Present status of peanuts and progression in its processing and preservation techniques

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Abstract: Peanut or groundnut is one of the major oilseed crops in the world. It is rich in oil and proteins. Developing countries account for about 95% of the world peanut production. Asia alone accounts for 70% of this amount where the major producers India and China together represent over two-third of global output. Traditionally, groundnuts are dried in open sun to its safe moisture level for storage. Natural and artificial (hot air drying) drying methods of groundnuts are being used throughout the world. Artificial peanuts drying devices consume very large amount of energy. In this paper, present status of peanut and a comprehensive review of its drying methods are discussed. Recent developments in preservation and storage of groundnuts are also highlighted.

Keywords: Groundnut/peanut; peanut drying; peanut preservation; peanut storage; moisture content; curing

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1 Introduction

Peanuts or groundnuts (arachis hypogaea) are important and powerful food source for people throughout the world (Reese and Leherer, 1999; Chang et al., 2013). Groundnut belongs to the Fabaceae (bean) family, is the ‘King’ of oilseeds derived from two Greek words, arachis means legume or beans and hypogaea means below groundnut (refers to formation of pods in the soil). It is also called a wonder nut, earth nut, monkey nut, goobers, pinder, panda, manila nut and poor men’s cashew nut (Woodroof, 1983; Madhusudana, 2013; Chang et al., 2013; Gadhiya et al., 2014). Groundnuts are reported to be originated in South America and spread to Brazil (Zhao et al., 2012). It was introduced by Portuguese from Brazil to West Africa and then to South Western India in the 16th Century. These are grown in almost all the tropical and subtropical countries of the world. Light, sandy loam soil is preferred for the production of groundnuts. Climatic conditions significantly influence the growth of groundnuts. Temperature of 30^{o}C is considered to be the optimum for rapid germination and development of pods (Nautiyal, 2002).

The worldwide groundnut production has reached to about 39.9 million metric tons per year (Torres et al., 2014). China is the world’s largest groundnut producer, followed by India and the United States (USDA, 2013). The area, yield and production of groundnut in world are shown in Table 1

Groundnut is the major edible oilseed crop of India. It accounts for 45% of the area and 55% of the production of total oilseeds in the country. It also accounts for 43% of total oil production in the country (Aher, 2014). Total area and production of groundnut in India are approximately 5 million hectares and 6 million metric tons respectively (State of Agriculture,

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Table 1 Area, yield and production of groundnut in various countries of world (USDA, 2013)

Country	Area (million hectares)	Yield (metric tons per hectares)	Production (million metric tons)
United States	0.65	4.73	3.07
China	4.64	3.60	16.69
India	5.00	1.00	6.00
Pakistan	0.11	0.90	0.10
Nigeria	2.42	1.27	3.07
Chad	0.71	0.98	0.69
Senegal	0.41	0.90	0.37
Ghana	0.35	1.38	0.48
Sudan	1.62	0.64	1.03
Congo (Kinshasa)	0.48	0.78	0.37
Burkina	0.36	0.73	0.26
Guinea	0.22	1.38	0.30
Cameroon	0.41	1.39	0.57
Mali	0.34	0.95	0.33
Malkawi	0.35	1.09	0.39
Cote d'Ivoire	0.08	1.21	0.09
Uganda	0.30	1.00	0.30
Central African Republic	0.10	1.55	0.15
Benin	0.13	0.65	0.08
Mozambique	0.39	0.29	0.11
Niger	0.74	0.39	0.29
South Africa	0.05	1.19	0.06
Indonesia	0.68	1.68	1.15
Burma	0.88	1.56	1.37
Vietnam	0.22	2.28	0.49
Thailand	0.03	1.53	0.05
Argentina	0.38	2.63	1.00
Brazil	0.10	3.36	0.33
Egypt	0.06	3.17	0.19
Maxico	0.06	1.98	0.12
Others	0.18	2.58	0.47

2013). About 75% of groundnut crop is produced in Karif (June – September) and remaining 25% in Rabi season (November – March). The major groundnut producing states in India are Andhra Pradesh, Gujarat, Tamil Nadu, Karnataka, Rajasthan, Madhya Pradesh, Maharashtra, Uttar Pradesh, West Bengal, Chhattisgarh and Punjab. The area and production of groundnut in India, state wise for the year 2012-13, are shown in Figure 1 (Production of Agriculture and Animal Sector, 2012-2013) and state wise productivity of groundnut in India is shown in Figure 2 (Production of Agriculture and Animal Sector, 2012-2013). Export of groundnuts since 1999-2000 to 2012-2013 is shown in Figure 3 (Export Import Data Bank, Ministry of Commerec, India, 2012-13). From Figure 1, it is seen that Andhra Pradesh is the leading state in area and production of groundnuts followed by Gujarat in Area and Tamilnadu in production respectively, whereas West Bengal is the leading state in productivity followed by Tamilnadu and Punjab.

Groundnut is mainly produced in Asian countries with China the largest groundnuts producer followed by India. In area, India ranked first with 22.27% share of the world during 2012-2013.

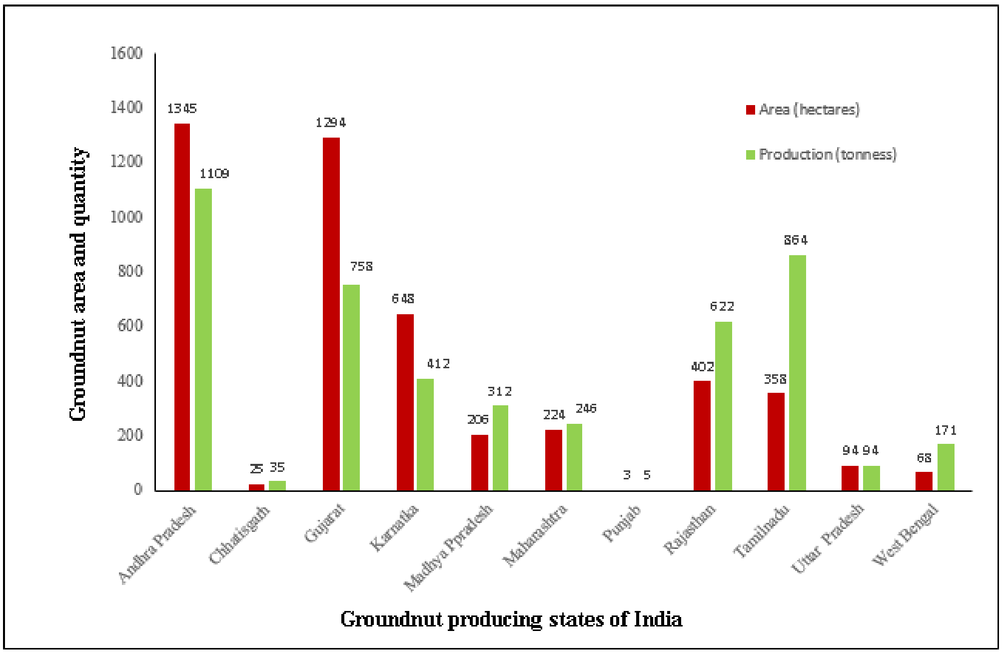

Figure 1 Area and production of groundnut for the year 2012-13 (Production of Agriculture and Animal Sector, 2012-2013)

