Groundnut Grower's Guide for Mozambique: Production, Harvesting and Post-harvest Handling

Groundnut (*Arachis hypogaea*)

Submitted to:

Olipa-Odes
c/o CNFA-Mozambique
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Front cover: Köhler, Franz Eugen (1887) ‘Groundnuts’ in *Medizinal-Pflanzen*, Leipzig, Germany: Gera-Untermhaus.

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Abbreviations and Acronyms

CNFA	Citizens Network for Foreign Affairs
CLUSA	Cooperative League of the USA
IPM	Integrated Pest Management
MT	Metric Ton
NCBA	National Cooperative Business Association
NGO	Non-Governmental Organization
USAID	United States Agency for International Development

1. Agricultural technical assistance for Mozambique

The groundnut (*Arachis hypogeal L.*), also known as peanut, earth-nut, monkey nut, booger, panda, pinder, and Manilla nut is an important crop for Mozambique. It is important in terms of being an essential source of livestock feed and a component in rural and urban diets. The groundnut is consumed in various forms including consumption of the pods, roasted, or boiled. In addition, peanut butter is incorporated in traditional African dishes and it used as a basic condiment. Once considered a food crop, today the groundnut is considered a cash crop due to its economic importance and ability to generate income for Mozambique farmers.

Notwithstanding the fact four local types of groundnut are cultivated (Ramas, Virginia, Spanish, and Valencia) throughout Mozambique, a number of factors are responsible for low production yields. In general, farmers lack high-quality farm inputs and training in good agricultural practices. Soil fertility, scarcity of rainfall, diseases, and local pests also contribute to low productivity.

Most groundnut farmers are smallholders who use traditional methods of cultivation and farm less than 1 ha. Farmers struggle with having to sow seed varieties that are not uniform in size or color, have limited technical knowledge to improve productivity, and their post-harvest practices encourage rather than prevent or limit aflatoxin contamination (Muindi & Bernardo, 2010).

To address these problems, Olipa-Odes, a local horticultural NGO located in the northern province of Nampula, applied to CNFA, a USAID-funded international development organization, for technical assistance in pre- and post-harvest handling of groundnuts. With improved production practices via technical assistance, farmers can expand their groundnut sales to Ikuru and Olam International, two large wholesalers that export to European markets (Fondo & Bernardo, 2009).

This *Groundnut Grower's Guide for Mozambique: Production, Harvest, and Post-harvest Handling* is provided by CNFA in compliance with Olipa's request. This groundnut handbook addresses all aspects of plant cultivation and harvest and post-harvest handling. Further, this *Grower's Guide* was used to accompany extensive training in groundnuts for Olipa staff in a train-the-trainer program during October 2011.

1.1 CNFA

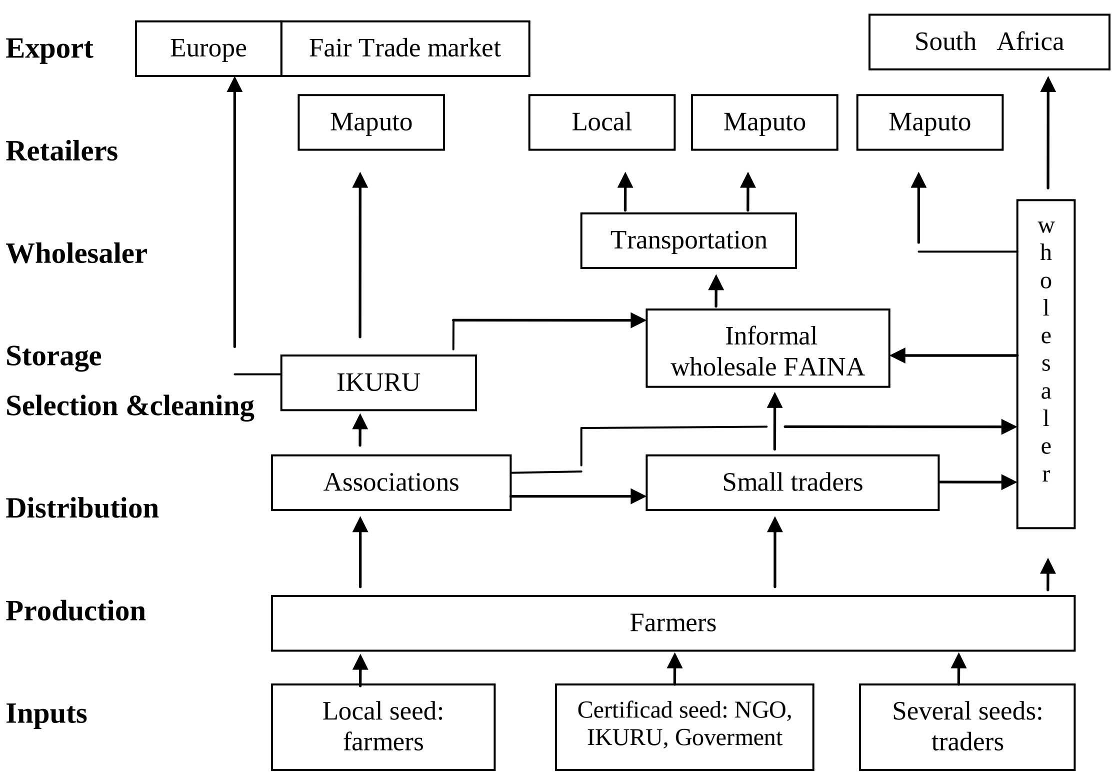
CNFA was established in 1985 as a not-for-profit organization to stimulate economic growth around the world by supporting entrepreneurship, private enterprise, and market linkages. CNFA's core competencies are strengthening market linkages, building input supply networks, promoting enterprise growth and development, agribusiness financing, and improving processing and post-harvest handling. Headquartered in Washington, D.C., CNFA's programs extend from ex-Soviet republics and the Caucasus, to Central Asia and Africa. CNFA's current five-year USAID Southern Africa Program is authorized by the current Farm Bill (PL. 110-234), and it targets technical assistance to improve agricultural markets and improve productivity. Through this program, CNFA contributes to helping Mozambique farmers increase competitiveness, expand exports, and generate higher income along the value chain (CNFA, 2011).

1.2 OLIPA-ODES

Olipa-Odes (organization for sustainable development) was formed in 1999 and was registered as a horticultural NGO in 2000 as part of the Group Rural Enterprise Development Programme implemented by the Cooperative League of the USA (CLUSA). CLUSA has worked in developing countries for more than 50 years to economically empower individuals and communities by developing sustainable cooperative businesses focused on agriculture and agribusiness. To date, CLUSA has managed more than 200 long-term projects in 55 countries. By helping establish Olipa, CLUSA contributed to increasing incomes and building organizational capacity in marginalized rural communities (NCBA, 2011).

Olipa's mission is to strengthen producer associations by providing marketing support and market information, provide agricultural training, agro-processing management, and micro-financing. Improved food security, gender equality, and environmental education are also objectives of the organization (Hivos, 2011). With farmers-producer associations at the core of economic development in remote communities, Olipa has mapped the groundnut value-chain as shown in Figure 1.1.

Figure 1.1 Groundnut value chain



Source: Muindi & Bernardo (2010)

By providing groundnut farmers with targeted and comprehensive training in pre- and post-harvest techniques, Olipa expects farmers will increase their yield and produce higher quality product to take advantage of regional and international market opportunities. In so doing, Olipa expects that incomes will increase as much as 30% in Mecate and Murrupula districts (Muindi & Bernardo, 2010). Wholesale buyers interested in high quality groundnuts are Ikura and Olam International.

1.3 Ikuru

Ikuru is a Mozambique-owned agricultural processing and trading company. Ikuru was founded in 2003 and financed through shares issued to ethical investors Oxfam Novib (45%), GAPI, a local NGO (45%), and various forums (10%). In total, Ikuru is owned by more than 22,000 farmer-shareholders grouped in 29 farmer associations in northern Mozambique. Forty percent of its shareholders are women. Ikuru means 'strength'.

Ikuru is one of Mozambique's most successful farmer-owned businesses. The total volume of crops its members market has increased from 300 MT in 2004 to 2,250 MT in 2009, representing an annual growth of around 50% per year. Ikura conducts research on seed varieties, purchases, processes, and packages agricultural products for export on behalf of its shareholders, owns a sesame cleaning factory and groundnut grading line, and has an on-site Quality Control Lab to verify quality standards before exporting to markets in Europe and southern Africa. Ikuru has been certified by FairTrade Products (cashew nuts and groundnuts) and Eco-Cert Organic Products (soybeans, sesame, and groundnuts).

Ikuru is located in Nampula, a major groundnut producing area in northern Mozambique. The majority of Ikuru shareholder-farmers are groundnut producers, growing predominately the Spanish (locally called Nametil) variety. Groundnuts are sold by producers to middlemen for resale in the capital city of Maputo, 1,200 miles to the south, but this is a volatile market and beginning in 2006 Ikuru members began exporting groundnuts to FairTrade and organic markets in Europe (Ikuru, 2011). To maintain these markets it is critical for Ikuru to be able to continue to supply high-quality groundnuts that have not been contaminated by aflatoxin (IKURU, 2011).

1.4 Olam International

Olam International is also interested in Mozambique groundnuts. Olam International is a Singapore-based enterprise in supply chain management of agricultural products and food ingredients, sourcing 20 products with a direct presence in over 60 countries and supplying them to over 10,000 customers in more than 55 destination markets. Olam International was established in 1989 and has evolved from a single-product, single-country business to a multi-product, multi-national, integrated supply chain manager. Between 1993 and 1995 Olam grew first within West Africa (including Benin, Togo, Ghana, Cote d'Ivoire, Burkina Faso, Senegal, Guinea Bissau, Cameroon and Gabon) and then East Africa (Tanzania, Kenya, Uganda, and Mozambique) and finally India. Its move into multiple origin countries coincided with the deregulation of the agricultural commodity markets.

Olam trades agricultural commodities such as cocoa, coffee, sesame, rice, cashews, and other nuts. Although an estimated one-third of the world's raw cashew nuts are produced in Africa, 80% of these are exported to Vietnam or India for processing. Initially, Olam began exporting cashews from Nigeria to India for processing. Later Olam expanded into other key producing countries in West Africa, including Mozambique. Today Olam maintains an office in Maputo, processes cashews in the country, and also deals in groundnuts. Producing groundnuts in large volume that meet international export standards will also increase the number of transactions between Olam and Mozambique farmers (Olam, 2011; Wikipedia-Olam, 2011).

2. Groundnuts

The groundnut or peanut (*Arachis hypogaea*) is a species in the legume or bean family (Fabaceae). The botanical name for groundnut, *Archis hypogaea* Linn., is derived from two Greek words, *Archis* meaning a legume and *hypogaea* meaning below ground, referring to the formation of pods in the soil (Nautiyal, 2002).

The groundnut is an annual herbaceous plant growing 30-50 cm. (0.98-1.5 feet) tall. The leaves are opposite, pinnate with four leaflets (two opposite pairs; no terminal leaflet), with each leaflet 1-7 cm. (3/8 to 2-3/4 inches) long and 1-3 cm. (3/8-1 inch) broad. The flowers are a typical pea flower in shape, 2-4 cm. (3/4 to 1-1/2 inches) across, yellow with reddish veining. Pods are 3-7 cm (1.2-2.8 inches) long, containing 1 to 4 seeds. The flower is borne above ground and after it withers the stalk elongates, bends down, and forces the ovary underground. The seed matures below the surface, and the plant thrives in light sandy soil. Once the seed matures the inner lining of the pods or seed coat, change from white to brownish. The entire plant, including most of the roots, is removed from the soil during harvesting (Wikipedia-Peanut, 2011).

