alanya and Finike (domestic cv.), W. Navel and Shamouti (foreign cv.)) were found to be statistically significant at the 0.1% probability level. The length of both the W. Navel and Shamouti fruits was significantly greater than the length of the Alanya and Finike fruits, varying from 82.60 to 81.74 mm, and from 69.21 to 69.44 mm, respectively. The diameter of the W. Navel variety (80.14 mm) was significantly greater than other varieties (Topuz *et al.,* 2005).

Badhe *et al.,* (2007) determined the physical properties of Alphonso mango at raw and ripe stages. The volume of the fruit found as 269.61 and 221.51 cm^3, specific gravity (1.01 and 1.09), average length (95.97 and 94.62 mm), average breadth (77.73 and 74.20 mm) and average thickness (69.54 and 65.60 mm) at raw and ripe stage, respectively.

Sharifi *et al.,* (2007) presented mean length of oranges of different grades. The length grade one (large), two (medium) and three (small) oranges were 90.4, 84.06 and 77.93 mm, and for the mean width were 85.03, 77.93 and 70.62 mm, respectively.

Goyal *et al.,* (2007) reported that length of the anola fruit of cultivar NA-7 was higher than that of cultivar krishna and chakaiya, but the diameter of the chakaiya fruits was higher. The size of three cultivar fruits ranged from 3.37 to 3.44 cm. Due to the greater diameter, sphericity of chakaiya fruits was higher.

Jannatizadeh *et al.,* (2008) determined the linear dimensions and geometric mean diameter of six apricot cultivars (Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8, and Gheysi-2) The greatest dimensional characteristics were found for Djahangiri cultivar, varying from 41.70 to 53.10, 39.80 to 50.40, and 38.70 to 49.10 mm, related to length, width and thickness, respectively. Nakhjavan had the lowest values of length, width and thickness among the studied cultivars.

Jahromi *et al.,* (2008) evaluated the linear dimensions of date fruit ranged from 29.8 to 40.2 mm in length, 15.7 to 20.2 mm in width, and 15 to 19.7 mm in thickness. The major axis has been found to be useful by indicating the natural rest position of the fruit.

Shidenur *et al.,* (2017) determined length and diameter of jackfruit by image processing technique. The mean length and diameter of the fruit were found to be 38±7.79 and 22.67±2.55 respectively. The length of the fruit is important for fixing the length of core removing tool and height of peeler screw shaft assembly. Diameter of fruit is considered for fixing width of core removing tool.

2.6.1.2. Shape

Sphericity indicates the shape character of a solid relative to that of a sphere of same volume (Mohsenin, 1986).

Aydin (2002) reported the average values of geometric mean diameter and sphericity of hazel nuts as 8.36mm and 87.59%, respectively.

Li *et al.,* (2003) reported that the locule number of two tomato cultivar have significant effect on the sphericity, height, diameter, arithmetic mean diameter, geometric mean diameter and surface area.

The average of 1.97 ± 0.13 shape index was estimated for the white onion while it was 0.96 ±0.14 for the red onion and 0.92 ± 0.10 for the yellow onion. It indicated that the onion bulbs of both Beheri and Giza 20 are a spherical in shape (Bahnasawy *et al.,* 2004).

Sirisomboon *et al.,* (2007) reported physical properties of *Jatropha curcas L.* fruits, nuts and kernels. The sphericity values indicated that fruit shape (0.95) is close to a sphere compared to nut (0.64) and kernel (0.68), both of which are close to an ellipsoid.

Owolarafe *et al.,* (2007) investigated the physical and mechanical properties of two varieties of fresh oil palm fruits (dura and tenera). The sphericity and aspect ratio for dura variety were found to be 70.67 and 67.78 per cent, respectively. The higher sphericity value of the palm fruit indicates the near spherical shape of fruit. The tenera variety recorded sphericity and aspect ratio of 64.23 and 56.77 per cent, respectively. This indicates that tenera variety is less spherical in shape as compared to dura variety.

Naderi-Boldaji *et al.,* (2008) reported that the sphericity values had significant difference among the tested apricot cultivars (Shams, Nakhjavan, and Jahangiri). The values were 0.971, 0.917, and 0.973 for Shams, Nakhjavan, and Jahangiri cultivars, respectively.

In a study conducted by Janatizadeh *et al.,*(2008) the sphericity values of Iranian apricot was differed significantly among the tested cultivars and mean values were 0.971, 0.917, 0.973, 0.925, 0.923, and 0.875 for Shams, Nakhjavan, Djahangiri, Sefide damavand, Shahroud-8, and Gheysi-2 cultivars, respectively.