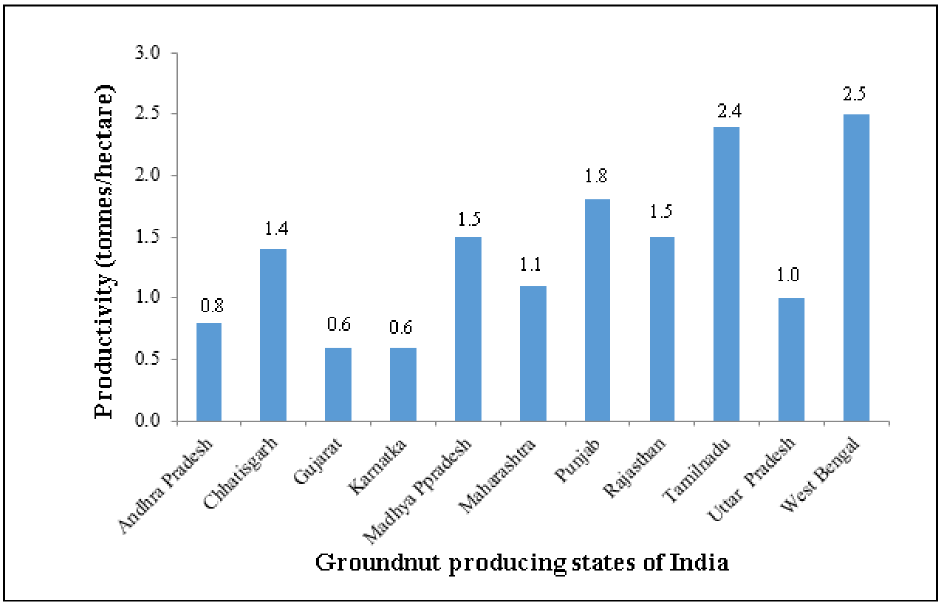

Figure 2 State wise productivity of groundnut in India for the year 2012-13 (Production of Agriculture and Animal Sector, 2012-2013)

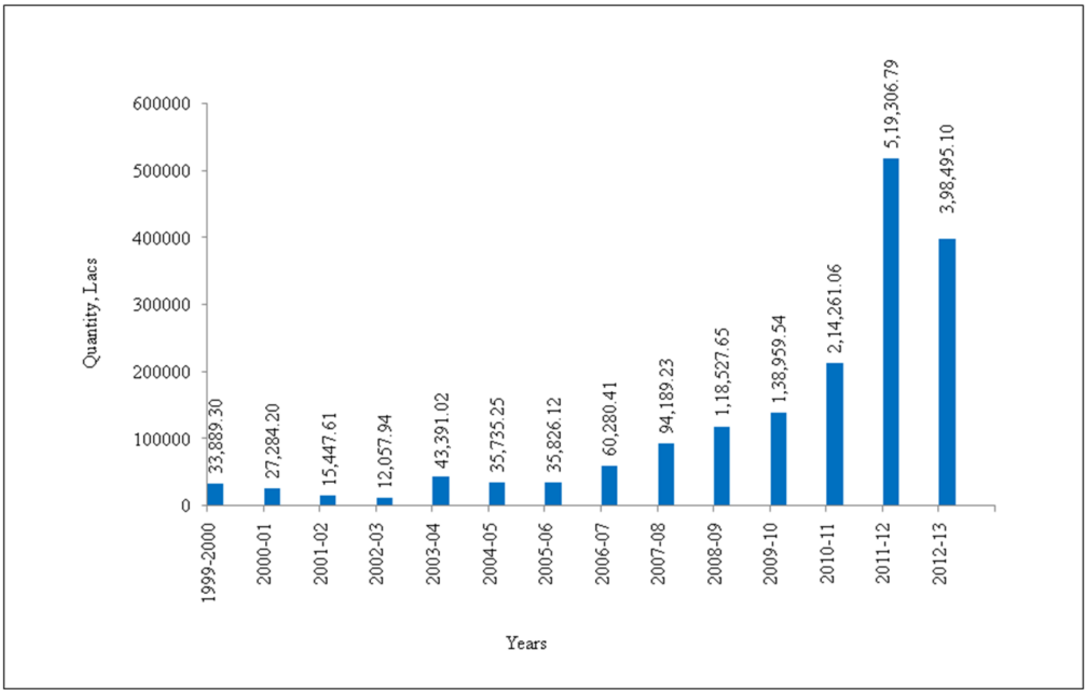

Figure 3 Export of groundnut from India (Export Import Data Bank, Ministry of commerce, India, 2012-13.)

2 General and physical aspects of peanuts

Groundnut is a major oilseed crop in India and is highly nutritious. It is major source of oil and proteins (Reddy and Bentilan, 2012). Nutrient values of groundnuts along with its types, qualities and utilities are discussed in this section. Groundnuts kernels are rich and cheap source of oil, proteins, minerals, vitamins (Dwivedi et al., 1996). The nutrients values for groundnut are given in Table 2 (Gadhiya et al., 2014; Akcali et al., 2006; and Woodroof, 1983) and the comparative nutrient values with other protein foods are shown in Table 3 (Talawar, 2004).