2.1 History

The origin of the groundnut is uncertain, although they were known as early as 950 B.C. The groundnut was supposed to have been first domesticated in Brazil or Peru. Cultivation spread as far as Mesoamerica where the Spanish conquistadors found the *tlalcacahuatl* (Nahuatl= 'peanut', hence, Mexican Spanish, *cacahuate* and French *cacahuète*) being offered for sale in the marketplace of Tenochtitlan (modern day Mexico City). When the Spaniards returned to Europe they took groundnuts with them. Later, traders were responsible for spreading the groundnut to Asia and African countries such as Mozambique (Higgins, 1951; Wikipedia-Peanut, 2011; Pattee & Young, 1982).

2.2 Varied applications

Groundnuts are one of the most important food crops in the tropics and subtropics. All parts of the plant can be used. The groundnut, grown primarily for human consumption, has several uses as whole seeds or as processed to make peanut butter, oil, and other products. The seed contains 25 to 32% protein (average of 25% digestible protein) and 42 to 52% oil. A pound of groundnuts are high in food energy and provides approximately the same energy value as 2 pounds of beef, 1.5 pounds of Cheddar cheese, 9 pints of milk, or 36 medium-size eggs.

Groundnut oil is often used in cooking because it has a mild flavor and a relatively high smoke point. Due to its high monounsaturated content, it is considered healthier than saturated oils, and is resistant to rancidity. There are several types of groundnut oil including: aromatic roasted groundnut oil, refined groundnut oil, extra virgin or cold pressed groundnut oil, and groundnut extract.

Flour is also made from groundnuts. Groundnut flour is lower in fat than peanut butter and it is popular with cooks because of its high protein content that makes it suitable as a flavor enhancer. Groundnut flour is used because it is gluten-free.

Non-food products such as soaps, medicines, cosmetics, and lubricants can be made from groundnuts. The vines with leaves are excellent high protein hay for horses and ruminant livestock. The pods or shells serve as high fiber roughage in livestock feed, fuel (fireplace logs), mulch, and are even used in manufacturing particle board or fertilizer (Woodroof, 1973; Putnam et al., 1991; Augstburger, 2002; Wikipedia-peanut, 2011).

2.3 Worldwide production

Groundnuts are currently grown on approximately 42 million acres worldwide. It is the third major oilseed of the world next to soybean and cotton. China leads in production of groundnuts, having the greatest share of overall world production, followed by India and then the United States. See Table 2.1. In contrast to these large producers, Mozambique produced 0.11 million metric tons from a total of 279,000 ha (Putnam et al., 1991; Nautiyal, 2002; USDA-FAS, 2010).

Table 2.1 Top ten producers of groundnuts in 2008/2009

Country	Production (million metric tons)
People's Republic of China	14.30
India	6.25
United States	2.34
Nigeria	1.55
Indonesia	1.25
Myanmar	1.00
Sudan	0.85
Senegal	0.71
Argentina	0.58
Vietnam	0.50
Mozambique	**0.11**
Other countries	4.99
World total	**34.43**

Source: Adapted from USDA-FAS (2010)

In most developing countries, the productivity levels are lower than in developed countries. Mozambique is no exception. A number of production constraints confront Mozambique farmers, such as cultivation of the crop on marginal lands under rain fed conditions, occurrence of frequent drought stress due to vagaries of storms, a higher incidence of disease and pest attacks, low input-use, and factors related to socio-economic infrastructure.

Most of the groundnuts produced in developing countries are used for extraction of oil for domestic consumption and export. As a high-quality cooking oil it is an important source of protein for both human and animal diet and also provides much needed foreign exchange by exporting the kernels and cakes. Indeed, over half of the groundnut harvested worldwide is crushed for oil and a substantial quantity of groundnut produced in developing countries is traded in domestic markets. International trade of groundnuts is mainly in the form of in shell (pods), shelled (kernels), and meal (cake). A large trade of confectionery groundnut is also booming in the international market. The international price of groundnuts is generally decided by the crop size and quality in the United States (Nautiyal, 2002).

2.4 Nutritional value

Groundnuts are rich in nutrients, providing over 30 essential nutrients and phytonutrients. Groundnuts are a good source of:

Niacin—niacin contributes to brain health and blood flow;

Folate—Folate is a B vitamin associated with heart health, cancer prevention, and decreases the risk of birth defects in babies;

Fiber—Fiber helps to lower blood cholesterol and is essential for healthy bowel function;

Magnesium—Magnesium is a mineral essential for good nerve and muscle function and for strong bones;

Vitamin E—Vitamin E is an antioxidant that helps protect tissues in the body from damage;

Zinc—Zinc is needed for many processes in the body and is necessary for a strong immune system and healing and protecting skin: and

Coenzyme Q10—Coenzyme Q10 is also found in oily fish, beef, soybeans, and spinach (Wilkinson, 2005).

Groundnuts are also naturally free of trans-fats and sodium amd contain about 25% protein. See Table 2.2.

Table 2.2 Groundnut calorie, protein, and fat content

Groundnuts-no salt (100 grams)	Calories	Proteins	Total Fat	Saturated Fat	Unsaturated Fat
Dry-roasted	585	23.7	49.7	6.9	40.3
Peanut butter (chunky-style)	589	24.06	49.9	8.1	39.4
Peanut butter (smooth-style)	588	25.1	50.4	10.3	37.6

Source: Adapted from Weightlossforall (2011)

2.5 Growth habits

The Groundnut is a self-pollinating, indeterminate, annual herbaceous, legume. Natural cross pollination occurs at rates of less than 1% to greater than 6% due to atypical flowers or action of bees. The fruit is a pod with one to five seeds that develops underground within a needlelike structure called a peg, an elongated ovarian structure.

Peanut emergence is intermediate between the epigeal (hypocotyl elongates and cotyledons emerge above ground as in soybean) and hypogeal (cotyledons remain below ground as in fieldpea) types. The hypocotyl elongates but usually stops before cotyledons emerge. Leaves are alternate and pinnate with four leaflets (two pairs of leaflets per leaf). The peanut plant can be erect or prostrate (15-61 cm./6-24 inches tall or more) with a well developed taproot and many lateral roots and nodules. Plants develop three major stems, i.e. two stems from the cotyledonary axillary buds equal in size to the central stem during early growth.

Bright yellow flowers with both male and female parts are located on inflorescences resembling spikes in the axils of leaves. One to several flowers may be present at each node and are usually more abundant at lower nodes. The first flowers appear at 4 to 6 weeks after planting and maximum flower production occurs 6 to 10 weeks after planting. See Table 2.3 for groundnut growth stages.

Eight to 14 days after pollination aerial pegs will grow 5-7.5 cm. (2-3 inches) into the soil and then turn to a horizontal orientation to mature into a groundnut pod. Pods reach maximum size after 2 to 3 weeks in the soil, maximum oil content in 6 to 7 weeks, and maximum protein content after 5 to 8 weeks. The groundnut crop matures after 7 to 9 weeks in the soil, which is indicated by maximum levels of protein, oil, dry matter, and presence of darkened veining and brown splotching inside the pod. Groundnuts usually require a minimum of 100 to 150 days from planting to maturity depending on the variety planted.

Flowering continues over a long period and pods are in all stages of development at harvest. Pegs will eventually rot in the soil (25% after 12 weeks in the soil) and the resulting loose pods are lost during the harvest (Coffelt, 1989; Putnam et al., 1991).

Table 2.3 Groundnut growth stages

Approx. days after planting*	**Growth stage**	**Description**
7	Emergence	Seedling 'cracking' the ground and cotyledons visible
35	Bloom	One-half of the plants with a bloom
45	Peg	Half of the plants with a visible peg
50	Swollen peg	Half of the plants with a peg tip swollen to twice the peg diameter
60	Full size pod/begin pod-fill	Half of the plants with a full size pod and a visible seed beginning to form
75	Full size seed	Half of the plants with a seed filling the pod cavity
100	Early harvest	Half of the plants with a pod having interior hull color and orange to brown mesocarp
130-140	Harvest maturity	70% of harvestable pods have an orange, brown, or black mesocarp (scrape pod saddle with knife) and interior hull color (crack pod open)
150	Over-maturity	Kernels in oldest pods develop tran-brown seed coat and pegs may have deteriorated; over-mature pods have coal-black mesocarp color
***Based on adequate soil moisture and average temperature conditions for mid-maturity (130-140 day variety).**		

Source: Chapin (2010)

2.6 Cultivars

Thousands of groundnut cultivars are grown, with four major market groups being the most popular: Spanish, Runner, Virginia, and Valencia. All four types are cultivated in Mozambique, mostly growing in the Mogovolas region of the country. Overall, specific cultivar groups are preferred for particular uses because of differences in flavor, oil content, size, shape, and disease resistance. For many uses the different cultivars are interchangeable. Most groundnuts marketed in the shell are of the Virginia type, along with some Valencias selected for large size and attractive appearance of the shell. Spanish groundnuts are used mostly for candy, salted nuts, and peanut butter. Most Runners are used to make peanut butter.

The various types are distinguished by branching habit and branch length. There are two main growth forms—bunch and runner. Bunch types grow upright, while runner types grow near the ground. Virginia types and Runner types are different from Valencias and Spanish types in that neither the Virginia nor Runner types bloom and produce fruit on the upright main stem. The difference between a Virginia and a Runner is based on pod size. If at least 40% of pods ride a 34/64 inch roller standard, then that variety technically has enough 'fancy pods' to qualify as a

Virginia market type. Additional characteristics of each type are as follows (Peanut Bureau of Canada, 2004; Chapin, 2010; Wikipedia-Peanut, 2011):

2.6.1 Virginia group

Virginia types are long (occasionally medium) season, have a high calcium requirement and are high-yielding in most situations. The larger kernels from the Virginia type are used in the snack-food trade (e.g. beer nuts). They are increasing popular due to demand for large peanuts for processing, particularly for salting, confections, and roasting in the shells.

Virginia groundnuts are either bunch or running in growth habit. The bunch type is upright to spreading. It attains a height of 45 to 55 cm. (18 to 22 inches), and a spread of 70 to 80 cm. (28 to 31 inches), with 80 to 90 cm. (31 to 35 inches) rows that seldom cover the ground. The pods are borne within 5 to 10 cm. (2-4 inches) of the base of the plant. Cultivars of Virginia type peanuts include NC 7, NC 9, NC 10C, NC-V 11, VA 93B, NC 12C, VA-C 92R, Gregory, VA 98R, Perry, Wilson, Hull, AT VC-2 and Shulamit.

2.6.2 Runner Group

Runner types have a smaller kernel compared to Virginia types and often have a flatter bush. They are long (occasionally medium) season and generally respond well to irrigation. Runner kernels are mainly used for confectionery (e.g. chocolate, muesli bars) and manufacturing (e.g. peanut butter).

Runner has become a dominate type due to the introduction in the early 1970s of a new runner variety—the Florunner, which was responsible for a spectacular increase in yields. Runners have rapidly gained wide acceptance because of their attractive kernel size range; a high proportion of runners are used for peanut butter and salting.

Cultivars of Runners include Southeastern Runner 56-15, Dixie Runner, Early Runner, Virginia Bunch 67, Bradford Runner, Egyptian Giant (also known as Virginia Bunch and Giant), Rhodesian Spanish Bunch (Valencia and Virginia Bunch), North Carolina Runner 56-15, Virugard, Georgia Green, Tamrun 96, Flavor Runner 458, Tamrun OL01, Tamrun OL02 and AT-108.

2.6.3 Spanish Group

Spanish types are quicker to mature and may therefore escape drought. Most have an erect bush and are easier to pull on heavier soils because the pods cluster tightly around the taproot with strong pegs. Spanish groundnuts can tolerate slightly more acidic soils than the other types. However, they are not as high-yielding as the Virginia or runner types in good conditions and are more prone to pod splitting when the soil remains wet. Spanish kernels are mainly used for confectionery and manufacturing. They have a higher oil content than other types of groundnuts which is advantageous when crushing for oil. Prices are usually not as high as for Virginia or runner types.