The geometric mean diameter, sphericity and surface area of date fruit (cv. Dairi) varied from 19.54 to 25.03 mm, 0.58 to 0.69, and 1200.04 to 1968.26 mm^2, respectively (Jahromi *et al.,* 2008).

2.6.1.3. Bulk density

Topuz *et al.,* (2005) reported that the bulk density and porosity of four different orange varieties (Alanya, Finike, W. Navel, and Shamouti) were insignificant at different probability levels (5%, 1% or 0.1%).

Owolarafe *et al.,* (2007) studied the bulk density of two varieties of fresh oil palm fruit (dura and tenera). They observed that the bulk density of dura and tenera varieties were 659.40 kg/m^3 and 611.04 kg/m^3, respectively.

Jannatizadeh *et al.,* (2008) determined the bulk density of six different cultivars of Iranian apricot fruits. namely Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8, and Gheysi-2. It was observed that the bulk density was 463, 457.47, 455.27 453.61, 444.75, and 431.57 kg m^{-3}, respectively for Nakhjavan, Djahangiri, Gheysi-2, Shams, Sefide Damavand, Shahroud-8. It was also observed that the average fruit density of Shams cultivars was varying from 8504.33 to 1280.35, and Nakhjavan from 9534.57 to 1043.51 kg m^{-3}, which are much higher than the other cultivars. Sharifi *et al*. (2007) conducted a similar study and found that the average fruit density of orange (Var. Tompson) varied from 1.01 to 1.04 g cm^{-3} and it was suggested that this fruit density may be useful in separation and transportation of fruit by hydrodynamic means in water canals.

2.6.1.4. True density

Kato (1997) described the relationship between the true density and maturity of Japanese watermelon. It was found that watermelon that does not include cavities has a density that is equal to or greater than 0.934.

The fruit density of the orange varieties (Alanya, Finike, W. Navel, and Shamouti) was found to be statistically significant at the 5% probability level, but the bulk density and the porosity was not significant, varying from 515.27 to 527.80 kg/m^3 and 0.396 to 0.432, respectively (Topuz *et al.,* (2005).

Owolarafe *et al.,* (2007) found true density of two varities (*Dura and Tenera*) of palm was 1112.50 and 995.70 kg/m3, respectively.

Jannatizadeh *et al.,* (2008) determined the true density of six cultivars of Iranian apricot fruits namely Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8, and Gheysi-2. It was found that the average fruit density of both variety Shams and Nakhjavan cultivars were considerably greater than that of the other cultivars. The average true density varied from 8504.33 to 1280.35, and 9534.57 to 1043.51 kg m^{-3}, respectively compared to the other cultivars. Sharifi *et al*. (2007) also performed a similar study which considered physical properties of orange (Var. Tompson) fruit and it was understood that this property was much useful in fruit separation and transportation by using hydrodynamics or use of water canals.

Chandrasekar *et al.* (2013) reported that the true density of coleus tubers decreased from 484.03 to 299.123 kg/m^3 when the moisture content decreased from 466.62 to 21.52 per cent (db), respectively.

2.7. Frictional Properties

The frictional properties such as angle of repose and coefficient of external friction are recognized by engineers as important properties concerned with rational design of seed bins and other storage structures including the compressibility and flow behaviour of materials (Kachru *et al.,* 1994). Frictional properties help to understand the ease with which the given material moves over the given surfaces.

The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of material through the chute. In addition, it is important to design the conveyors because friction is necessary to hold the nuts and kernels to the conveying surface without slipping or sliding backward. If the handling of the crop is needed, the rougher surface like rubber must be used, and on the other hand, if it is necessary to discharge the product, the smoother surface like fiberglass might be useful (Razavi *et al.,* 2007).

2.7.1. Coefficient of friction

Li *et al.,* (2003) found that static friction coefficients ranged from 0.375 to 0.488 for stainless steel, 0.408 to 0.641 for lacquered stainless steel, and 0.396 to 0.503 for rubber for tomato cultivar Fenguan 906 fruits; it was 0.437 to 0.483 for stainless steel, 0.612 to 0.622 for lacquered stainless steel, and 0.511 to 0.534 for rubber in Jinguan 28 fruits. The rubber and stainless steel showed no significant differences in static friction coefficients of tomato fruits, whereas, the higher sliding friction coefficient was on rubber than stainless steel. This is due to the properties of friction surfaces (Ozguven and Vursavus, 2005). Similar results were found by Kabas and Ozmerzi (2008) for cherry tomato fruits, Jannatizadeh *et al.,* (2008) for Iranian apricot, Jahromi *et al.,* (2008) for date.