Table 2 Nutrients value for 100 g of groundnut (Gadhiya et al., 2014; Akcali et al., 2006; Woodroof, 1983; Torres et al., 2014; and Misra, 2004)

Nutrients	Nutrition value (per 100 g)
Calories	593 calories
Proteins	20-50%
Calcium	61 mg
Potassium	725 mg
Magnesium	176 mg
Phosphorous	396.4 mg
Sodium	320 mg
Folate	120 mcg
Carbohydrates	10-20%
Dietary Fibre	9.3 g
Total fat	40-50%
Edible oil	43-55%

Table 3 Food value of groundnuts (Talawar, 2004)

Protein foods	Milk (cow)	Egg (fowl)	Mutton	Beef	Red gram	Groundnut
Protein, %	3.3	13.3	18.5	22.6	22.3	25.33
Carbohydrate, %	4.8	-	-	-	57.2	10.2
Fat, %	3.6	13.3	13.3	2.6	1.7	40.5
Caloric value	65	17.3	194	114	333	500 – 600

The various popular types of groundnuts are Spanish, Runner, Virginia and Valencia (USDA, 1954; Woodroof, 1983; and Talawar, 2004) where Spanish types are generally grown in South Africa and the Southern western United States and are still extensively grown in California, Texas and Oklahoma and India. After 1940, Spanish type of peanuts was shifted to Runner type in Southern United States. This was due to higher yields and wider use of Runner varieties in peanut butter and salted peanuts. Virginia types of peanuts are grown in India, Virginia, North Carolina, Tennessee and parts of Georgia. These large seeded peanuts are very popular due to its demand for large peanuts for processing. Valencia types of peanuts are grown in Portaies Valley of New Mexico. These are large, smooth, and bright with red, white, pink or purple kernels. These are sweet flavoured nuts with 3-4 seeds per pod. These are popular because of ease of hand shelling and roasting (Woodroof, 1983).

Qualities of groundnuts are decided by flavour, texture and colour (Misra, 2004; Chang et al., 2013). Among these factors flavour of the groundnut plays an important role in acceptability of the groundnut products. Most of the flavour of peanuts lies in its oil. Crunchy and crisp are textural attributes which are important and desirable qualities of groundnuts. Crisp food is one which is stiff and snaps easily with crunchy sound. Crispness has been reported to be the most versatile single texture parameter. Colour of raw groundnut is attributed to taste and oil.

Indian groundnuts are very popular in the international market because of its characteristic natural flavour, taste and crunchy texture. Therefore, Indian groundnuts have better export opportunity. Groundnuts are consumed in the form of nuts. Groundnuts are being consumed throughout world in many forms (Woodroof, 1983). About every part of groundnut is of commercial use such as groundnut oil which is 43% to 55% present in the groundnut and is primarily used as a cooking oil and salad oil. It is also used in preparations of soap making, cosmetics, shaving cream, leather dressings, furniture cream, lubricants, preservation medium, chutney etc. It is used in vanaspati ghee also. Groundnut/peanut oil can be used as an alternate fuel for diesel engines (Oniya and Bamgboye, 2014). Roasted groundnuts/peanuts are used for the manufacturing of peanut butter (Smartt, 1994). It is consumed at houses and large quantities are also used in manufacturing of sandwiches, candies, and bakery items. Although the food value of peanuts is highest when it is eaten raw (peanut kernels). Dry and oil roasted, boiled peanuts are excellent foods and can even be combined with other commonly used foods. Peanuts are added in salads, desserts, cookies, chocolates, coffee cakes, breads, bakery products, ice cream etc. to make them more nutritious. The residue left after the extraction of groundnut oil is called groundnut oil cake and is mainly used as cattle feed. Every part of groundnut has economical and agricultural value. The plant is a legume and produces *Rhizobia genus bacteria* on the roots, which is a soil improvement crop. The high nutritional value of groundnut vines and leaves make it good feed for cattle, sheep, goats, mules etc. Groundnut shells are used as fuel.

3 Harvesting and curing of groundnuts

Groundnut is one of the most important oil and protein producing crop in the world. In most of the countries, groundnut kernels are used for oil extraction, food and ingredients or confectionery products. The residual cake, after extraction, is processed for animal feed and is used for human consumption also. Production of fungus ‘Aspergillus flavus’ to the groundnut kernels is a serious problem in the trade of groundnuts in the international market which has hampered the export market of the developing countries. Most of the developing countries have poor drying and storage facilities. Therefore, the need is felt to look for minimizing fungus and use of proper drying and storage methods to get the better quality of the groundnuts.

Therefore, pre-harvest control of fungus of groundnuts must be taken into consideration. The factors can vary from one location to another and season to season of the same location. Although proper use of agricultural practices such as crop rotation, proper tillage, accurate planting date, proper use of fertilizers and properly managed irrigation may save groundnuts from fungus contamination.

Fields, selected for growing of groundnuts, should have suitable type of soil, as groundnuts grow in deep well drained, friable, loose and sandy loam. Sand should be light textured and free from stones, gravel, glass pieces and other materials that cannot be easily removed or blown out of groundnuts. Soil should contain slightly acid reactive (pH of 6.0 – 6.4), enough lime and other elements for normal development.

Groundnut crop rotation with other crops such as maize, cotton, sorghum, pigeon pea and castor is beneficial (Nautiyal, 2002; Torres et al., 2014) in respect of effective use of residual soil fertility, controlling weeds and reducing soil borne disease.

Sowing depends on weather and soil conditions. It is always desirable to plant groundnut seeds early with settled weather and a well warm soil. Seed should be covered to a depth of 5-6 cm. For rapid emergence soil temperature above 21^{o}C is required. The temperature of the most rapid germination and seedling development was reported to be about 30^{o}C (Nautiyal, 2002). The groundnut plant produces horizontal stems, which in turn produce flowers at each node which are self-pollinate and produce peg which penetrates the ground. And pods are produced at the tips of the pegs. High yield and superior quality peanuts require a moderate growing period of 4–5 months. The growing season should be long, warm and moist and the harvesting season should be dry (Beattie, 1954).

Harvesting usually consists of operations like digging, lifting, windrowing, stocking and threshing. Groundnuts should be harvested when approximately 75% of the pods have reached maturity (vine begins to turn yellow and leaf shedding starts and pods have dark markings inside the shell). If harvested too early, the seeds will shrink during drying and lowering the oil content and quality of the seed. But delays in harvesting will result in poor quality pod due to mould infection and aflatoxin contamination of the pods. These are best harvested during clear weather when the soil is dry enough such that it will not stick to the stems and pods. Plants are lifted and collected in bundles of 10-20 plants and are placed in stacks. The harvested groundnuts have a moisture content of approximately 35%-50% (Woodroof, 1983). Groundnuts are separated from all other materials during threshing which can be done manually or operated by a diesel engine.

Groundnuts, after harvesting, are dried naturally or artificially. Some of the naturally adopted methods in different countries are: (i) spread on ground, (ii) windrow, (iii) DOR method, (iv) NRCG method, (v) stacks, (vi) platform, (vii) racks, (viii) trays and (ix) solar driers. Some of the artificial methods available in the literature are (i) batch dryers, (ii) in bulk and (iii) continuous flow dryers.