Cultivars of the Spanish group include Dixie Spanish, Improved Spanish 2B, GFA Spanish, Argentine, Spantex, Spanette, Shaffers Spanish, Natal Common (Spanish), White Kernel Varieties, Starr, Comet, Florispan, Spanhoma, Spancross, OLin, Tamspan 90, AT 9899-14, Spanco, Wilco I, GG 2, GG 4 and TMV 2.

2.6.4 Valencia Group

Valencia Group groundnuts are coarse, and they have heavy reddish stems and large foliage. They are comparatively tall, having a height of 125 cm. (49 inches) and a spread of 75 cm. (30 inches). Valencia pods are borne on pegs arising from the main stem and the side branches. Most of the pods are clustered around the base of the plant, and only a few are found several inches away. Valencia types are three seeded and smooth, with no constriction between the seeds. Seeds are oval and tightly crowded into the pods. There are two strains, one with flesh and the other with red seeds. Typical seed weight is 0.4 to 0.5 g. Valencia groundnuts usually have three or more small kernels to a pod. They are very sweet and usually roasted and sold in the shell.

2.7 Molding

Groundnuts, regardless of their variety, are extremely susceptible to molding. Molds can manifest themselves by discoloring seed coats to completely destroying groundnut kernels. In some cases, groundnuts mat together. The growth of molds on groundnuts is the direct result of too much moisture, regardless of contributing causes which are many and varied. Many types of molds and other soil organisms are present on the nuts when harvested, and during shelling and handling the seed may become infected with other organisms. Since there is no commercially feasible method of washing or sterilizing without risking damage to the groundnuts, the growth of organisms contaminating the surface of edible groundnuts is best prevented by low moisture (Woodroof, 1973).

2.7.1 Mycotoxin problems

Several species of fungi infect agricultural crops both in the field and during storage. These include *Aspergillus*, *Fusarium*, *Penicillium*, *Alternaria*, *Cladosporium* and *Nigrospora* species. These species have been mainly found associated with cereals, spices, and nuts. In addition to these fungi reducing crop yields, some of these molds produce mycotoxins (Hocking, 1991).

Mycotoxins are toxic substances produced by fungi and can be classified according to their fungal origin, chemical structure, and biological activity. These toxins occur in foods mainly as a result of direct contamination of a food product. Over 200 mycotoxins have been reported but only those occurring naturally in foods are of significance in terms of food safety. These are produced mainly by species of *Aspergillus*, *Penicillium*, and *Fusarium*. See Table 2.4. The most widely studied and dangerous mycotoxins are aflatoxins (Smith & Moss, 1985; Scott, 1991; Miller, 1991).

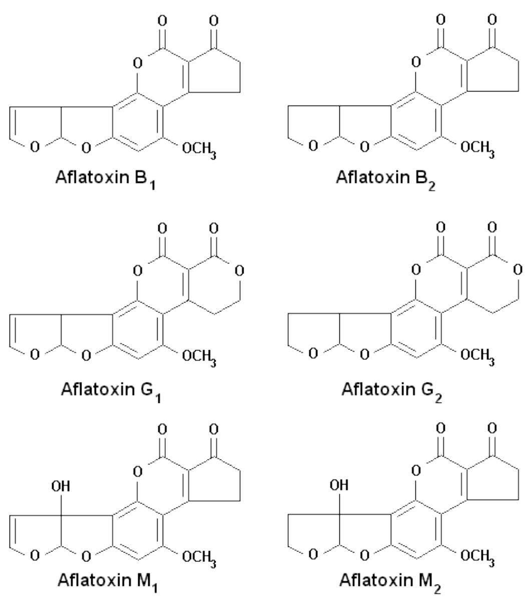
Table 2.4 Common mycotoxins found in foodstuffs

Mycotoxin	Main causal agent	Foods commonly contaminated
Aflatoxin	*Aspergillus flavus, A. parasiticus*	All grains, dried fruits, nuts
Fumonisin	*Fusarium verticillioides*	Maize
Zearalenone	*Fusarium graminearum*	Maize
Ochratoxin	*Aspergillus ochraceous*	Coffee, cocoa
Trichothecenes (T2 Toxins and deoxynivalenol)	*Fusarium spp*	Cereals (wheat, barley, maize, rice)
Patulin	*Penicillium digitatum*	Apples

Source: Okello et al. (2010)

A. flavus is common and widespread in nature and is most often found in food products under stressful conditions such as drought. This mold is found widely in subtropical and tropical climates throughout the world. There are four major aflatoxins: B_1, B_2, G_1, and G_2, plus two additional metabolic products, M_1 and M_2. The chemical structures of these toxins are presented in Figure 2.1.

Figure 2.1 Chemical structures of Aflatoxin B_1, Aflatoxin B_2, Aflatoxin G_1, Aflatoxin G_2, Aflatoxin M_1, and Aflatoxin M_2



Source: Alexander, N. (2011)

It should be noted that it is difficult to eliminate aflatoxins completely from food after they have developed, although some reduction can occur during processing. Aflatoxins persist under extreme environmental conditions and are even relatively heat stable at temperatures above 100° C./212°F., the boiling point of water (Jacobsen et al., 2011).

Considerable research has found that aflatoxin B_1 is the most common occurring form of aflatoxin. All aflatoxins, however, can be toxic at certain concentrations and may primarily cause liver cancer in animals and human. Aflatoxins can also cause a lack of appetite, weight loss, hemorrhaging, and abortions. Young livestock are more sensitive and vulnerable to aflatoxicosis than older animals.

There are two types of aflatoxin toxicity: (1) direct toxicity and (2) relative toxicity. Both can be acute or chronic. Aflatoxins have become a subject for concern in agriculture on a global scale. Many countries have assigned high priority to research to find a solution to aflatoxins that contaminate groundnuts. Aflatoxins are a serious problem, especially in countries like Mozambique with warm to hot subtropical conditions, and the problem is more acute during and following alternative dry and wet periods, i.e. drought followed by rain showers. Fungal growth and aflatoxin production in the pods is most favorable when temperatures range from 20-30°C./68-86°F. and the relative humidity in the pod microenvironment ranges from 85-95%. Fungus can invade groundnuts during flower and peg formation, gradually as the pod matures and rapidly once the pod has become over mature (Okello et al., 2010).

Strain variation in the fungus, interference by other micro-organisms, moisture temperature, and the pH are also important factors. In addition, the incidence and levels of fungal infection and aflatoxin contamination vary from one geographic location to another. In most instances, however, aflatoxins are formed after harvest, particularly when harvesting takes place during floods, or unseasonal rains or when groundnuts are poorly stored after not having been sufficiently dried (Smith & Moss, 1985; Kaaya et al., 2006).

The following factors have been singled out as those that mainly encourage mold growth and aflatoxin production in groundnuts (Okello et al., 2010)

<u>Moisture content</u>: The amount of moisture affects both the grade and storability of groundnuts and has a critical effect on mould growth and mycotoxin production. It is one of the most important considerations in determining whether aflatoxin will develop in groundnuts after harvest. *A. flavus* grows when the moisture content exceeds 9%, at 80-85% relative humidity and above.

Soil moisture stress has also been reported to enhance pre-harvest aflatoxin contamination. Groundnuts exposed to drought stress in the field have been reported to have more *A. flavus* infected kernels than in irrigated plots. Excessive drought causes strains on groundnut pods and testas thus providing entry points for infection by fungi.

<u>Temperature</u>: The effect of temperature is difficult to separate from the effect of moisture. Under favorable temperature and relative humidity conditions, aflatoxigenic fungi grows on cereals and groundnuts. Production of aflatoxins is optimal at relatively high temperatures, so contamination is most acute and widespread in warm, humid climates.

Handling and drying: Mechanical damage to kernels makes them much more vulnerable to mold attacks. Fungal growth is several times faster in damaged kernels in comparison to intact kernels.

Traditional groundnut drying techniques in Mozambique involving field and bare ground drying are a major source of fungal contamination. They are slow, time consuming and labor-intensive involving lots of crop handling, and due to rains that can occur at harvesting and drying times, it is difficult to achieve the recommended moisture level for safe storage.

Storage conditions: The fundamental reason why commodities are stored dry is to increase storability and in part, prevent growth of storage fungi. If commodities are incorrectly stored, that is, in an improperly dried state or under high humidity with inadequate protection, fungi will inevitably grow. Duration of storage is an important factor when considering mycotoxin formation. The longer the retention in storage the greater will be the possibility of building up environmental conditions conducive to groundnut fungi growth (Kaaya et al., 2000).

Storage structures commonly used by farmers in Mozambique are traditional and may not maintain an even, cool and dry internal atmosphere. They do not provide adequate protection from insects and rodents, are not easy to clean, and above all they are not waterproof. All of these conditions invite mold growth and aflatoxin production.

Insect infestation or damage: Insect infestation during storage is one of the major problems that can contribute to fungal colonization in different ways. Fungal spores can be carried by insects. Also toxin-producing fungi can infect growing crops, due to insect damage, and can produce toxins pre- and post-harvest and during storage. During storage, insects, due to their metabolic heat and water, can increase the water activity and temperature of groundnuts to levels suitable for fungal growth. Thus, it is important that insects are controlled both pre and post-harvest (Hell et al., 2000).

2.7.2 Health effects of aflatoxins

Aflatoxins (especially aflatoxin B_1) are potent carcinogens in animals and humans. There are a range of possible consequences of exposure to aflatoxins, largely determined by the dose and the duration of exposure. In all cases, the young are more susceptible than adults.

Acute illness and death: Acute illness is the result of consuming foods contaminated with very high levels of aflatoxin. People die as a result of jaundice and liver failure. In 2004, more than 200 people died in Kenya and more children than that died in Kenya last year consuming maize contaminated with aflatoxins. No animal species is resistant to acute toxic effects of aflatoxins (Williams et al., 2004).

Chronic illnesses/Cancers: The International Cancer Research Institute identifies aflatoxin as a Class 1 carcinogen. This classification is the basis for the regulation of this toxin to exceptionally low levels in traded commodities (in the U.S.10 ppb in grain; and 0 ppb in milk; in the EU 4 ppb and 0 ppb in milk).

Aflatoxin is predominantly perceived as being associated with liver cancers. For a country like Mozambique, the the synergistic effects of aflatoxin compound the risk due to Hepatitis B virus (HBV), which is the other predominant cause of liver cancer.

Immunology: Aflatoxins have been reported to reduce immunity in humans and animals. This is as a result of aflatoxins interfering with the activities of important cells that boost immunity in the body. Thus, aflatoxins have been strongly linked to HIV/AIDS and malaria throughout Africa.

Nutritional illnesses: In animals studies have proven that aflatoxin in the diet decreases the rate of growth and productivity. In children, especially those under three years of age, aflatoxin exposure enhances stunting and underweight. Generally, from the animal health perspective, aflatoxins causes growth reduction due to interference with proteins and micronutrients, such as vitamins A, B12, C, D, and E; and minerals such as zinc, iron, and calcium. Hence, aflatoxins put consumers' health at high risk (Okello et al., 2010).

2.7.3 Economic effects of aflatoxins

Aflatoxins in groundnuts, as in all crops, can have a direct economic impact that results in the loss of an agricultural product or the loss of market value. Aflatoxins also increase costs for veterinary and human health services, costs for food-borne disease surveillance, and food monitoring. The presence of high levels of aflatoxins in groundnuts can make them unacceptable for marketing, causing financial loss to the farmer and the food retailers.

Depending on the size of the market, economic losses can reach 100%, when the entire product is rejected by the market if aflatoxin levels are higher than acceptable standards. It is estimated that Africa loses over USD670 million annually due to requirements for EU aflatoxin standards. Worldwide, billions of dollars are lost by farmers and traders due to aflatoxin contamination. It is therefore essential that contamination from mycotoxins in groundnuts be minimized as much as possible (Otsuki et al., 2001; Guo et al., 2009). See Table 2.5.