Sessiz *et al.,* (2007) reported that the static and dynamic coefficient of friction on four different surfaces, namely, galvanized steel, plywood, rubber, and metal steel for caper fruit. On all surfaces, they obtained value of the static coefficient of friction more than dynamic coefficient of friction.

In a study, the static friction coefficient on sheet iron, galvanized sheet iron, and rubber surfaces were reported as 0.201, 0.181, 0.281 for Zerdali cultivar (Hacisefrogullari *et al.,* 2007).

Naderiboldaji *et al.*, (2008) reported the static coefficient of friction for six Iranian sweet cherry cultivars (Mashad, Siah Mashad, Dorageh Karaj, Shabestar, Siah Daneshkadeh and Ghazvin). On the iron surface, the coefficient of static friction of the Siah Daneshkadeh and Ghazvin cultivars were found to be the lowest and highest with means of 0.178 and 0.409, respectively. On the rubber surface, the coefficient of static friction of the Ghazvin fruit, with mean of 0.439, was significantly greater than that of the other cultivars. This value for the Shabestar, Dorageh Karaj and Siah Mashad was found to be 0.412, 0.338 and 0.349, respectively and was followed by the Mashad and Siah Daneshkadeh, with a mean of 0.291 and 0.251 respectively. On galvanized iron sheet, the highest coefficient of static friction was obtained for Ghazvin fruit with a mean of 0.316 while the corresponding value was 0.146 for Siah Daneshkadeh as the lowest coefficient.

On rubber surface, the coefficient of static friction of the 'Nakhjavan' fruit, with mean of 0.344, was significantly greater than that of the other cultivars of apricot. The value for 'Jahangiri' and 'Shams' were 0.333 and 0.286, respectively (Naderi-Boldajia *et al.,* 2008).

Riyahi *et al.*, (2011) determined that the coefficient of friction of pomegranate on glass surface gave the highest values with 0.82 and wood surface had lowest valve with 0.45 for.

Reza Tabatabaekoloor (2013) determined that peach varieties (Elberta and Spring time) had no significant effect on the static friction coefficients on all surfaces studied. The plywood and steel showed no significant differences in the static coefficient of friction for both cultivars, but there was a significant difference ($p<0.05$) between the static friction coefficient of rubber surface with two other materials. This was because the rubber surface has higher frictional properties which made fruit difficult to move on.

2.8. Importance of Grading Fruits and Vegetables

Mamoria and Joshi (1997) studied the factors affecting marketing cost of fruits and stated that grading and standardization are important factors affecting cost in the market. They noticed that negligence in proper grading of products in accordance with standards resulted in lower price to the producers and higher prices to the consumers.

Krishnamurthy and Rao (2001) reported that considerable variation existed in the quality of harvested fruits due to genetical, environmental and agronomical factors and therefore, grading is required to get suitable return. According to their observations, proper grading facilities were lacking, which required for the effective marketing of fruits. Systematic grading coupled with the scientific packaging and storage reduces the post-harvest losses and marketing costs substantially, which enable the producers to fetch a competitive price.

The end users buy the fruits and vegetables mostly on the basis of size, appearance and visible defects. Hence, sizing and inspection of the product prior to marketing were considered as basic requirements to command a premium price. The same was discussed by McRae (1985) and McRae graded the fruit and vegetables on the basis of size and inspection. Inspection involved manual elimination of unwanted material.

Grading of fruits into size groups is often necessary in the food industry, to meet the requirements of some processing machines, or to assign process differentials of large and small produce. For example, extractors in citrus juice plants are usually designed for a given fruit size. Peeling machines in artichoke canning factories require correctly sized vegetables for working. In the peach canning industry, fruits must be size graded to accommodate the pitting machines (Moreda *et al.*, 2009).

Manual sizing is beset by slow sizing rates, considerable errors and mechanical damage. For example, the manual sizing of fresh mangosteen (Jarimopas *et al.*, 2007) and durian (Jarimopas *et al.*, 1992) was found to cause error ratios of 34 and 43%, respectively.

Many researchers developed various kinds of classification machines according to market demand and processing aspects. The available literatures dealing mainly with size and weight grading machines are listed below.