In natural methods of drying, groundnuts are dried by spreading the plants on ground directly exposed to sun for several days to its optimum moisture content. Open sun drying is the oldest and most common traditional method to preserve agricultural products in which products are spread on ground directly exposed to solar radiations. The solar radiations falling on the surface is partly reflected and partly absorbed. The absorbed radiations and surrounding air heat up the surface. A part of this heat is utilized to evaporate the moisture from the surface to the surrounding air. The part of this heat is lost through long wave length radiations to the atmosphere and through the conduction to the ground. If groundnuts are left for a longer duration, then sunlight may discolour the nuts. Mould may develop and may cause breaking of pods. In case of windrow drying, bunch of about ten plants are left on the ground of the field. Windrow drying is recommended prior to drying in sacks.

DOR (Directorate of Oilseeds Research, 1983) method and NRCG (National Research Centre for Groundnut) (Figure 4) method have also been attempted for drying of groundnuts.

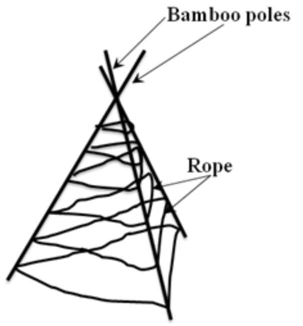

Figure 4 Schematic of NRCG method of drying pods (Nautiyal, 2002)

In some countries, plants are spread on trays and exposed to sun during day time and shifted into house at night. Sometimes cured pods form the plants were kept on platforms to complete drying. Whereas high moisture pods are kept in bags and every day these are brought out of the store-room and spread in open sun for drying. Sometimes, groundnuts of 30% moisture content kept in open bags and suspended vertically supported at both ends by strong vertical posts. This method (rack drying) took around 10 days to dry the groundnut pods to reach safe moisture level. During humid conditions, heat was used to reach safe moisture level.

After partial windrow drying groundnuts on the haulms are to be dried in batch dryers by using a heater and fan. In Tanzania tests were carried out in batch dryers and maximum temperature was reported to be 54°C in single layer of sacks to dry groundnuts from moisture content of 48% to 8%. Groundnuts were also dried in tray drier in Tanzania and two feet deep freshly harvested pods were dried from initial moisture content of 48% to final moisture content of 8% using air temperature maintained at 38°C. Simple twin tray dryers were also used in Tanzania in which fan was driven by diesel engine. In continuous flow dryers, temperature of hot air was also maintained at 38°C which was drawn under gravity through the product (Woodroof, 1983).

4 Previous studies carried out on drying of groundnuts

Groundnuts are required to be dried to its safe moisture level before delivering to buyer or stored. Otherwise fungal infection (aflatoxins contamination) may induce and reduce the seed quality for consumption. For drying purpose, groundnuts, traditionally are spread in thin layer on ground directly exposing to solar radiations for 2-5 days to dry to its required moisture content for storing. During curing process groundnuts are to be dried to an average moisture content of approximately 10%–15% (Nautiyal, 2002). Groundnuts are being cleaned of the foreign materials (about 5%) such as dirt, rock pieces, sticks, previous crop residue, immature pods, leaves, stems, weed fruit, seed, grass, metal etc. Many researchers have carried out studies on drying of groundnuts by different methods which are discussed in this section

4.1 Natural drying

In natural method of drying, groundnuts are placed on the ground exposed to solar radiations for removal of moisture content from the pods. Ahmed et al. (1967) carried out the natural sun drying and accelerated drying of groundnuts. Sun dried groundnuts were reported to have low value of free fatty acids during the storage period. The economic and management characteristics of five types of on farm peanut drying systems were compared by Bloome et al. (1983). Blankenship and Davidson (1984) presented automatic cut-off method of full scale peanut dryer when peanuts approach prescribed moisture content without periodic sampling. The method was compared with the conventional methods. Automatic cut-off method was reported to require less labour, provide better moisture control and reduce the danger of over drying. Thin drying characteristics of Thai peanuts (variety Tainan-9) were studied by Phongpipatpong (1991). Various thin layer equations were used and among them two term exponential and modified exponential equation were reported to be the best fit for peanuts with initial moisture contents more than 55% (db) and below 55% (db) respectively. Noomhorm et al. (1992) compared sun drying and conduction drying for wet season groundnut (Taiwan – 9). Conduction drying was reported to be seven to ten fold faster than sun drying.

Syarief et al. (1996) presented the free convection type drier for peanut seed drying from initial moisture content of 47.12% to final moisture content of 10.23% and determined the quality of the seed. 150 kg peanut seeds were reported to be dried from initial moisture content of 47.21% to final moisture content of 10.23%. The dryer consumed 86 kg of coconut stone as fuel. Dimante et al. (1998) carried out the simulation study of deep bed drying of peanut at various drying conditions by a simple model based on the Hukill's analysis. The simulation model was reported to be adequate to describe the deep bed drying of peanuts. Ezekoya and Enebe (2006) designed and developed a modified portable low temperature solar grain dryer (Figure 5), for drying pepper and groundnuts. Eight days were reported to be taken to dry groundnuts at average relative humidity of 43% and average temperature of 63^{o}C. The average collector efficiency was found to be 10%, while the dryer efficiency was 22%.

Recently Mannouche et al. (2014) studied the peanut drying in natural indirect solar dryer in the climatic conditions of Ouarbla, Algeria. The effect of drying on peanut extraction process was also carried out. Yield of oil in dried peanut was reported to be increased by 16.26% as compared to the fresh peanut.

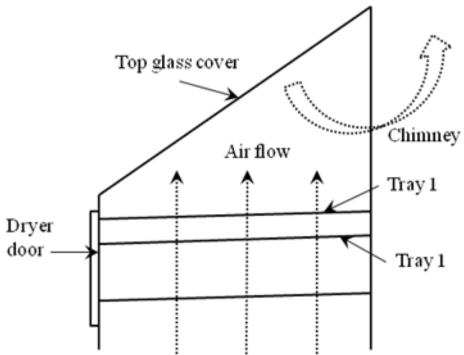

Figure 5 Schematic of solar grain dryer (Ezekoya and Enebe, 2006)

From the literature, it is found that groundnuts/peanuts were dried naturally under open sun or by using natural dryers to the safe moisture level. But time taken for drying of groundnuts was more and qualities of dried groundnuts were also reported to be low. The analysis of the natural drying of groundnuts are summarised in Table 4.