Table 2.5 Examples of types of economic losses associated with aflatoxin (and other mycotoxins) contamination

Bearer	Economic losses and costs
National level	
Primary producer	• Outright food and feed loss • Less income from contaminated food • Reduced productivity of livestock
Intermediary	• Less income for products refused, condemned, or sold at a discount • Increased storage, transport, and packing costs • Potential loss of market • Increased costs due to surveillance and control
National government	• Increased costs due to surveillance and control • Increased costs of shipment, sampling, and analysis of products for export • Increased need for expenditures in human health and livestock care services • Increased costs of training, communication, and extension programs
Consumer (human or livestock)	• Impaired health and productive capacity • Possible higher medical and veterinary costs
International level	• Loss of market value or market • Trade distortions

Source: Adapted from Jemmali (1987)

2.7.4 Maximum tolerable levels of enforcement

Mozambique does not have clearly set standards on aflatoxin contamination based on aflatoxin levels in most local foodstuffs. However, Mozambique in collaboration with other bureau of standards from the East African Community has nonetheless set a limit of 10 ppb for all foods and feeds but only currently certified products intended for export. Other countries have different maximum tolerable levels of aflatoxin contamination with the EU having the most stringent standards. See Table 2.6.

Table 2.6 Maximum level of total aflatoxin in foodstuffs

Country	Product	Maximum tolerable limit (ppb)
EU	Groundnuts-ready to eat	4
USA	Groundnuts (all products)	20
India	Groundnuts (all products)	30
Kenya	Groundnuts (all products)	10
Uganda	Groundnuts (all products)	10
Mozambique	**Groundnuts (all products)**	**10**

Source: Adapted from Okello (2010)

2.7.5 Aflatoxin testing in Nampula

Currently there is no central policy or strategies on aflatoxin contamination and management in Mozambique. However, capacity exists within the country to test for aflatoxin levels in foodstuffs.

The World Food Programme's Purchase for Progress (WFP/P4P) initiative uses the WFP's purchasing power and its expertise in logistics and food quality to offer smallholder farmer's opportunities to access agricultural markets. In so doing, this five-year initiative began in 2010 to invest in providing equipment to and training the technical team at the UniLurio laboratory, a microbiology laboratory at Lurio University, Nampula. The WFP investment enables the laboratory to conduct advanced scientific research in the area of food contamination, and to efficiently provide the quality control services normally required by the WFP, including aflatoxin testing.

Once trained, fully equipped and accredited, the laboratory and its technicians will provide quality testing services to the public. Prior to this laboratory's capacity, commodity trading companies used the services of a South African laboratory to screen for aflatoxin contamination at a total cost of approximately USD150. The results would take three weeks. The new laboratory will offer the same test for USD36.00 and with results available within the hour (World Food Programme, 2011).

For more information about the WFP/P4P initiative and the Lurio University laboratory's testing abilities, contact: WFP/Rome: Mary-Ellen McGroarty, Senior Programme Advisor for Mozambique at: Mary-Ellen.McGroarty@wfp.org or P4P Country Coordinator-Mozambique Billy Mwiinga at: Billy.Mwiinga@wfp.org (WFP/P4P, 2011).

3. Aspects of plant cultivation

3.1 Site requirements

The groundnut is very adaptable and it is cultivated in continental areas with hot summers and predominately grows between the latitudes of 40° N. and 40° S. The main latitude of Mozambique is 18° 15' S., with Nampula being 15° 06' S. Mozambique falls in between the Equator and the Tropic of Capricorn. See Figure 3.1. The close proximity of latitudes of Mozambique to the Tropic of Capricorn is responsible for the sub-tropical type of climate in most of the country (Maps of the World, 2011).

Figure 3.1 Map of Mozambique

Source: Lonely Planet (2011)

3.2 Climatic requirements

<u>Temperature</u>

The rate of growth and vegetation period of groundnuts are highly influenced by temperature. 30-34°C. (86-93.2°F.) is optimum for germination (max. 45°C./113°F., min. 15°C./59°F.). Under 20°C. (68°F) the capacity to germinate, the rate of growth and development are rapidly reduced, and at around 14°C. (57°F.) they cease altogether. 25-30°C. (77-86°F.) is optimum for vegetative growth. Temperatures above 34°C. (93.2°F.) can damage the flower formation. The optimum temperature influences the net rate of photosynthesis, the flower formation and the growth of the pods, and is therefore responsible for the greater yields outside the hot tropics. Night-time temperatures should not sink below 10°C. (50°F.) during the fructification process. Frost will always kill off the plant.

Light

The groundnut can tolerate shade; it poses no problems when cultivated with trees or with other mixed crops. When placed in shade, the leaves get bigger, and the number of reproductive organs lessens, meaning that the yield will only be reduced if the plant is subjected to extremely shady conditions. When the light is very intense, the groundnut (a C3-plant) achieves a comparable level of photosynthesis as C4-plants. The groundnut plant is in a photoperiodic sense, practically neutral, although photoperiodic sensitive and insensitive varieties also exist.

Water

The optimum time to sow, which corresponds in many places with the rainy season, depends largely on the rain, as the yield sinks rapidly when the plants are sown outside the optimum planting time. The germination process requires enough air in the soil. A grown groundnut plant can tolerate flooding conditions for up to a week, providing the water then flows away completely without leaving behind any stagnant pools. In case of regular heavy rain fall during the vegetation period, the ground must be well drained, or the plant planted on ridges.

500-1000 mm. (19.5-39.3 inches) of rainfall during the growth period will produce good yields among the late ripening varieties (up to 145 days vegetation period). 300-500 mm. (11.8-19.5 inches) permits the planting of early ripening varieties (up to 100 days vegetation period). 250-400 mm (9.8-15.7 inches) of rainfall, when evenly spread, is sufficient for varieties that ripen extremely early. The type of soil, and its capacity to retain water after it has been saturated with water before sowing also play an important role. At least 300 mm. (11.8 inches) of rainfall should be available between the plant's appearance and the main flowering period, in order to ensure sufficient vegetative growth, because there is a direct correspondence between the number of branches and flowers, and the eventual number of pods. Moist soil allows the pegs to penetrate into the ground more easily. Precise information on the average spread of the rainfall to be expected on the farm is useful in choosing the correct variety, which will then ripen before the dry season. Stress due to drought during the ripening period of the seeds can lead to an aflatoxin infection (Augstburger et al., 2002).

3.3 Soil requirements

Soil for peanut production should be a light-colored, light textured with good drainage, and with moderately low amounts of organic matter. Such soil is preferred since it is usually loose and permits easier penetration of roots and pegs, better percolation of rainfall, and easier harvesting. Light-colored soils reduce staining of pods which ensures greater aesthetic appeal when the crop is used for unshelled nuts. Well-drained soils provide proper aeration for the roots and nitrifying bacteria that are necessary for proper mineral nutrition of the plant. Medium to heavy soils or those with high clay content should also be avoided due to excessive loss of pods when harvesting groundnuts. The disadvantages of heavy/clay soils are that:

- they are more difficult at harvest—especially when harvesting manually (though this can be alleviated with the appropriate tools and by planting on ridges);
- there is the possibility of malformed pods;
- there is a tendency for harvest losses through pegs breaking off;
- pods can become dirty and discolored due to the soil sticking to them (which might affect sales).

Organic matter should be maintained at a level of 1 to 2% to improve water-holding capacity of the soil and supply plant nutrients. Groundnuts grow best in slightly acidic soils with a pH of 6.0 to 6.5, but a range of 5.5 to 7.0 is acceptable. Saline soils are not suitable since groundnuts have a very low salt tolerance (Weiss, 1983; Putnam et al., 1991).

3.4 Cropping systems

Groundnuts should not be grown on the same land for successive years, but should be worked into a crop rotation system. There are several factors to consider in a crop rotation plan.

Since groundnuts can use fertilizers in large quantities from a previous crop, it is a desirable crop to follow heavily fertilized crops, ones that do not result in disease build-up such as corn. A crop like cotton makes land preparation more difficult. It is also desirable to follow groundnuts with a soil-improvement crop, particularly where the hay is not returned to the soil. Groundnuts are considered a soil-depleting crop when the entire plants are removed and a soil-improvement crop when the vines and leaves are returned to the soil.

Crops that are susceptible to attack by the same nematodes, fungi, or bacteria should not succeed on another in rotation. The possible toxic effects of decomposing crop residues on the succeeding crop must also be considered. Generally speaking, groundnuts do better following grass crops such as sod, small grains, and corn. When groundnuts follow sweet potatoes, soybeans, or other nematode susceptible crops that leave large quantities of heavy-stemmed green vegetable matter at or near the surface of the soil, the conditions are favorable for the winter carry-over of southern root rot, a disease that may cause heavy losses to groundnuts. Thus, rotation helps in control of nematodes, white mold, and leaf spots. It also maintains a greater balance of groundnut nutrients.

A recommended three-year crop rotation is: (1) corn with crimson clover as a cover crop; (2) potatoes followed by grain sorghum; and (3) groundnuts followed by rye as a winter cover crop.

A two-year rotation followed in congested groundnut areas is the growing of groundnuts and corn on alternative years. Corn is desirable just before groundnuts, as it is resistant to root-knot nematodes and to southern stem rot, and is a clean cultivated, heavily fertilized crop.

Immediately following harvest, the land should be planted to a crop to cover the soil and prevent erosion. Oats, rye, and other rapidly growing crops are good. The grain should be well fertilized and grazed or turned under 4 to 6 weeks prior to planting groundnuts (Woodroof, 1973).

3.5 Soil preparation

The latest and most effective system for preparation of land for groundnuts is to turn the land deep and bury all plant debris to a depth of at least 7.6-10 cm. (3-4 inches) below the surface of the soil. An effective procedure for preparing land in this manner is as follows: shred or cut stalks of preceding crop as soon after harvest as possible and dig/disk into the upper 7.6-10 cm. (3-4 inches) of soil. This practice allows more time for decay of stalks and other litter. Winter cover crops can be planted shallow on most soils without working the litter to the surface.

Groundnuts benefit from this type of land reparation in several ways. Burying the plant debris aids greatly in preventing damage from root rot disease. Weed and grass seed will be more adequately covered and destroyed, and deep plowing breaks up the hard pan and provides for better root penetration (Boyle, 1952).

Aflatoxin management recommendation(s):

Application of lime (0.5 t/ha), farm yard manure (10t/ha) and cereal crop residue (5 t/ha) at the time of sowing helps reduce *A. flavus* seed infection and aflatoxin contamination by 50-90%. Lime, a source of calcium, enhances groundnut wall thickness and pod filling and decreases fungal infection. Organic supplements, such as farmyard manure and crop residues, favor growth of native microbial antagonists and suppress soil- and seed-borne infections. These three components also improve the water-holding capacity of the soil, minimizing the effect of end-of-the-season moisture stress, and thereby limiting aflatoxin accumulation in groundnuts. Lime and farmyard manure are cheap and easily available in Mozambique (Karthikeyan, 1996; Rosolem et al., 1997).

3.5 Fertilizers

Many changes have occurred in the recommended use of fertilizers on groundnuts over the years as a result of agricultural research. More reliance is being placed on the results from soil testing for fertilizer requirements for groundnuts. With improvements of recent years, larger quantities of more complete fertilizers are being found profitable, and broadcasting is the recommended method of applying lime and fertilizers. This avoids injury to the seed and plants. Much of the increase in yield has been due to better use of fertilizers, particularly to those crops immediately preceding groundnuts in rotation. Several months before planting and as a part of soil preparation, enough lime should be added to bring the pH to 6.0 to 6.4. If the soil is low in phosphorus and potassium, 400 to 1000 lbs. of 0-10-20 (nitrogen-phosphorus-potassium), fertilizer should be broadcast per acre. Certain micro-nutrients, particularly copper, boron, and sulfur, may be beneficial. Since groundnuts are a legume, nitrogen fertilizer should not be required. Small amounts (4-12-12 or 5-10-15), however, are beneficial.