2.9. Size Grading

Sizing is considerably labour-intensive postharvest unit operation. Sizing is necessary, as it fetches higher value, attracts buyers and facilitates packaging designs (Peleg, 1985; Jarimopas *et al.*, 2007), improves handling and brings an overall improvement in the marketing system.

Tabatabaeefar *et al.*, (2000) have listed several types of sizing machines existing, including perforated conveyer sizers, Greefa type belt and board sizers, rotary Greefa sizers, belt and roller sizers, Wayland-type belt and roller sizers, diverging belts Jansen-type sizers, diverging roller sizers, and weight sizers. The sizing parameters in some of these sizers are the diameter and length or a combination of these two. Dattatraya Londhe *et al.* (2013) have added some more mechanical grading sorters to the list based on size, viz., expanding pitch rollers, inclined vibrating plate, rotary disc type, counter rotating roller having inclination type, sieve type grader.

2.9.1. Screen or sieve type grader

Matouk *et al*. (1999) designed and constructed a portable machine for sorting, cleaning and grading sphere-like crops. They concluded that, at any sieve slope in the range of 5 to 20 degree and all sieve rocking speed in the range of 150 to 300 rpm the mechanical damage percentage of fruit increased as the speed of fruit feeding chain increased from 0.15 - 0.3 m/s. They added that, at high sieve rocking speed the grading efficiency of fruit decreased.

Doraiswamy (2000) developed a sieve type grader for grading groundnuts into three different sizes. The output capacity was 600 kg/h and was powered by a 1 hp 3- phase electric motor. Re-orientation of pods in sieve holes was observed which required modification in shaking system.

Using capron net a small potato grading machine was designed and developed. The design was characterized by a spiral structure covered with a capron net to form a cribriform rotating drum as the grading surface. The design parameters included net stiffness (T), rotating drum speed (n) and feeding rate (q). The grading accuracy of the machine was evaluated to determine optimum condition of machine performance.

An acceptable grading accuracy of about 70% with a low tuber damage of 5.5% were obtained at T = 0.14 N/mm, n = 27 rpm and q = 2,500 kg/h (Ghanbarian *et al.,* 2008).

Gayathri *et al.,* (2016) designed and developed a manually operated onion grader. The experiments were conducted with three types of slopes, at each three different feed gate opening lengths and swing directions. The statistical analysis showed that the standardized parameters were 4°slope, length wise swing direction and feed gate at full opening. The grader had a grading capacity 1105 kg/h at overall grading efficiency 75 per cent.

2.9.2. Diversion type grader

Bundit and Sakson (1990) developed a lemon grader which consists of four inclined grading portions. Spaced PVC tube was provided at spacing of 34.0, 37.3, 40.5 and 51.1 mm for lemon grades 3, 2, 1 and 0, respectively. The capacity of the lemon grader was about 684.7 kg/h with the sizing efficiency of 84.6%.

Nevkar (1990) developed and tested divergent roller type grader for lemon and chiku (sapota). It was observed that the separation efficiency decreased with increase in roller speed. The overall separation efficiency for lemon and chiku were 71.71% and 66.75% respectively

Abdel-Mageed and Abd Alla (1994) developed a laboratory-grading machine to grade sphere-like crops. Three machine parameters such as grade inclination angles, height of sizing element (dividers height) and dividers tilt angle were investigated. They stated that adjusting divider height is the most effective parameter on grading efficiency to grade sphere-like crops such as tomatoes.

Nevkar and Kanawade (1996) developed a fruit grading machine and tested its performance for lemon and sapota. The machine parameters tested were roller speed, inclination of roller and gap between diverging rollers. The maximum sorting capacities of 1140 and 1531.9 kg/h were achieved respectively for lemon and sapota. The overall separation efficiency of the machine was 69.1%.

EL-Raie *et al*. (1998) designed and fabricated grading machine for orange using diverging bar and roller cylinder. They showed that the optimum speed of feeding conveyor was 70 rpm, the most suitable lines for the grading unit were the cylinder system, and the most suitable tilt angle of grading unit ranged from 3 to 6 deg.

Pandey (2000) developed differential speed V-belt type of mango grader. The test showed that a maximum separation efficiency of 82.18% occurred at a grader shaft speed 25 rpm and a feed rate of 750 kg/h.