Table 4 Summary of natural drying of groundnuts

S. No.	Author	Year	Remarks
1	Ahmed et al.	1967	Compared sun drying and accelerated drying of groundnuts
2	Boloome et al.	1983	Compared economic and management characteristics of on farm peanut drying systems
3	Blankenship and Davidson J. I.	1984	Presented automatic cut-off method of full scale peanut drying
4	Phongpipatpong	1991	Thin layer drying characteristics of Thai peanuts were studied using various thin layer equations.
5	Noomhorm et al.	1992	Compared sun drying and conduction drying of groundnuts (Taiwan-9)
6	Syarief et al.	1996	Presented free convection drier for peanut seed drying. Moisture content was maintained up to 10.23%.
7	Dimante et al.	1998	Reported simulation model to be adequate for deep bed drying of peanuts.
8	Ezekoya and Eneba	2006	Designed and developed a modified portable low temperature solar grain dryer for drying groundnuts.
9	Mannouche et al.	2014	Proposed indirect solar dryer for peanut for increasing the extraction of oil. Peanut were dried from initial moisture content of 34.15% (w.b.) to final moisture content of 8.31% (w.b.) in three days.

4.2 Mechanical drying

Disadvantages of open sun drying has led to replace it with mechanical dryers which use fossil fuels to heat the drying air and air is forced through the agricultural products. Limtragoal and Directkstaporn (1985) studied the performance of solar groundnut dryers and the quality of the dried groundnuts in Northwest of Thailand. They also discussed the economic aspects. Delwiche et al. (1986) performed the analysis of variance of microwave vacuum drying of Florunner peanuts (at 4, 8, 16 and 32 times the normal rate of conventional wagon drying). The percentage of normal strong germinated kernels from microwave treatments was reported to be significantly lower than from the deep bed dried and dried within shell treatments. Parti and Young (1992) compared the peanut bulk drying model result and Virginia-type peanuts experiments test results. Chung-Pfost equation was reported to be more accurate in describing the hull moisture content but less accurate in describing the kernel moisture content history as compared to Henderson equation. Dowell et al. (1993) reported the average and single kernel moisture measured during curing and storage and studied the drying behaviour of kernels during mechanical drying and storage. Samples (average moisture content less than 13.5%) were reported to be safe from mold or aflatoxins problems.

Ketkaeo (2002) presented oven with heater infrared drying for peanuts and proposed 70°C suitable temperature for baking the groundnut. Boldor et al. (2005) investigated the effect of microwave energy level on temperature profiles and moisture reduction of farmer stock peanuts during continuous microwave drying using a planar applicator. Solar drying of groundnuts was also carried out in a mixed mode natural convection solar dryer with biomass burner (Figure 6) in Thailand (Tarigan and Tekasakul, 2005). The dryer consisted of a collector of (2.75 × 1.75) m^2 area, absorber (made of black painted zinc plate 0.05 cm thick), glass cover 0.5 cm thick, a biomass burner as a backup heating system and drying chamber. Drying tests were conducted at 35 kg and 64 kg fresh unshelled groundnuts. During the test of drying 35 kg groundnuts, the biomass burner was used at night by burning 40 kg of wood. About 16 hours were taken to dry groundnuts from initial moisture content of 135 % (db) to final moisture content of 13% (db). However, it took three days for drying of 64 kg of groundnuts when burner was not used at night. System efficiency was reported to be 21.3% and 23% and backup heater was reported to have efficiency of 40%. Krzyzanowski et al. (2006) determined the potential of the heat pipe technology (HPT) system in drying peanut seed. Peanut seeds were dried from initial moisture content of 17.4% to final moisture content of 7.3%. The effect of drying on physical and physiological qualities of peanut was also determined. Summary of peanut drying mechanically is given in Table 5.

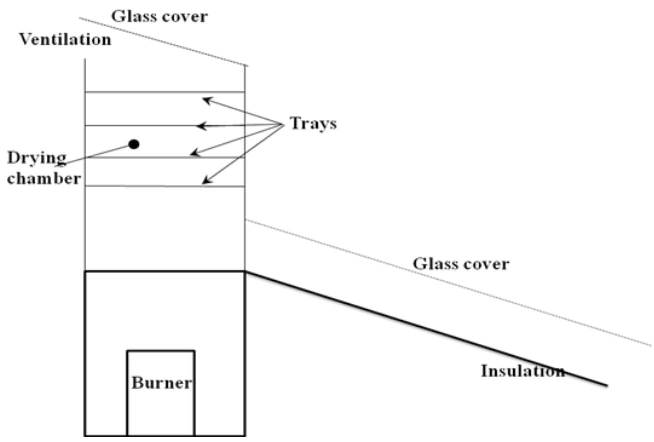

Figure 6 Schematic of Solar Dryer with biomass burner (Tarigan and Tekasakul; 2005)

It is observed from the literature, that peanut kernels are dried mechanically to increase the quality of groundnuts and reduce the drying time. But mechanically dried peanuts consume much energy and making it costly.

Table 5 Summary of peanuts drying mechanically

S. No.	Author	Year	Remarks
1	Limtragoal and Directkstaporn	1985	Studied the performance of solar groundnut dryers in Thailand
2	Delwiche et al.	1986	Performed microwave vacuum drying of flowrunner peanuts
3	Parti and Young	1992	Presented the comparison of peanut bulk drying model result and Virginia-type peanuts experiments test results using various drying equations
4	Dowell et al.	1993	Studied the drying behaviour of kernels during mechanical drying and storage. Moisture content was maintained up to 13.5%.
5	Ketkaeo	2002	Presented oven with heater infrared drying for peanuts and proposed 70°C suitable temperature for baking the groundnut
6	Boldor et al.	2005	Presented microwave drying using a planar applicator.
7	Tarigan and Tekasakul	2005	Proposed mixed mode natural convection solar dryer with biomass burner for drying groundnuts. Moisture content was maintained up to 13 % (db).
8	Krzyzanowski et al.	2006	Presented heat pipe system for drying of peanut seeds. Moisture content was maintained up to 7.3%.