It is also recommended that gypsum be applied to all plantings of large seeded types of groundnuts at a minimum rate of 500-700 lbs. per acre. If applied directly on top of the plants during the early boom stage, it falls or is washed from the plants to the soil at the base of the plants. Here it provides a high concentration of readily available calcium in the top few inches of the soil where the pods develop. Gypsum will not be effective if broadcast or applied in the rows before planting. Gypsum is used because it is readily soluble and because it does not appreciably affect the acidity of the soil (Perry, 1963).

3.6 Seeds

Since groundnut flowers are self-fertile and varieties seldom cross in the field, the seed of a certain variety may be considered genetically uniform. However, individual nuts vary in size, maturity, mechanical injury and contamination by soil organisms. All of these influence the germinability and vigor of the seedlings.

3.6.1 Seed selection

Whether the groundnut seed is grown by the farmer-grower for his own use or for sale, care must be exercised in selecting seed groundnuts. Seed that is to be planted must be true to the variety and type. Frequently rouge plants in the field cause plantings to become mixed. Inspections should be made during the growing period for off-type, diseased, or otherwise objectionable plants that should be removed.

Aflatoxin management recommendation(s):

Groundnut varieties should be chosen, when possible, that are genetically more resistant to the growth of fungus and the production of aflatoxins (for example, Serenut 2). Drought tolerant varieties also have found to have greatly reduced aflatoxin contamination. Additionally, choosing varieties which are resistant to diseases and pests can help reduce aflatoxin contamination (Okello et al., 2010).

Groundnuts intended for seed should be harvested when a maximum number of pods have reached suitable maturity without loss of appreciable numbers through discoloration and decay. Daily inspection is desirable as harvest time approaches to determine the optimum time for harvesting. After removing from the soil all diseased, off-type or poor-yielding, plants should be removed for commercial use leaving only selected plants for seed purposes.

Pods should not be exposed to direct sun rays for long periods. Quick drying and curing of groundnuts at relatively high temperatures reduces viability and causes splitting or skinning during shelling. Groundnuts intended for seed should be carefully picked. The seeds should be harvested manually whereby the pods should also be removed from the plant by hand to avoid damage (Woodroof, 1973; Augstburger et al., 2002).

3.6.2 Seed storage

Special care should be taken to protect seed from insects, mice, or other pests, as well as from high temperatures and high humidity. The groundnuts should be relatively dry before storage, about 8% or less for unshelled seed and 6% or less for shelled seed.

Storage temperature affects viability. To maintain peanuts that are highly germinative, the moisture should be six percent or lower and the temperature should be well below 20°C. (68°F.). It is considered good practice to shell seed groundnuts in the fall as soon as they are thoroughly dry. Place in ventilated bags and store at 2.2°C. (36°F.) with 65% relative humidity. Under these conditions the seed will remain viable for up to two years (Woodroof, 1973).

3.6.3 Seed shelling

Groundnut seed should be shelled in advance of the planting season when there is plenty of time to perform the work. Care should be taken to prevent a minimum of scratching, skinning, or damaging of the seeds. Any form of injury to the seed coat is harmful and breaking or splitting the kernels renders them useless for seed.

Very dry groundnuts, those having 4-5% moisture, are skinned and broken easily during shelling. With 7-8% moisture, the damage is usually less than half as much. Groundnuts dried quickly at high temperatures in the sun usually have excessively high skinning and breakage losses during shelling.

Commercial equipment for shelling groundnut seed is available in sizes for the small farmer. With all shellers some handpicking to remove skinned, weather-damaged, or otherwise undesirable seeds is advisable. Very large, very small, and immature kernels should be screened out. The use of uniform-sized seed, having a range in size or not over 1.6 mm. (4/64 inch) in diameter is desirable.

Shelled groundnut seed should not be roughly handled. Skinning and breakage may result from pouring seed from one metal container into another or into the metal hopper of the planter. After planting, soil organisms may enter damaged seed and cause rotting of the seed. Bags used for groundnut seed should be tied tightly so seed is not jostled (Beattie, 1954; Woodroof, 1973).

3.6.4 Seed bed preparation

Many Mozambique farmers prefer planting groundnuts on raised beds instead of flat planting. Raised beds can facilitate quicker germination and early growth, provide adequate water drainage, and may reduce pod losses during harvest. During this time, fungi can cause seed and seed rot, manifested by seeds not germinating (seed rot), seeds germinating but not penetrating the soil surface (pre-emergence damping off), and seeds dying shortly after emergence (post-emergence damping off). To avert this, special attention should be taken to properly prepare groundnut seed beds (Okito, 2009).

Seed beds should be prepared deep, loose, and not too fine—to avoid becoming muddy during any periods of rain. The upper 10 cm. (3.9 inches) should not be kept loose over a longer period in order to assist the pegs to bore down and the pods to have space to develop.

If planting occurs on ridges or in flat beds, this eases harvesting. They can be formed during sowing or afterward while tilling weeds. To protect against erosion, the ridges should run along contour lines so they retain water. Furrows will help to further improve water retention capacity (Augstburger et al., 2002).

3.7 Crop rotation

Groundnuts should only be planted in a three year crop rotation. Otherwise soil-borne diseases can accumulate and humus be lost due to excessive soil loosening during the harvest. The amount of nitrogen fixed in the upper soil layers by groundnuts should not be over-estimated. Additional sources of nitrogen fixing should be planned within the crop rotation system. The nutrient content of the soil is especially depleted when not only the foliage, but also the weeds are used as fodder, thereby leaving little residue to be worked back into the soil. Nevertheless, groundnuts possess good soil enrichment potential for non-leguminosae, and act as an excellent crop prior to planting grain. The previous crop should leave little in the way of weeds behind, and be harvested early, to allow plenty of time to work over the soil to permit early sowing to take place. The previous crop should be allowed to largely go to seed. Suitable crop partners include grain, sorgo, pearl barley, maize, rice, as well as sesame, bastard saffron, cotton, sweet potatoes and grain leguminosae, such as mung beans (*Vigna mungo*) or cowpea (*Vigna unguiculata*) (Augstburger et al., 2002).

Aflatoxin management recommendation(s):

The continued cultivation of groundnuts on the same land can lead to a build-up of *A.flavus/A. parasiticus* in the soil, which will increase the probability of infection and aflatoxin contamination. A rotation of 3 years or longer can usually reduce disease, pest and weed problems. Because of pests and soil-borne diseases, groundnuts should not be grown after cotton, although cotton can be used in rotation after groundnut. Other legumes, tomatoes and certain other vegetables can cause a build-up of nematodes and soil-borne diseases. These should be avoided in rotation with groundnuts. Crops such as cassava, sweet potato and sunflower can also be used, while crops such as maize should be avoided in rotations as it is susceptible to *Aspergillus* infection (Okello et al., 2010).

3.8 Mixed crops

Planting groundnuts in mixed crop systems is widely practiced and it is more often the rule than the exception on small farms. Some advantages to mix crop systems are

1) Avoidance of the total failure of a crop;
2) Greater total production per area;
3) Reduction of transpiration especially in alley-cropping;
4) Better regulation of erosion and weeds; and
5) Reduced susceptibility to pests.

Due to their tolerance for shading, groundnuts are especially suited to mixed cultivation together with tall-growing crops such as pearl barley, sorghums, maize, cotton, hibiscus (*Hibiscus* *sabdariffa*), manioc and sunflowers; and as an under-sown crop together with such other crops as bananas, pigeon peas (*Cajanus cajan*), castor beans (*Ricinus communis*), sugar cane, or permanent crops such as e.g. coconut palms, oil palms, rubber and cocoa.

When their vegetation periods are similar in length, other crops cultivated together with groundnuts will benefit by a gain in yield. Even greater increases in yield have been observed for some crops, e.g. cotton –which have a vegetation period which is up to 3 months longer. The success of cultivating in a mixed system is dependent largely upon choosing site-appropriate crops and the way the combination of crops work together (Azam-Ali et al., 1990; Roy, Samsal, & Bhattacharjee, 1990; Peter & Runge-Metzer, 1994; Waterworth, 1994; Schrot, Balle, & Pelthier, 1995; Tonye & Titi-Newl, 1995).

3.9 Sowing

Weather and soil conditions determine the best time for planting groundnuts. Early planting, consistent with settled weather and a well-warmed soil is usually ideal. However, some growers make succession plantings of the same variety a few days apart for the purpose of increasing the length of the harvesting season. Because of variable weather and soil conditions, this plan does not always work. A better plan is to plant early-, midseason-, and late-maturing varieties at one time. Differences of as much as three weeks may be often obtained in the harvesting dates between the early and the late sorts.

Groundnut seeds are very sensitive to unfavorable conditions for germination and it is wise to defer planting until a warm, moist seedbed is available. Planting dates vary with the geographical location. Groundnut seed should be covered to a depth of about 6.3 cm. (2-1/2 inches) on light-textured soil, and slightly shallower on heavier soils (Woodroof, 1973).

Planting 2-3 seeds per hole instead of only one seed will increase the prospects for plant growth, provide more pods, and contribute to a higher yield (Okito, 2009).

3.9.1 Method and rate of sowing

Seeds should be planted on smooth, uniform, well-prepared seedbeds to prevent damage to the seed. Seed that splits will not germinate and grow. The short plant height of Spanish varieties results in them not filling 76 cm. (30 inch) rows, yet other varieties may fill them by midsummer. Spanish and Valencia varieties have greater yield with 46 cm. (/18 inch) row spacing than 76 cm. (30 inch) rows, except on dry land sand. See Table 3.1.

Table 3.1 Effects of different row spacings and soil types on yields of groundnuts

Soil type	Row spacing (centimeters)	
	46	76
	Lbs pods/acre	
Silt loam	1580	1370
Dry land sand	1210	1250
Irrigated sand	1870	1680

Source: Adapted from Putnam et al. (1991)

3.10 Weed control

Because groundnuts are a low-growing crop, weeds can out-compete them for light, water, and nutrients. Weeds also cause losses during harvest. The presence of weed seed and/or plant parts in the harvest crop may cause spoilage during groundnut drying or storage. All these factors result in reduced yield or quality and thereby reduce economic return.

Other factors that make weed control more difficult in groundnuts than in other crops such as corn or soybeans include:

- slow early-season growth;
- the limited number of herbicides available;
- the need for precision, flat, cultivation.

Crop rotation is just as important for weed control as it is for disease control. The best time to start a weed control program for groundnuts is 2 or more years <u>before</u> planting the crop (Weeks, 2000).

Thoroughly preparing the soil prior to planting is a distinct aid to later cultivation of a groundnut crop. The control of weeds is the most important benefit of cultivation, but cultivation that leaves the surface mellow and smooth is an aid in retaining rainfall and reduces erosion. Cultivation keeps the soil mellow around the plants as they spread. This condition is best insured by adequate and initial deep land turning which leaves the soil smooth.

Two critical periods occur in the control of weeds in groundnuts: first, when the plants are very small and second, when the plants start setting fruit. If used, cultivating tools must not be allowed to come too close to plants to interfere with the developing pegs bearing the pods that are buried an inch or two deep in the soil. Chemical weed control may help with the weed-control problem during the early as well as the late period of growth.

Chemical weed control products will reduce or eliminate the need for close cultivation. They also reduce development of southern blight. Furthermore, heavy movement of the soil which covers lower portions of the groundnut plant limits normal branching, flower, and pod development. Research has shown that conventional cultivation is more harmful to yield than is any other currently used weed control system (McGill & Samples, 1965; Woodroof, 1973).

3.11 Scouting

Scouting is a tool that groundnut producers have used since the 1970s to make appropriate treatment decisions about diseases and pests. Scouting is only one part of an overall management program called Integrated Pest Management (IPM). The goal of IPM is to apply the most up-to-date technology to keep pest populations below economic levels so that growers can produce a quality crop more profitably with minimal effects on the environment.