Atwal and Gulati (2001) developed a rubber roller type potato grader. It consisted of hollow rubber rollers resembling the shape of a tambourine and having hole (21mm diameter) in the centre, mounted on steel shafts as the grading mechanism. Six categories of grades could be obtained with this grader with almost negligible bruising. More than 6000 kg of potatoes could be graded in an hour when the speed of conveyor belt as 14 m/min and roller revolving at 83 rpm.

Muhammad *et al.*, (2007) designed and developed a spool type grading machine for fruits and vegetables. It was reported that for potatoes grading take-in conveyor speed of 20 m/min, grading spool speed of 50 rpm and take away conveyor speed of 10 m/min is the appropriate for optimum results. Take-in conveyor speed contributed 47 % of the total damage index while grading spool speed shared 44 % of the total damage index. Damage index was increased 4.66 % when the take-in conveyor speed was decreased to 15 m/min and when further decreased to 10 m/min the damage index was increased 8.29 %. Therefore it was concluded that the take-in conveyor speed had an inverse effect on damage index of potatoes.

Shahir and Thirupathi (2009) developed and tested a divergent type roller grader for tomato, potato and onion. The performance evaluation of the unit was carried out for different feed rates (480,580, and 680 kg/hr) and slopes (5, 7, and 9^0). It was reported that at a slope of seven degrees and feed rate of 480 kg/h the maximum separation was 86.7 % for onion, 84.3% for potato and for tomato 82.4 %.

Ukey and Unde (2010) developed a roller type sapota grader. They reported that the best combination of roller speed, its inclination and roller gap was found to be 223 rpm, 4.50 and 38 to 64 mm, respectively for highest efficiency of 89.5%. The capacity of machine was 1440 kg/h and cost was Rs11, 450/- (without electric motor).

Treeamnuk *et al.,* (2010) developed a sizing machine for java apple fruit to minimize the damage. The sizing machine comprised a feeding unit and a diverging belt sizing unit that are powered by two 220 V 50 Hz electric motors, gear reducer and pulleys. Performance tests indicated that velocity and inclination angle of the sizing belt; feeding belt velocity and the fruit orientation significantly affects the sizing performance at $p < 0.05$. The optimum conditions for continuous mechanical sizing depended on the variety. The optimum sizing performance was characterised by a contamination or error ratio of 10.8-16.5%, separation efficiency of 85- 95.10 % and a throughput capacity of 149.7 - 195.1 kg h^{-1} with no significantly noticeable damage to the sized fruits.

Borkar *et al.*, (2013) tested the performance of spherical fruit grader for apple and pomegranate. It was reported that for maximum response of grading efficiency, the input factors viz., feed rate and down slope of grader were optimized to 35.84 kg/min and 30.21% respectively for Apple and 31.91 kg/min and 22.57% for Pomegranate. By using these optimized input factors, the grading efficiency and capacity was found to be 76.35% and 12.14 tonnes/day of 8 hours for Apple. For Pomegranate, the grading efficiency and capacity was found to be 86.63% and 12.25 tonnes/day of 8 hours by using optimized input parameters.

Pawar and Khodke (2016) developed a grader for kagzi- lime. The machine consists of feeding, grading, collection and power transmission units. Fruits were graded into three grades viz., Grade-I – above 40 mm, Grade-II- between 40 to 36 mm and Grade-III- below-36 mm. The efficiency of 95 per cent with actual capacity 354.45 kg/h of grader for Kagzi-lime was resulted at 14 rpm of the speed of grading unit and 7 degree feed trough angle. But when speed of grading cylinder and feed trough angle increased beyond 17 rpm and 7 degree, respectively, the Kagzi- lime roll down with high speed from trough towards the inlet of grading cylinder resulting in chocking the inlet and improper grading (Ali *et al.*, 2011).

2.9.3. Expanding pitch type grader

Singh (1980) developed differential belt speed expanding pitch type potato grader. The main components of the grader were feed conveyor, frame, grading unit, collecting platform and power transmission unit. The grader required 1 hp electric motor to drive various components at full load. The maximum separation efficiency at optimum speed (45 rpm) of grader shaft 4.4 m per min of belt speed was found to be 87 per cent. Capacity of the grader with maximum efficiency was 15 q/h.

Kachru *et al.* (1986) reported that G.B. Pant University of Agriculture and Technology, Pantnagar has developed a power operated, differential speed V-belt expanding pitch type apple grader which consists of six number of V-belts with 24 wooden pulleys mounted over four shafts. The distance between adjacent belts increases gradually from 20 mm from the feed end to 55 mm at the delivery end. The upper portion of the belts between the upper pulleys acts as grading, sections and the whole grading length is divided into three parts to gives three different grades. Due to difference in speed of belts over which an apple moves, there is rotational effect imparted on the apple, which helps in better separation. This machine can also be used for potato. The capacity of machine was 15q/h and grader was operated with 2 hp electric motor and two labours were required for operation.