4.3 Forced drying

Natural drying of groundnuts is the cheapest method but the qualities of groundnuts were found to be low and drying time was also more. Therefore, to improve the qualities of groundnuts and reduce the drying time, forced drying of groundnuts is discussed in this section. Blankenship and Chew (1979) studied the drying of peanuts in single and double trailer dryer and total peanut drying time was reported to be shorter in single trailer dryer as compared with double trailer dryer. Troeger and Butler (1980) studied the drying of peanuts of different moisture contents by interrupting airflow for 15, 30 or 45 min/h. They used solar heated water or liquefied petroleum gas to heat the drying air. Troeger and Butler (1980a) constructed a solar drier to compare three systems (solar heated water, solar heated air with rock storage and conventional liquefied petroleum gas) for drying peanuts. The dryer used fans and LPG burners. Heat energy from solar storage was used to preheat the air entering the fan. The solar heated water and air systems used 41% and 74% solar energy respectively, the remaining energy supplied by petrol burners. Troeger (1982) carried out the analysis of various factors affecting energy consumption and drying time of peanut using a computer simulation model. Airflow was recommended to speed up the drying of peanut. Steele (1982) developed microprocessor based peanut dryer control system and proposed energy controlled techniques for drying peanut to minimize energy consumption and compared with conventional control procedures. First energy control technique was reported to reduce liquid petroleum gas consumption by 49%, electric energy by 39% and increased time on dryer by 65%. Net saving of $5.61 per tonne or 25% reduction in peanut drying costs was reported for Virginia conditions.

Nawungkalatusart and Tamtawatchai (1989) carried out the continuous drying of groundnut kernels at various temperatures (35°C, 40°C, 45°C, 50°C and 55°C). Kernels dried at 55°C were reported to have lowest germination of seed. Kumar and Kanagarajah (1990) investigated the drying characteristics of peanut in forced air oven and batch type rotary drier at various temperatures. They designed and developed a rotary conduction drier with sand as heating medium. Peanut dried in forced air oven was reported to be superior than dried in batch type rotary drier. Also, conduction drying using sand as heating medium was reported to increase the drying rate and quality of peanut as compared to conduction drying using batch type rotary drier. Gowda et al. (1991) studied the drying of groundnut (DH-3-30) seeds at various drying air temperatures with initial moisture contents of 35, 43 and 67 % (db), at air flow rate of 4 m^3/min and loading weight of 5 kg using the drying unit and were stored for 180 days to evaluate the seed quality. Among these groundnut dries at 45°C and 50°C with initial moisture content of 67 and 43% (db) respectively were reported to be stored safely for 180 days.

Noomhorn et al. (1994) proposed rotary conduction drier using sand as the heating medium for drying peanuts up to the safe moisture content of 10% wb. The performance characteristics of the drier were also determined in terms of peanut quality and drying time. Quality indexes of peanuts were reported to be dependent on the operating conditions of the drier. Optimum kernel temperature during conduction drying was reported to be 40°C for good quality dried peanuts. Bader et al. (1996) evaluated the total energy consumption and curing time for various methods of curing peanuts with dual-trailer driers. Three dryers were operated continuously and three dryers were operated intermittently. Electrical demand was reported to be 23.8 kW and 32.1 kW for cycled and continuous dryers respectively. Tumbel et al. (1997) presented a rack type dryer "tray dryer" for peanut drying from 63.23% moisture content to 10.12% moisture content. They also studied and investigated the quality of the dried beans. The energy consumption and overall thermal efficiency of the dryer were reported to be 790,000 kCal and 3.35% respectively.

Butts and Omary (1999) presented the comparison between conventional peanut curing wagons and the bin dryer in which the moisture content was maintained up to 11%. A total of 451,717 kg peanuts were reported to be cured in two stage dryer and 215,460 kg in convectional dryers. A single batch in the two-stage dryer was reported to be equivalent to three wagons. Ertas et al. (1999) also proposed a semi trailer drying system for drying peanuts for West Texas in which the temperature inside the dryer was maintained at 35°C. Labour cost was also reported to be reduced. Jain et al. (2004) compared the drying of groundnut, ginger and garlic in a forced convection solar dryer consisting of flat plate collector panel and electrically operated tray type mechanical dryer. The benefit cost ratio for the solar dryer and mechanical dryer was found to be 1.56 and 1.18 respectively. The drying cost for drying groundnuts in forced convection solar dryer was found to be 20% less as compared to mechanical dryer. Palacios et al. (2004) dried the remoistened peanut pods (various initial moisture contents) in batch dryer (Figure 7) at different temperatures. They also evaluated effective diffusivity for peanuts (in-shell and shelled) by applying short time analytical model to measured data and analysed its values in connection with structures of shell and grains.

Decision support system was developed by Butts et al. (2004) to manage commercial peanut drying facilities and developed an empirical method for determining peanut drying time and compared with the observed drying time. Yang et al. (2007) carried out the simulation study of peanut drying in a trailer-type dryer with various thin layer drying models. Among these models Henderson-Pabis model along with the Hummeida model for Barberton model variety and modified Oswin EMC model was reported to be the most suitable. Ahmed and Murani (2012) proposed low cost mobile flat-bed dryer for drying of groundnuts from initial moisture content of 23.3% to final moisture content of 14%. The drying efficiency was reported to be 69%. Capacity of the dryer was reported to be 1818 kg. The cost of drying of groundnut was reported to be Rs. 1.45 per kg. Study carried out on forced drying of groundnuts are summarised in Table 6.

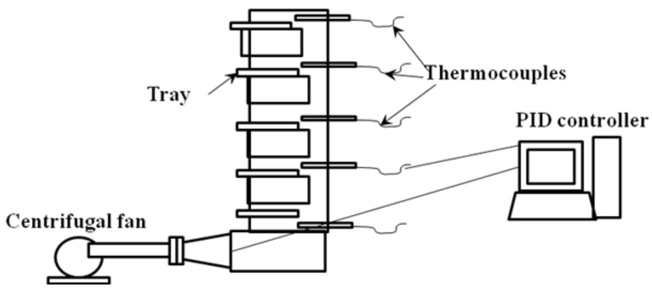

Figure 7 Schematic of Pilot plant batch dryer (Palacios et al., 2004)

Different types of dryers have been used to dry the peanuts to safe moisture level. Peanuts dried under forced convection drying were reported to be superior. Various means were also used to increase the drying rate and quality of peanuts.