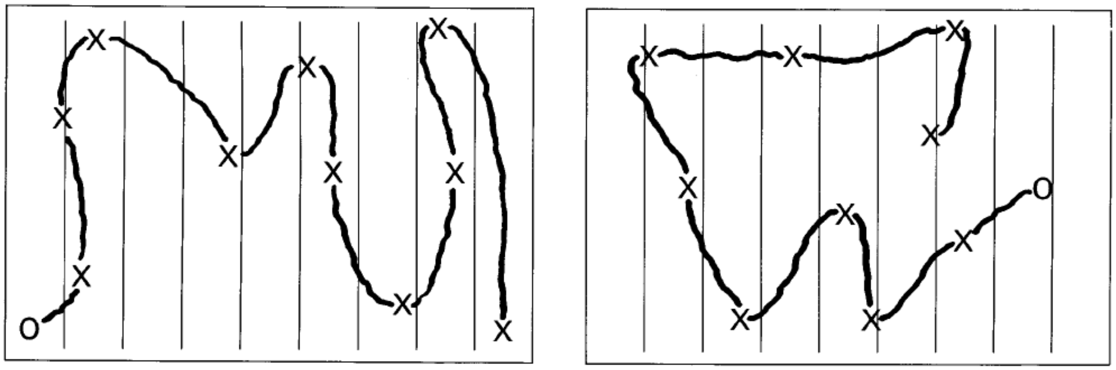
Scouting is a fundamental part of IPM. It involves correctly identifying the disease or pest, determining the pest population level, and evaluating the amount of damage to the crop. Then treatment decisions can be based on established thresholds for a particular pest or on the level of damage caused to the crop plants.

IPM includes many other techniques for managing pests, including crop rotation, use of resistant varieties, proper use of tillage, fertility management, conservation of beneficial insects, biological control materials, irrigation management, and use of pheromone traps to monitor adult insect populations. Blending or integrating any or all of these techniques into a program for each farm is the goal of groundnut IPM.

Scouting should begin as soon as groundnuts emerge from the soil and until just prior to harvest. To become a good groundnut scout you must learn what to look for and when. During mid-season a scout should check fields once a week to monitor pest populations and evaluate plant damage.

To make an accurate evaluation of an entire field, a scout should walk groundnut fields in a random manner to check for problems. Since some pests are likely to be a problem in sandy soil fields and others in heavier, clay soils, all areas of a field should be covered. Some pests may occur in 'hot spots' or along field margins, so samples should be taken in these areas, too. Scouts should also walk different routes each time in a particular field. Figure 3.2 shows how a groundnut field might be walked for two consecutive weeks.

Figure 3.2 Field scouting pattern



Field scouting pattern for Week 1 Field scouting pattern for Week 2

0=Start X=Scouting site

Source: Weeks et al. (2000)

Scouting allows for a sampling for insects and leaf spot at a scouting site. A scouting site is a location picked at random as you walk the patterns illustrated in Figure 3.2. A thorough scouting of each field allows a scout to get a sample of the pest populations and conditions in the field. The farmer can then use this information to make treatment decisions. Weekly scouting information should be recorded on a groundnut scout form. These scouting reports, other information on weed and soil-disease losses, and results of nematode and fertility soil tests should be compiled yearly for each field to develop a field history. Plans for next year's weed, nematode, and fertilizer management program can be obtained from this field history (Weeks, 2000).

3.12 Diseases

Controlling diseases results in a greater number of healthier plants, increased yield of better quality groundnuts, and more hay for feed or soil improvement. The most important methods of avoiding diseases are:

1) Crop rotation;
2) Choosing the right variety;
3) Sufficient supply of nutrients;
4) Uproot infesting plants to stop the disease spreading; and
5) Destruction of any invested plant parts after the harvest.

Two of the most important groundnut diseases in Mozambique are groundnut rosette virus and leaf spot. These and other diseases are discussed below.

3.12.1 Groundnut rosette virus (GRV)

Groundnut rosette virus or simply rosette is the most destructive virus diseases in groundnuts in Africa. Some rosette epidemics have been devastating. In 1975 rosette affected almost 0.7 million ha of groundnut in Nigeria and caused yield losses estimated at over 0.5 million tons, with a value estimated at USD250 million. In 1995, about 43,000 ha were affected in eastern Zambia, with losses amounting to USD5 million. Unpredictability is an important feature of the disease: the sudden unexpected loss of an important source of protein and cooking oil, of income, and of the seed for the next crop, has led farmers to abandon growing groundnuts in subsequent years. Following the epidemic in Malawi in 1994/5, groundnut plantings decreased by 23%, from 89,000 to 69,700 ha (Yaycock et al., 1976; Anon, 1996).

Rosette is transmitted to the plant through an aphid (*Aphis craccivora*), a small insect that feeds on groundnut leaves. The disease is transmitted after the insect feeds on one leaf at a time. Aphids may be seen on young leaves as early as the first three weeks of planting. Rosette only occurs throughout Africa south of the Sahara and it has manifested itself in three varieties—chlorotic rosette, green rosette, and mosaic rosette. Since only African groundnuts are affected by rosette disease, this suggests that the causal agents of rosette are endemic to Africa and are pathogens of a wild African plant species (Murant, Robinson, & Taliansky, 1996; Okito, 2009).

Groundnut rosette virus control recommendations:

1) Plant early and plant densely. This reduces the incidence of disease because the landing area of the aphid is limited as the ground becomes covered by plant growth;

2) Develop resistant cultivars. This is the best approach. Resistance is currently available in late-maturing cultivars derived from groundnut material found in the border region between Côte d'Ivoire and Burkina Faso. The resistance, however, does not amount to absolute immunity, though it is effective against both Chorotic and Green forms of rosette (Murant, Robinson, & Taliansky, 1996).

3.12.2 Leaf spot

Early leaf spot (caused by *Cercospora arachidicola*) and late leaf spot (caused by *Cercosporidium personatum*) are widespread and potentially destructive diseases of groundnuts. Late leaf spot is the more destructive of the two.

The earliest symptoms of both diseases appear as small yellow spots on the leaves—rounded blemishes caused by parasitic fungi. Spots of early leaf spot on groundnuts are usually reddish brown and surrounded by a yellow halo. Those of late leaf spot are dark brown and almost black, particularly on the lower leaf surface.

Spots of early leaf spot appear smooth, because the fungus produces few spores on the upper surface of the leaves. Because the late leaf spot fungus produces many spores on both leaf surfaces, the spots have a raised or tufted appearance. The spore masses of both fungi can be seen with a hand lens (20x). On plants severely damaged by late leaf spot, the characteristic black spots may also be seen on the leaf petioles and stems.

Heavily spotted leaves are shed well before harvest. Leaf shed usually starts at the base of the stem and continues upward until all but the youngest leaves are lost. To avoid heavy losses to early pod shed, badly defoliated groundnuts must be harvested well before their expected crop maturity date.

Leaf spot diseases can easily be mistaken for injury caused by soil- and foliar-applied pesticides. Pesticide injury is more likely on fast-growing young groundnut plants, while leaf spot diseases are more likely from mid-season to harvest.

The common symptoms of injury from soil-applied pesticides are early-leaf-spot-like spots (up to a dozen) around the margin of young peanut leaves. Typically, injury from foliar-applied pesticides will be seen within a day or two of the application; the randomly scattered brown to reddish brown spots will appear, concentrated in the upper canopy of the plants. In indirect light, white areas of pesticide residue may be seen within these spots.

Three fungi produce spots on the leaves, stems, and pegs of groundnuts. Unless leaf spot is controlled one year, damage may be more severe the following year. The disease is progressive; the oldest leaves turn yellow and drop off, then the stems weaken and the plant (with nuts) dies prematurely.

Leaf spot control recommendations:

1) Crop rotation will slow early-season development of leaf spot diseases on future groundnut crops. Ideally, groundnuts should not be grown more often than every third year in a given field;

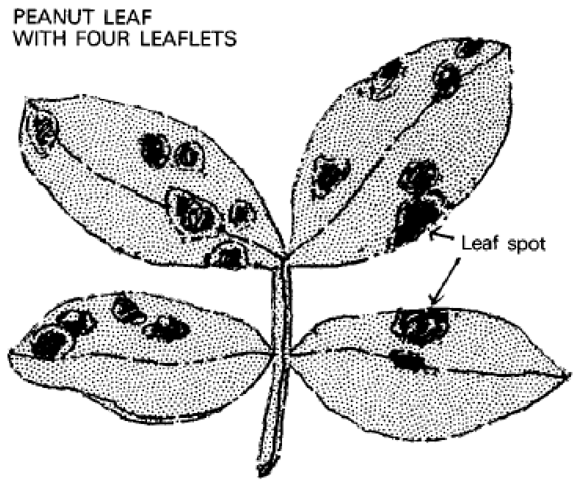
2) Deep-turning the debris from the previous peanut crop will also help delay disease development;

3) If possible, apply a recommended fungicide within 45 days of planting. In most fields fungicide applications made on a 12-14 day schedule should give good protection from leaf spot. In irrigated fields frequently cropped in groundnuts, consider following 10-12 day spray schedules for fungicide applications. Continue fungicide applications until 2 weeks before digging in all fields;

4) Establish a leaf spot-tolerant cultivar such as the Southern Runner or Georgia Green in fields where heavy leaf spot pressure is expected.

Scouting for leaf spot will help determine how advanced and persistent the disease is. Scouting should begin about 9 weeks after planting. The first visit should pick up any outbreaks of early leaf spot. Collect a total of fifty leaves, each with four or five leaflets, from five or more separate locations in the field. Select leaves in the groundnut canopy midway between the ground and newest leaves. Count the total number of leaf spots on the leaves. See Figure 3.3. Make two more collections at two week intervals to further assess the situation.

Figure 3.3 Assessment of Groundnut leaf spot control

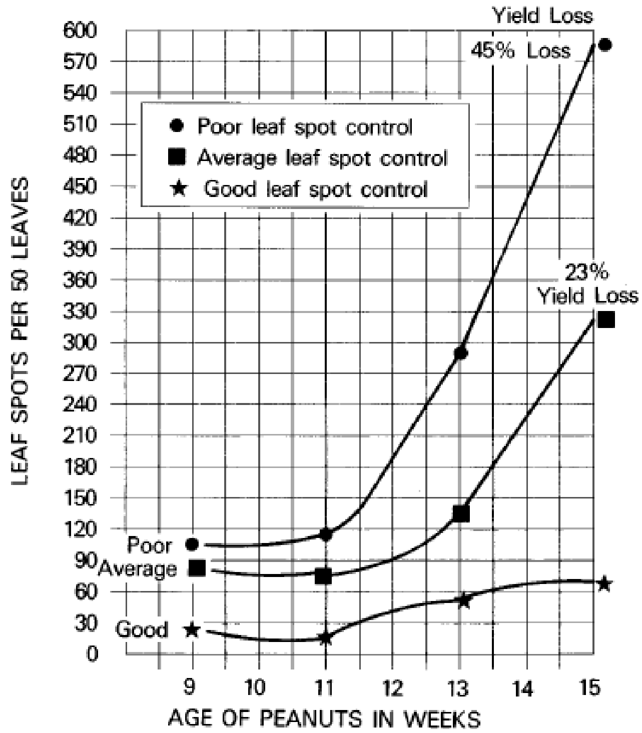


50 leaves should be collected *midway* from the ground to the top.

Source: Weeks, et al. (2000)

Locate the number of leaf spots counted on the left side of Figure 3.4. Pinpoint the age of the groundnut plant at the base of the graph. Then, connect the vertical and horizontal lines within the graph to determine the effectiveness of your leaf spot remedy (Weeks et al., 2000).

Figure 3.4 Leaf spot control graph



Source: Weeks et al. (2000)

3.12.3 White mold (aka southern blight or southern stem)

White mold, which is also known as southern blight or southern stem is among the most damaging diseases of groundnuts. This disease, caused by *Sclerotium rolfsii*, occurs in nearly every field where groundnuts are cultivated. Yield loss to white mold is heaviest where groundnuts are grown each year or every other year. Estimated losses in these fields may reach 20% or more of expected yields.