Mangaraj *et al.*, (2009) have developed a stepwise expanding pitch fruit grader based on the principle of changing the flap spacing along the length of movement of fruits with provision to separate fruits into four grades by adjusting flap spacing between 45 to 140 mm. They could obtain an overall grading efficiency of 91.5% and 88.5% for sweet lemon and orange, respectively. The capacity of the grader was 3.5 ton/h at grading conveyor speed of 6 m/min.

2.9.4. Belt grader

Amar Singh and Ilyas (2001) have designed and developed a vegetable-cum-fruit grader for onion and potato. The speed of operation was 10 m/min. Mechanical damage; grade coefficient and energy consumption was also studied. The machine has a grading capacity of 1500 to1800 kg/h. The external mechanical damage (bruising, skinning and cutting) was found below 1 percent. The electrical energy consumption per tonne of potatoes was found to be 80 watts/ hr. The weight of machine was 300 kg.

El- Sheikha *et al.,* (2004) developed a belt grading machine for olive fruit. A 0.25kw and 220 volts electrical motor with suitable transmission system was used to drive the grading machine at a speed of 300 rpm. The maximum grading efficiency of olive varieties Manzanillo, Agiza and Picual, were reported as 93 %, 92 % and 91, %, respectively. These results were obtained at the operation conditions of feed rate 50 g/s, belts speed 0.110 m/s and tilt angle of -0.035 Rad.

Mostafa and Bahnasawy (2009) developed an onion sizing machine capable of working under different operating conditions (variable belt speed and side and longitudinal angles). They reported that grading efficiency increased with the increase in the side angle for the selected belt speeds and table longitudinal angle. Further, in regards to the change in the longitudinal angle, data show that the change of side angle had greater effect on the grading efficiency compared to the longitudinal angle, where the change of longitudinal angle from 0-20^0 caused the grading efficiency to increase by 5.4, 2.0, -0.3 and – 1.5 % at 0.10, 0.17, 0.23 and 0.30 m/s, respectively. Contrary to this, the change in the side angle from 10-30º increased the grading efficiency by 7.9, 7.7, and 7.2% at 0, 10 and 20º longitudinal angles.

2.9.5. Rotary disc type grader

A factory prototype of the mangosteen fruit sizing machine was developed with reference to the optimum design parameters of the laboratory model. The fruit move along the sizing board and drop down to the receiving tray whenever the diameter of the fruit is less than the sizing gap. Performance testing of the factory prototype showed that minimal fruit damage (0.48%) occurred at mean contamination ratio 22.8% and capacity 1026 kg/h (Jarimopas *et al.*, 2007).

2.9.6. Cylinder type grader

Amin (1994) fabricated a laboratory cylinder grader for potato tubers, he concluded that by increasing both of drum speed and its axial slope the length of the drum has to be increased, to get a reasonable grading efficiency of the machine. The machine capacities at optimum drum speed of 25 rpm and slop of zero degree was 1.2 t/h with tuber damage of 0.23%.

Abd El-Rahman and Magda (2011) developed a small cylinder type grading machine to suit grading of onion sets. They studied that at any riddles revolving speed from 35 to 65 rpm, the total grading efficiency increased as riddles feeding rates were increased from 75 to 100 kg/h. However, at 125 kg/h riddles feeding rates the total grading efficiency tended to decrease slightly from 94.34 to 94.2 % as riddles revolving speed was increased from 55 to 65 rpm. The best result were obtained at 55 rpm riddles revolving speeds and 125 kg/h riddles feeding rate with 4.66% permissible mechanical damage of onion sets.

Gunathilake *et al.*, (2016) developed a low cost size grading machine for big onion bulbs. It was reported that optimized machine adjustments for its maximum performance were 3^{o}inclined angle of the grading cylinder against horizontal axis and 15 rpm rotating speed of the grading cylinder. Maximum grading efficiencies under optimized machine adjustments for small, medium and large sizes were reported as 84.47%, 93.46% and 90.14 respectively. The capacity of the grading machine was 630 kg/h under the optimized operational conditions.