Table 6 Summary of forced drying of groundnuts

S. No	Authors	Year	Remarks
1	Blankenship and Chew	1979	Compared single and double trailer dryer for peanut drying. Drying time was reported to be shorter in single trailer dryer.
2	Troeger and Butler	1980	Presented drying of peanuts of different moisture content by different interrupting airflow (15, 30 or 45 min/h) with solar heated water or LPG as preheating the air.
3	Troeger and Butler	1980a	Presented solar drier with fans and LPG burners.
4	Steele	1982	Developed microprocessor based peanut dryer control system and proposed energy controlled drying techniques to minimize energy consumption.
5	Troeger	1982	Used computer simulation model to carry out the analysis of various factors affecting energy consumption and drying of peanuts and recommended air flow to speed up drying.
6	Nawungkalatusart and Tamtawatchai	1989	Proposed 55°C temperature for lowest germination.
7	Kumar and Kanagarajah	1990	Proposed forced air oven drying for peanuts as compared to batch type rotary drying.
8	Gowda et al.	1991	Proposed drying of groundnut seeds (DH-3-30) at 45°C and 55°C for safe storage up to 180 days.
9	Noomhorn et al.	1994	Proposed rotary conduction drier (40°C) using sand as the heating medium. Moisture content was maintained up to 10% wb.
10	Bader et al.	1996	Determined total energy consumption and cutting time for different methods of drying peanuts.
11	Tumbel et al.	1997	Presented a rack type drier “tray dryer”. Moisture content was maintained up to 10.12%.
12	Ertas et al.	1999	Proposed semi trailer drying system (maintained at 35°C) for peanut drying
13	Butts and Omary	1999	Compared conventional peanut curing wagon and bin drying. The moisture content was maintained up to 11%.
14	Butts et al.	2004	Developed decision support system to manage commercial peanut drying facilities and developed an empirical method for determining peanut drying time.
15	Palacios et al.	2004	Presented short time analytical model and determined the effective diffusivity.
16	Jain et al.	2004	Proposed forced convection type solar dryer consisting of flat plate solar collector for drying of groundnuts. Groundnuts were dried from initial moisture content of 104.9% (d.b.) to final moisture content of 15.8%.
17	Yang et al.	2007	Presented the simulation study of peanut drying in a trailer-type dryer with various thin layer drying models.
18	Ahmed and Murani	2012	Proposed low cost mobile flat-bed dryer and moisture content was maintained up to 14%.

5 Studies on storage and preservation of groundnuts/peanuts

Work carried out on storage and preservation of groundnuts is discussed in this section. After drying, groundnuts are to be stored in gunny bags for storage. Some of the requirements for successful storage of groundnuts are: (i) place should be free from mold, insects, and rancidity, (ii) temperature should be low. Storage life of shelled and unshelled groundnuts at various temperatures is given in Table 7 (Woodroof, 1983), (iii) relative humidity should be low. At relative humidity of 65%-70%, groundnuts equalize at a moisture content of about 7%. Above 70% of groundnuts are likely to mold and below this they lose weight, become brittle and may split during handling, and (iv). The atmosphere should be well circulated and free from odors. Groundnuts can be stored from about four months to ten years by varying the temperature from 0 °C to -12.2°C (Woodroof, 1983).

Anjelo and Ory (1974) studied the development of peroxidation in peanut varieties for 12 months at 4°C. They proposed packing under nitrogen or vacuum for retarding peroxidation. Hoover and Miller (1974) presented the pre treatment of Green peanuts with hot water (120^{o}F) and fungicides before packaging which improved the reduction of microbial infection. Sanders et al. (1981) studied the parameters (excess moisture, high temperature and mechanical damage) on peanuts from five warehouses. They suggested improved storage environment such as improved ventilation for minimizing the damage to peanuts during storage and increase its quality. Smith et al. (1983) determined and compared the temperature profiles within the peanuts in flat type storage with natural and mechanical ventilation for during the storage season. The mechanical ventilated warehouse was found to be at a mean temperature of 1^{o}C–4^{o}C less than the naturally ventilated warehouse throughout of the storage period.

Smith et al. (1984) determined the effects of mechanical and natural ventilation on over space environment throughout the normal storage period for farmers stock peanuts. Wilson et al. (1985) carried out pilot scale peanut (US No. 1) storage tests using several sizes of containers with peanuts stored under air, burner gas (BG), N_2, CO_2 atmospheres. Peanuts were stored at 26^{o}C±2^{o}C for one year. Moisture content, relative humidity, temperature, seed microflora aflatoxin contamination and CO_2, N_2, O_2 and N_2 levels in the storage containers were measured periodically. Branch et al. (1987) carried out the studies to examine the immersion of peanuts in hot water at 79^{o}C for 90 seconds as a means of enhancing shelf life of peanut stored at non-refrigerated conditions for 8 months.

Smith and Sander (1987) developed a new concept of semi-underground storage of farmers stock peanuts by developing a small semi-underground warehouse. Temperatures and relative humidity were measured at various locations during storage and quality of peanuts was compared with the conventionally stored peanuts. Troeger (1989) developed a model for estimating the effects of curing conditions in the simulation model on milling quality and on aflatoxin production. Smith et al. (1989) evaluated the parameters (temperature, relative humidity and quality changes) occurring in farmers stock peanuts stored at 8% and 10% moisture content in naturally and mechanically ventilated warehouses.

Baker et al. (1993) developed a new dryer heat control method i.e. drying rate control (DRC) to avoid mold problems and milling quality losses. DRC was tested and compared with humidistat control (HC) and conventional control (CC) using a simulation model and laboratory tests. Airflow rates of 5, 10 and 15 $m^3/min/m^3$ were used. HC was reported to be better in respect of peanut quality as compared to CC with lower fuel cost but increased curing time. And DRC was reported to be better in respect of peanut quality as compared to CC with similar curing time and similar fuel cost.

Tripathi and Kumar (2007) proposed Putranjiva roxburghii oil as a preservative for peanut seeds against spoilage by fungi and insects during storage. Putranjiva leaf oil showed as a potent herbal preservative for management of post-harvest infestation of peanuts on the basis of its strong fungal toxicity at a low minimum inhibitory concentration, insect repellency and long shelf life. Poly lined gunny bag (PLGB), for highest germination (72%), as packing material with desiccant for storage of rabi or summer groundnuts were reported by Gowda and Reddy (2008). Silica gel (30g/kg pod) or Calcium chloride (10g/kg pod) was used as desiccant material.

Morton et al. (2008) determined the effect of different storage environment on peanut germination. Peanut pods of four cultivars were stored in four environments and seeds were subjected to standard germination tests and field emergence evaluation. Passone et al. (2008) studied the effect of food grade antioxidant emulsion on aflatoxigenic growth and aflatoxin accumulation on stored peanut pods to preserve the shelf life. Butylated hydroxyanisole (BHA), propyl paraben (PP) and butylated hydroxytouene (BHT) were reported to be reduced significantly during the storage of peanuts. Nakai et al. (2008) determined the mycoflora and occurrence of aflatoxins in stored hull and kernel samples from Tupa, State of Paulo, Brazil. And Dorner (2008) reviewed the techniques developed for managing aflatoxins contamination when it occurs and presented a newly developed methodology to prevent maximum contamination.