White mold is primarily a mid- to late-season disease. Wilting or flagging of a vine or central stem(s) starts to occur on randomly scattered plants across a field as the vines begin to cover the row middles. The leaves on the wilted vines or stems quickly turn brown and die. The wilting and death of the remaining stems on a diseased plant usually follow. The white mold fungus will also attack the roots, pods, and pegs of a groundnut plant. Pods on damaged pegs are usually shed. Diseased pods turn dark brown and disintegrate. Sometimes, severe pod rot may occur without any apparent damage to the rest of the plant.

A dense white mat of mycelia (filaments) of the white mold fungus may be seen on the soil surface, nearby crop debris, stems on or just above the soil surface, and occasionally lower leaves during humid, hot weather. This mat may grow across the soil surface to colonize adjacent healthy plants.

Round, light tan to brown, seed-like bodies called sclerotia usually form on this mat of filaments. They are usually most abundant on decaying groundnut stems and leaves. These dense white mats usually disappear when the soil dries or weather cools, but the sclerotia remain. The white mold fungus will survive in the soil as sclerotia until the next susceptible crop.

White mold control recommendations:

To make an informed decision on white mold control, you need good cropping history and scouting records for each groundnut field. Fungicides will give a good return in fields where light to moderate disease pressure is anticipated. In some fields, white mold causes such severe crop loss that rotation to a non-host crop is the only viable control measure.

While no single treatment controls the disease, the following are helpful:

1) Crop rotation is the most effective control for white mold. A 2-year minimum between groundnut crops is suggested;

2) Completely bury trash from preceding crop at least 10 cm./4 inches deep;

3) Plant early;

4) Plant groundnuts after a blight resistant crop, such as corn;

5) Plant some varieties of groundnuts that are more resistant than others—Southern Runner, or Georgia Green in field prone to heavy white mold pressure;

6) Avoid mechanical and insect injury to groundnut plants (Weeks, 2000).

3.12.4 Collar rot

Collar rot is associated with sunburn and is similar to white mold/southern blight. It occurs especially on Virginia type groundnuts following cotton. Treatment of the disease is the same as for white mold.

3.12.5 Peg rots

Peg rots are caused by organisms that are similar to those causing southern blight and they cause the seed to decay. Control is the same as for white mold.

3.12.6 Black pod

This is a calcium deficiency disease associated with varieties having large pods and seed. Various soil fungi attack the dead pod tissues causing discoloration. The trouble is worse following cotton or soybeans and during droughts early in the season. The methods for controlling black pod are poor but there are actions that can be taken. Research has shown that spacing plants closer can often yield healthier pods. Loss of pods from black pod also decreases when plants are inspected frequently and infected pods are removed when showing the earliest symptoms. Some control of black pod has also been obtained with other species of plants with copper fungicides, applied with either a hand sprayer or a power-sprayer (Woodroof, 1973; Thorold, 2008).

3.13 Insects and their control

Groundnut plants are attacked by a number of insect pests which feed on the foliage, pegs, pods, and kernels. Because cultural practices, weather conditions, and other factors vary widely, it is impossible to predict the insect problems a producer will encounter in a given year.

While some groundnut insects are controlled by cultural practices, most are controlled by the use of insecticides. Some years producers able a crop of groundnuts to grow without using insecticides. Other years, producers have needed to make several insecticide applications. With the continually increasing cost of insecticides and the importance of keeping the environment as pesticide-free as possible, groundnut producers should use insecticides only as needed.

Cultivation measures to prevent infestation by pests include:

1) Mixed crops and diversification of planting;

2) Provide alternative food sources (nectar/blooms) for parasitic insects;

3) Integrate habitats for natural enemies (e.g. selective weeding);

4) Include hedges and trees within the system;

5) Plant different varieties in strip form (e.g. alternative resistant with other types).

The following is a shortlist of common groundnut pests common to Mozambique:

3.13.1 Termites

Termites are serious groundnut pests throughout Africa. Species of *Microtermes* and *Odontotermes* are the most damaging, while *Macrotermes* cause occasional damage. The small-sized *Microtermes* spp., in particular, attack and invade growing groundnut plants through the roots and stem near ground level, hollowing them out and causing the plants to wilt and die with a consequent reduction in crop yield.

Roots damaged by other soil pests, such as white grubs, are also prone to attack by termites. Some termite species (*Macrotermes* spp., *Hodotermes mossambicus*) cut off stem bases, and may cause 25-100% of plant losses. As the crop ripens the outer layers of the pods are scarified (removal of soft corky tissue between the veins of the pod) by termites allowing contamination of the seed and soil fungi such as *Aspergillus flavus* which produce aflatoxins.

Scarification of pods is by far the most common type of termite damage at plant maturity, a factor often aggravated by late harvest. Scarification as high as 30% has been reported. Infested plants are not obviously diseased and are frequently harvested with and contaminate the rest of the crop. Species such as *Microtermes* spp. also penetrate the pod to feed off the soft inner lining, filling the pod with soil. This form of attack leads to additional loss through premature germination of kernels. Stacks of plants left drying in the fields are also frequently attacked by species such as *Odontotermes* spp. with farmers losing between 30-40% of their crop at this stage. Termite damage is generally most serious towards the end of the growing season just prior to harvesting, and it is particularly serious during periods of drought.

Termite control recommendations:

1) Remove any residues of previous cereal crops, such as sorghum, millet, or maize. Plant residues left in agricultural fields serve as food for termites, which may infest a new crop. Groundnut crops with high plant residues have been observed with 100% termite infestation;

2) Planting should be carried out early enough to avoid drought periods. Moisture deficiency may stress a crop and lead to attack by termites due to water-stressed plants;

3) Harvest promptly. Research has shown that termite damage increases with harvest delays. Furthermore, most groundnut-producing areas in Africa experience drought and high temperatures during the later part of the growing season, conditions that favor termite infestation;

4) The complete destruction of mounds and removal of queen termites are effective control measures against mound-building species (*Macrotermes* spp.). Partial destruction of mounds is unlikely to solve the problem, since replacement reproduction may develop from the remaining termites;

5) It has been reported that close spacing during planting helps to deter termite infestation. High density sowing, followed by thinning of surviving plants where necessary to reduce competition, offsets anticipated losses due to termites (Infonet-biovision, 2011).

3.13.2 White grubs

White grubs are the larvae of scarab 'chafer'/June beetles. There are about 200 known species. Mature grubs are about 1.3-2.5 cm. (0.5-1 inch) long with six prominent legs. The rear of the body is smooth, shiny, and usually black. White grubs have curved C-shaped bodies. They live in the soil and feed on the underground parts of the groundnut plant. Their life cycle varies in length from 1-4 years, depending on the species. Many species of white grubs are associated with groundnut damage in Africa.

White grubs attack groundnut plants at all stages of growth. They eat the roots and damage the pods. White grubs feed mainly on the taproots and/or peripheral roots leading to plant stunting or death. They inflict cuts in the crown region of taproots; these lesions are often invaded by rot-causing fungi. White grubs also cut out pods from the base of groundnut pegs and destroy larger, soft pods. Plants are often attacked in a row. White grubs seem to prefer soils with sandy or loamy sand textures and are seldom observed in clay soils.

White grubs control recommendations:

1) Allow enough time between manure application and groundnut planting. Note that the excessive use of organic manure in groundnut farms has been observed to increase the incidence of white grubs, especially when manure is applied during the cropping season;

2) Plough deeply and hand hoe tillage as it exposes soil pests to desiccation and to predators, thus helping to reduce their numbers and damage (Infonet-biovision, 2011).

3.13.3 Millipedes

Millipedes are persistent soil pest of groundnuts. They are brown to blackish in color and curl when disturbed. Millipedes attack groundnut seedlings between planting and approximately 20 days after planting, feeding on the emerging cotyledons and moving to the root system at the collar region. The cortex is often damaged serving as an entry point for secondary infection by microorganisms.

Millipedes also attack maturing groundnut plants during pod formation, e.g. when the pods are still soft. Immature pods from severed pegs are often perforated and thus suffer secondary infection or invasion by rot-causing organisms such as *Aspergillus flavus*. Millipedes may also damage flowers. Birds are the main predators of millipedes.

Millipede control recommendations:

1) Practice good farm sanitation;

2) Prepare the land properly before planting;

3) Select growing sites away from forest regions (breeding sites for millipedes);

4) Cover exposed pods;

5) Close any cracks in the soil;

6) Use groundnut varieties with pods well buried (Infonet-biovision, 2011).

3.13.4 Aphids

Aphids are a serious pest as a vector of virus diseases, such as the rosette virus disease (discussed earlier), and they are a major constraint to groundnut production, particularly in the dry season. The groundnut aphid is black or dark brown in color, variable in size (1.5 to 2.0 mm long) with two black cornicles (horns at the rear of the body), and a black tail.

Aphids control recommendations:

1) Plant early and plant close together. Early planting allows plants to start flowering before aphids appear. Dense planting provides a barrier to aphids penetrating in from field edges and discourages population build-up of aphids and reduces incident of rosette disease;

2) Conserve natural enemies: Ladybug beetles are important natural enemies in groundnuts;

3) Use neem seed or leaf extracts if necessary;

4) Do not cultivate groundnut or other legumes continuously on the same ground;

7) Use aphid-'resistant' varieties. The groundnut variety 'Nyanda' is reported to be tolerant of aphids (Infonet-biovision, 2011).

3.13.5 Thrips

Several species of thrips attack groundnuts. Thrips are small slender insects that jump or fly when disturbed. Thrips larvae are similarly shaped and are usually yellow. They feed in buds or plants on young, folded leaflets. The flower thrips (*Frankliniella schultzei* and *Megalurothrips sjostedti*) infest mainly buds and flowers. Attacked flowers are discolored and scarred; terminal leaf buds are blackened and distorted after unfolding. Other species of thrips (e.g. *Scirtothrips dorsalis and liothrips indicus*) infest foliage. Thrips feeding causes yellowish-green patches on the upper leaf surface and brown necrotic areas and silvery sheen on the lower surface of the leaf; leaves become thickened and some curling occurs. In severe infestations, young leaves are severely deformed, plants are stunted and leaves are blighted. In the past, controlling thrips has not consistently resulted in yield increases.

Thrips control recommendations:

1) Plough and harrow before transplanting. This can be useful in reducing thrips attacks by killing pupae in the soil;

2) Conserve natural enemies to thrips, such as lacewings and other predatory bugs;

3) If necessary, spray the crop with botanicals—some plant extracts (e.g. garlic, rotenone, neem, pyrethrum, etc.). A mixture of garlic and pepper has been recommended for organic growers in the United States (Infonet-biovision, 2011).

3.13.6 Leafminer

The Leafminer is a common pest of groundnuts in South and South-East Asia, a major pest in India, and leafminers have invaded Africa. Leafminers were first reported in Uganda in 1998 and have now been recorded in Mozambique, Malawi, Democratic Republic of Congo and South Africa. In all African countries where leafminers have been found, the pest has reached epidemic densities and severe yield losses have occurred.

The adult leafminer is a mottled moth, with a full wing span of up to 18mm. (18/24 inches). The moth lays eggs on the underside of the groundnut leaf. Yellowish green caterpillars hatch, tunnel into the leaves and feed between the upper and lower epidermis of the leaf. Mined leaves become distorted within a few days. Caterpillars are grey-green with a shiny black head.

Three or four attacks per groundnut leaflet can cause so much distortion that a leaf exposes as little as 30% of the potential photosynthetic area to the sun. Later, when the caterpillar becomes too large to occupy the mine, they emerge to the leaf surface and either fold over a single leaf and hold it down with silk, or web together two or more leaflets. Leafminers live and feed in the shelter they have constructed. Pupation takes place inside the webbed leaflets. Damaged leaves become brownish, rolled and desiccated, which results in early defoliation and affects the growth and yield of the plants.