Preetha *et al.*, (2016) evaluated the performance of the rotary drum grader for tomato. It was reported that the efficiency of grader was found to be 80% at 16^{o} inclination angle, 175 $kg.h^{-1}$ feed rate and 15 rpm peripheral speed. The cost of the machine was around Rs.4000/-.

2.9.7. Electronic size grader

Moreda *et al.*, (2009) classified electronic size determination systems into six different groups according to their principle of measurement. Although electronic sizers have now almost totally displaced mechanical ones, it is unclear whether they have resulted in a superior sizing accuracy.

García-Ramos *et al.*, (2004), using an instrumented sphere, assessed the mechanical aggressiveness of four different sizers commonly used in stone-fruit packing lines, three were electronic and the fourth was mechanical. By measuring the impact registered in the transfer points, they found no differences among the different sizers. They concluded that any sizer could perform correctly with a correct design of the transfer points.

Therefore, it has not been proven that electronic sizers have better performance compared with mechanical sizers, in terms of sizing accuracy and damaged to the produce. Some practical aspects can be considered that may account for the obsolescence of mechanical sizers (Moreda *et al.*, 2009)

2.10. Weight Grading

Weight grading of fruit can reduce packaging and transportation costs, and also provide an optimum packaging configuration (Peleg and Ramraz, 1975).

Weight sizing can be achieved by two methods, 1. Direct 2. Indirect methods

2.10.1. Weight grading by direct methods

Weight of the fruit can be directly determined either mechanically or by an electronic weight measurement scale. The main design difference between both concepts is that the mechanical sizer weight measurements are performed at the ejection points; each mechanical sizer ejection point represents a weight measurement point, whereas electronic weight sizers have a single weight measurement point per lane, typically arranged a short distance before the first ejection point (Moreda *et al.*, 2009).

2.10.1.1. Mechanical Weight Grading Machines for Vegetables and Fruits

Weight sorting based on catapult principle is used to sort apples accurately and without damage (Maggs, 1973). Generally, eggs are sorted on the basis of weight (Brennan *et al.*, 1976).

Ryall and Lipton (1972) reported that many fruits like apples, pears, citrus and vegetables like potatoes, carrots and onions were graded by weight. Typical weight grading machines carry fruits on tarred canvas pockets attached to pivoted beams fitted with counter balance weights. As the beams pass along the grader, the beam is moved towards the counter balance weight until such time as the weight of the fruit causes the beam to tip, discharging the fruit into the chutes in particular weight category.

Maggs (1973) described the fruit grading by weight. Weight grading using a catapult principle was claimed to grade apples, accurately and without damage, at a rate of 6000 fruits per hour into 12 weight categories. The fruits were fed, individually into adjustable spring loaded catapult arms that hurl the fruit into one of twelve padded collection plates carried on a momentum-observing frame. The height of the trajectory of fruits, the position of chute, which collects it, was related to the weight of fruit.

Omre and Saxena (2003) designed a weight grader which consists of frame, roller conveyor, fruit carrier, weighing unit, power transmission unit, chain and sprocket drive. The performance of the grader was evaluated at 5 (0.029 m/s), 10 (0.058 m/s), 15 (0.086 m/s) and 30 (0.173 m/s) rpm of fruit carrier on four types of fruits namely, apple, orange, mosambi and pomegranate. The performance was satisfactory at the carrier speed between 12 to 15 rpm. The capacity ranged from 150 to 200 kg/h depending upon the fruit type and variety. The overall grading efficiency was close to 96 per cent.

2.10.1.2. Electronic Weight Grading Machines for Fruits and Vegetables

Gaikwad *et al.,* (2014) developed an electronic weight grading machine which could sort oranges in four commercial weight-grades of less than 100 g, 100-150 g, 150-200 g and greater than 200 g. The unit comprises of feeding unit, main frame and chain conveyor assembly, guiding rail and roller idler, orange carrier cups, electronic weighing assembly and dropping and collection mechanism. Rack and pinion arrangement with stepper motor was used for dropping of fruits. The electronic weighing assembly consisted of dynamic load cell (type CSI-1B) of maximum capacity of 3 kg. Load cell was provided with input of 6 V from printed circuit board (PCB). The performance evaluation was carried out and optimum treatment combination of 15 rpm speed and microcontroller setting II (clock pulse frequency of 8000 Hz) reported higher grading efficiency. The capacity of grader was found to be 2275 fruits per hour with grading efficiency of 90 per cent. Mechanical injury was inflicted to 2 % of fruits. Power requirement of the grader was 0.5 kW.h.