Borker and Dharanguttikar (2014) evaluated twenty two groundnut genotypes to study the physiological analysis of growth and yield variation in groundnut genotypes. Ozonation technique was presented by Chen et al. (2014) to detoxify of aflatoxins in peanuts. HPLC-FLD (high performance liquid chromatography coupled to a fluorescence detector) method was also used to detect the presence and levels of aflatoxins in groundnuts in Turkey (Hepsag et al., 2014). Villers (2014) has reviewed the field experience and research on prevention of growth of aflatoxins during post harvest storage in hot and humid countries. Various preservation techniques for the farm products were presented by Olunike (2014).

Torres et al. (2014) also presented the various strategies and recent advances to prevent aflatoxins contamination in peanuts. Modified atmospheric storage condition was proposed by Vasudevan et al. (2014). The seeds stored with the gaseous combination of 60% N_2 + 0% O_2 + 40% CO_2 were reported to show better germination throughout the storage period followed by the seeds stored under vacuum. To increase the yield of groundnuts Aher (2014) proposed the use of improved technology i.e. *Rhizobium* bio-fertilizer. Gadhiya et al. (2014) studied the effectiveness of insecticides for the management of Helicoverpa armigera (Hubner) Hardwick and Spodoteralitura (Fabricius) infesting groundnut. Recently Sudini et al. (2014) suggested the triple layer “Purdue Improved Crop Storage (PICS)” bags for the sage storage of groundnut seeds.

Giradri et al. (2015) attempted to encapsulate the food grade antioxidants (butylated hydroxyanisolz i.e. BHA and butylated hydroxytoluene i.e. BHT) to increase the storage time for peanuts. The storage and preservation of groundnuts are summarised in Table 7.

Table 7 Summary of groundnuts during storage and preservation

S. No.	Author	Year	Remarks
1	Anjelo and Ory	1974	Proposed packing of peanuts at (4^oC) under nitrogen or vacuum for retarding peroxidation.
2	Hoover and Miller	1974	Proposed pre-treatment of Green peanuts with hot water and fungicides before packaging.
3	Sanders et al.	1981	Presented improved storage environment (improved ventilation) to reduce the peanut losses during storage and increase the quality.
4	Smith et al.	1983	Proposed mechanical ventilation for storage of peanuts.
5	Smith et al.	1984	Presented the importance of properly filled natural ventilated storage to avoid blocking air vents.
6	Wilson et al.	1985	Performed pilot scale experiments to determine the long term storage of US No. 1 peanuts in modified atmosphere with minimum deterioration through molding.
7	Branch et al.	1987	Proposed hot water immersion technique for preserving non refrigerated peanuts
8	Smith and Sander	1987	Proposed a new concept of storing peanuts in semi-underground warehouse
9	Troeger	1989	Modified the peanut curing model to indicate conditions which affect peanut quality.
10	Smith et al.	1989	Proposed the 10% or less as initial moisture content for farmers stock peanuts to be maintained during storage.
11	Baker et al.	1993	Proposed a new heater control method for peanut dryers.
12	Morton et al.	2008	Presented the effect of various storage environments on the germination and emergence of peanut cultivars.
13	Passone et al.	2008	Proposed food grade antioxidants to be applied on stored peanut pods to increase the shelf life.
14	Tripathi and Kumar	2007	Proposed Putranjiva oil as preservative for peanut seeds against fungus.
15	Gowda and Reddy	2008	Proposed PLGB as packing material for storage of groundnuts.
16	Nakai et al.	2008	Calculated mycoflora and occurrence of aflatoxins in stored samples.
17	Dorner	2008	Various techniques for managing aflatoxins contamination were reviewed
18	Borker and Dharanguttikar	2014	Groundnut genotypes were evaluated.
19	Chen et al.	2014	Ozonation method was presented to detoxify fungus in peanuts.
20	Hepsag et al.	2014	HPLC-FLD method was presented to detect aflatoxins presence and levels in groundnuts
21	Villers	2014	Comprehensive review of aflatoxins during post harvest storage in hot climates
22	Olunike	2014	Presented preservation techniques for farm products.
23	Torres et al.	2014	Presented strategies and recent advances to prevent aflatoxins
24	Vasudevan et al.	2014	Proposed modified atmospheric storage condition for better germination
25	Aher	2014	Introduced Rhizobium bio-fertilizer to increase yield of groundnut
26	Gadhiya et al.	2014	Effectiveness of insecticides was studied.
27	Sudini et al.	2014	Proposed PICS bags for storage of groundnut seeds.
28	Giradri et al.	2015	Presented food grade antioxidants to increase the storage time for peanuts.

Groundnuts are to be stored just after drying to its safe moisture content. From the literature, it is found that studies have been carried out to detect aflatoxins in stored groundnuts and methods have been proposed to detoxify them. Various methods have also been proposed for safe storage and preservation of groundnuts by using antioxidants, PICS bags, PLGB as packing materials, modified atmospheric conditions, Putranjiva oil etc. Use of bio-fertilizer has also been suggested to increase the yield of groundnut.

Summary

Groundnut is one of the major oilseed crops in the world and can be consumed as food. It is rich source of proteins. Its production is about 39.9 million metric tons per year. China is the leading country in world in groundnut production followed by India. Various types of groundnuts are consumed throughout the world in many forms. Groundnuts are grown in warm and dry season. Harvesting of groundnuts include digging, lifting, windrowing, stocking and trashing. After harvesting groundnuts are dried to its safe moisture content by various means. Open sun drying is the most primitive method of groundnut drying which is weather dependant and also prone to microbial and other contamination. In spite of many disadvantages open sun drying is still practised throughout the world.

Although the hot air industrial driers are available to get the good quality of the product, but they consume large amount of energy. The scarcity of fossil fuel, steep rise in the energy cost, and environmental pollution are the driving factors in the use of energy efficient and renewable drying process.

Groundnuts are stored and preserved in godowns for future consumption. Small farmers store groundnuts in-shell, in earthen pots, mud bins, bamboo baskets, gunny bags, polythene bags. Groundnuts are subjected to quality losses during storage through fungus, insects, rodent infestation etc. About 6%-10% of the groundnut kernels stored in bags are destroyed by insects. The post harvest losses of food grains are also considered to be about 20%-30%.

Solar energy is an important alternative source because it is abundant, non-pollutant, and inexhaustible. Also, it is environmentally benign, cheap, and renewable which can be effectively used for drying purposes, if harvested properly. Thus, there is urgent need for the assessment of post harvest losses and develop some means of drying and storage of groundnuts which are cheap, energy saving and easily available for farmers so that the losses can be minimized.

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