Ali *et al.,* (2011) developed an electronic weight grading machine for sapota. The grading unit was fitted at an angle of 15º to ensure free flow of the fruit. Two outlets were provided on the opposite side of the gate when the gate was operated by the standard door opening and closing mechanism. The pushing of the vertical member was effected by the pulling type solenoid switches. Two pulling type solenoids with a pulling capacity of 1 kg and stroke length of 30 mm were used in the grading unit. The overall separation efficiency of the grader for 20 rpm was 93.8 %. Capacity of the grader for cricket ball variety was 0.43 ton/hr. The cost of grading for cricket ball was found to be low, i.e., Rs. 0.06 / kg, compared to manual grading (Rs. 0.4/kg).

Golpira and Golpira, (2012) developed an apple sorting machine employing a load cell with rated capacity of 2 kg and 1 mv/v sensitivity. The output signal from the load cell was amplified before it is send to the control unit in order to easily detect by the microcontroller. Peak signal to noise ratio (PSNR) criterion was employed to analyze the machine performance which aids its improvement. It was concluded that the PSNR results as well as experimental results specify that vibration could significantly affect machine performance

In another study, Golpira and Golpira, (2013) developed a machine to grade an apple and it comprised of conveyor which works assistance of the gravity, measuring device and control system along with pneumatic cylinders as actuators. In order to determine the inclination angle and performance of the machine theoretical and practical calculations were performed. It was understood that increasing duct angle leads to the rising in velocity of the fruit. It was also noticed that the fruit speed of the last gate is more than the others and the maximum fruit velocity at that duct was 1 $m.s^{-1}$. In this study the duct slope was taken as 0.02 in order avoid the mechanical damage of fruits. It was understood that the time required to receive a fruit to the last gate from the load cell is 2 seconds.

Golpira and Golpîra, (2016) redesigned a sorting machine for apple fruits. The machine consists of (1) weight measuring and control unit, (2) material conveying system, (3) pneumatic cylinders and reservoir, and (4) magnetic valves. To avoid injury, damage, and bruising via material handling, critical forces and velocities for Golab variety of apple fruits were calculated and measured as 46 N and 1 ms^{-1}, respectively. Merge of experimental data and a signal processing technique, named peak signal to noise ratio (PSNR), was employed to analyse and modify the automatic sorter. Furthermore, the unwanted impact of digitalization accuracy on the work quality was significantly reduced by using oversampling technique, which virtually enhances analog to digital converter (ADC) resolution. Signal processing-based optimization of the chassis decreased vibrations and noises and increased machine performance.

2.10.2. Weight grading by indirect methods

Indirect methods were also used to estimate the weight of the fruit by dimensional measurements such as projected area with the help of a model or an equation (Jahns *et al.*, 2001; Varghese *et al.*, 1991; Jarimopas *et al.*, 1991; Davenel *et al.*, 1988).

Image processing techniques was also used as an important method to predict the volume and mass of citrus fruits (Omida *et al.*, 2010). In this method, volume of the citrus fruit was estimated by dividing the fruit image into a number of elementary elliptical frustums. The volumes calculated using the above method and the actual volumes estimated by water displacement method showed good agreement. Authors also found that the coefficient of determination for lemon, lime, orange, and tangerine was found to be 0.962, 0.970, 0.985, and 0.959, respectively.

Sa'ad *et al.*, (2015) used visible imaging as a tool in grading the mangoes. They estimated the weight of the mangoes from their images by applying cylinder approximation analysis method and reported that the scatter plot between the estimated and actual values of the weight shows high correlation, with R^2 equal to 94.0%. The high prediction accuracy obtained shows that this simple formula (w = 2.256 V - 157.7) is adequate for the prediction of fruit weight and volume (measured volume using the cylinder method). It was reported that the overall result for weight grading using cylinder approximation analysis yields 95% accuracy.

Sofu *et al.*, (2016) designed an automatic apple sorting machine. Three different apple cultivars were sorted into different classes by their colour, size and weight. They measured the apple weight using load cell sensors and also from the image areas using least square estimation. It was reported that the apple weights to within 5–6% gram error rates. This result was sufficient, but the ratio between the weight and area changes according to the apple cultivar, apple life and apple-keeping conditions. For those reasons, they suggested that using the load cell instead of estimation is more suitable to determine the apple weight. The system design was tested using three different conveyor band velocities and three apple cultivars and reported an average sorting accuracy rate of 73–96%.