Leafminer control recommendations:

1) Plant during the first short rains when normally the leafminer population is low;

2) Avoid drought stress by irrigating or sowing so as to avoid periods when drought is likely. Plants that are water-stressed are much more susceptible to leafminer attack than irrigated plants;

3) Use tolerant/resistant varieties. In Uganda, the variety 'Egola-1' has been reported to show signs of relative resistance (Infonet-biovision, 2011).

3.13.7 Nematodes

There are three types of nematodes—root-knot, meadow, and string, which cause stunting and yellowing of the plants. Plant parasitic nematodes can severely limit the production of groundnuts. Yield loss is closely tied to cropping sequence; the more often peanuts are grown, the higher the risk of significant crop injury. The peanut root-knot nematode (*Meloidogyne arenaria*) is the most widely distributed and destructive nematode pest of groundnuts. Other nematodes reported to damage groundnuts are the lesion nematode (*Pratylenchus brachyurus*) and the ring nematode (*Criconemoides* species). Nematode populations are usually highest in light, sandy soils.

Nematode injury is difficult to diagnose on the basis of above-ground symptoms. The damage may easily be mistaken for nutritional deficiency, a soil-related disorder, or drought stress. Nematode-damaged peanut plants are usually found in circular to irregular patches ranging from a few feet to several acres.

Symptoms of nematode injury never occur uniformly across a field. The foliage of damaged plants turns yellow and wilts at mid-day, even when soil moisture is plentiful. During periods of hot, dry summer weather, the death of severely damaged plants is common. At times, sizable yield reductions will occur without any apparent damage to the plant.

Galls form on roots invaded by the groundnut root-knot nematode; these galls can be several times the normal root diameter in size. Pegs and pods attacked by this nematode are also galled. Elongated, swollen areas may appear on heavily infested roots and pegs.

Development of the fibrous root system is greatly restricted by the peanut root-knot, lesion, and ring nematodes. Affected roots usually are discolored and stunted. Small brown to black spots associated with the feeding of the lesion nematode often give damaged pods a speckled appearance. Pods weakened by nematode feeding often break when the vines are inverted and are left scattered across the soil surface.

An assay of soil for plant parasitic nematodes is generally needed for the accurate diagnosis of nematodes. More importantly, soil assays can also be used to identify fields with potentially damaging nematode populations and to begin effective control measures before significant loss occurs. Collecting soil samples for nematode analysis is recommended for all fields going into groundnuts the next year, regardless of previous cropping history. Particular attention must be paid to those fields cropped to groundnuts nearly every year. Fields fallowed the previous summer should also be sampled for nematodes.

Nematodes control recommendations:

1) Crop rotation can be used to prevent nematode populations, particularly those of the groundnut root-knot nematode, from reaching damaging levels. The best rotation is 1 to 2 years of groundnuts behind 4 to 5 years of a pasture grass. Otherwise, a 2-year minimum between groundnuts crops is recommended. Avoid groundnut-soybean rotations;

2) Turn over summer-fallowed fields several times to destroy groundnut stands;

3) Granular and fumigant nematicides will give some control of nematodes (Weeks, 2000).

3.13.8 Moths and beetles

Stored groundnuts may be attacked by moths (*Ephestia cautella*, *Plodia interpunctella*, *Cadra cautella*), and beetles (*Caryedon serratus*, *Tribolium castaneum*, *Trogoderma granarium*). The larvae of moths and the grubs and adult beetles bore into and damage seeds. Moths cause extensive webbing. The bruchid beetle *Caryedon serratus* is the major pest of groundnuts in shells. A good post harvest pest management program based on good storage practices is very important.

Moths and beetles control recommendations:

1) As most post-harvest groundnut pests, except bruchids, are unable to penetrate intact pods, leave the crop in the shell for as long as possible during storage for an effective method of limiting damage;

2) Adding sand as an abrasive material at the farm level has also been shown to be effective (Infonet-biovision, 2011).

3.14 Irrigation

Groundnuts are mostly grown on the residual moisture without any supplementary irrigation. Apart from reducing the buildup of aflatoxin, well co-ordinated irrigation will also produce higher yields.

Groundnuts respond well to two or three irrigations given at an interval of 12-15 days starting from 75 days after sowing. The results from trials show an increase of 35-40% in pod yield corresponding to extra pod yield of 300-400 kg/ha.

Aflatoxin management recommendation(s):

Drought conditions favor aflatoxin contamination. Avoid end-of-season drought with supplementary irrigation or timely planting groundnut varieities with maturity period fitting in the rainfall cycle. Drought resistant varieties also help withstand an end or mid-season drought (Okello et al., 2010).

Irrigation is usually stopped before the harvest as soon as two-thirds of the pods have ripened. After two more weeks, harvesting can begin, when the soil is sprinkled directly beforehand in order to loosen it and ease the work. If the temperature allows, groundnuts can be planted during the dry season when irrigated, so eventually two harvests are possible per year (Augstburger, et al., 2002).

4. Harvest and post-harvest handling

4.1 Time of harvesting

The crop must be harvested at the proper time. This will depend on the variety grown and its duration. The optimum time for harvesting is when most pods have a veined surface, seed coats are colored, and 60-75% of pods show darkening on the inner surface of the hull. As the groundnut produces flowers almost daily over a number of weeks, the nuts, even on a single plant, do not mature simultaneously. While some of the oldest kernels may be mature and even sprout in hot weather, many are still newly formed. Plants in different parts of a field should, therefore, be examined at intervals of 2-3 days. Bush varieties mature in 110-130 days after sowing; branching varieties in 130-15 days.

Aflatoxin management recommendation(s):

It is very important to harvest groundnuts at optimum maturity, as excessive numbers of over-mature or very immature pods at harvest can be reflected in high levels of aflatoxin in the production. Also delays in harvesting will result in poor quality seed due to mold infections and subsequent aflatoxin contamination of the seeds/pods (Okello et al., 2010).

The symptoms like yellowing and drying of lower leaves and reddish color of the kernels after the pods are broken are the visual indicators to decide upon harvesting. The individual seeds are ripe when:

- The structure of the pods is easily recognizable;
- The pods have been largely filled with seeds within;
- The inner walls of the pods has taken on a darker color (brown).

As soon as 60-75% of the pods are ripe, any further delays in harvesting will result in losses. The optimum period for harvesting is very short. If harvesting takes place either 5-10 days before this time or after this time, then up to 25-50% of the production may be lost. If groundnuts are harvested too late, especially in hard and dry soils, this will result in the pegs breaking off, since they will already be quite brittle. The pegs often stay stuck in the soil when the plant is pulled out (Augstburger et al., 2002).

4.2 Methods of harvest

Manual harvesting of groundnuts is commonly practiced in Mozambique. Manual harvesting usually consists of a series of operations comprising digging, lifting, windrowing, stocking, and threshing. Manual harvesting can be more profitable over mechanical harvesting for small areas since fewer pods are left in the soil and they are less likely to be damaged. Planting on ridges, especially in hard soils, can make harvesting easier. The plants can be extracted by hand with a hoe; this can be made easier still by cutting below all the rows with special uprooting blades (pulled by either animals or a tractor). In light soils, harvesting machines—similar to those used for potato crops—can used, and for heavy soils, special groundnut uprooters.

Aflatoxin management recommendation(s):

Damage to pods at the time of harvest should avoided as much as possible since this can lead to rapid invasion of the pods by *A. flavus*/*A. parasiticus* which leads to aflatoxin contamination. Remove excessive moisture from the pods after harvesting through shaking (Okello et al., 2010).

In bunch type groundnuts, pod development is confined to the base of the plant and the pegs carrying the pods into the soil are thick and strong. Almost all the pods are recovered with the plants when they are pulled out of the soil. The bunch type of groundnut is mostly harvested by pulling out the plants by hand. Usually 12 to 14 field workers can harvest a one-hectare area of groundnut crop in one day.

Harvesting may sometimes become a problem especially when the crop has passed the stage of full maturity and the soil has hardened. In this case, it is necessary to lift the plants by loosening the soil either by working a hand hoe or a plough along the plant rows. If after lifting the crop manually it is observed that a good percentage of the pods have been left in the soil, the same implements may be used to pick the leftover pods. In the latter case, additional work will be required. In the case of the spreading type groundnut, the process of up-rooting the crop from the soil is a rather difficult operation as pod formation takes place all along the creeping branches of the plant. The pegs are comparatively thinner and more delicate.

As compared to manual uprooting, animal-drawn diggers are satisfactory and economical. The digger lifts groundnut plants from a depth of 10-12 cm. (3.9-4.7 inches). Several models are available in local African markets to be operated either by the animal draught or by a power tiller drive (3-6 hp).

Harvesting delays may be caused by the logistics of lifting plants from the ground. Many models of ploughs or digger blades can be used to up-root one or several rows. The design depends on whether the digger is animal operated or mechanically powered. It is essential that the blade or ploughshare be set deep enough to cut below all the pods, but not so deep as to increase draughts unnecessarily. Slow speeds and additional implements are preferable to higher speeds with fewer tools.

Harvesting techniques can also affect the milling quality of groundnuts. Sweeps or fingers may be necessary on the digging blades to ensure that the plants are left well to one side of the opened furrow and not covered with soil. Where it is necessary to combine several rows of plants into one, this operation must be carried out soon after lifting as practicable or pod loss can occur. Raking early in the day when plants are moist reduces this issue.

The groundnut pods from freshly harvested plants still have a moisture content of around 35-50% and need to be rapidly dried to a moisture content of around 20-25% so that they can easily be separated from the plants. The best method is to pre-dry them in windrows for 2-3 days. After the tap roots have been cut away, the plants are stacked on their leaves with the pods facing downwards. The advantages of this are:

- rapid drying;
- avoidance of contact with the soil;
- a reduction of attacks by insects and the risk of infestation by *Aspergillus* spp.

The quicker the pods are dried after being uprooted, the less aflatoxin is created. Nevertheless, care must be taken not to dry them too quickly, as this can result in a weakening of the testa, which protects the seeds from decay (Nautiyal, 2002; Augstburger et al., 2002).

4.3 Picking

After being dried out in the field, the pods may then be separated from the plants. The groundnuts are picked from the plants when they can be pulled from the nut stalks without short coarse threads breaking from the pods or shells. By this time the kernels rattle in the pods and have a nutty flavor. Depending on how the plants are stacked, and the prevailing weather conditions, the curing in the stacks takes from 2-6 weeks.

The picking is done by hand or by means of drawn or stationary picking machines. The stacks should be taken off the field for picking, thereby saving a considerable amount of hay. There is then also less likelihood of fields becoming systematically infected with the stem and nut rot fungus, sometimes found in the debris left wherever a stack has been picked.

Nuts of different qualities should, wherever practical, be picked separately so that discolored or moldy nuts are not mixed with clean and bright ones. Discolored pods frequently contain moldy kernels which lower the grade of shelled and unshelled nuts (Woodroof, 1973).

4.4 Making hay

Foliage from groundnut plants provide excellent protein-rich fodder, with similar nutritional values as alfalfa, and is therefore often also harvested. Foliage can be cut down just before the uprooting takes place and dried into hay. One method of carefully drying after the whole plant has been harvested is to dry the foliage on hay racks or upright poles, after it has been left to wilt for a while on a windrow (Augustburger, 2002).

4.5 Cleaning

When groundnuts are harvested they contain a wide range of foreign material. This affects quality, beginning with airflow restrictions and uneven moisture distribution during drying. More than 5% foreign material can result in reducing the value of a farmer's salable product in the market.

Aflatoxin management recommendation(s):

Freshly harvested groundnuts should be cleaned and sorted to remove damaged nuts and other foreign matter. It is important to shake the plant after lifting/harvesting to remove soil from pods and avoid forming optimum conditions for aflatoxin development. Damage to pods at the time of harvest should be avoided as much as possible since this can lead to rapid invasion of the pods by *A. flavus*/*A. parasiticus*. Every effort should be made to minimize physical damage at all stages of harvesting and transportation. Individual plants that die from pest attacks (e.g. termites, nematodes) and diseases (e.g. rosette, pod rots, etc.) should be harvested separately as their produce is likely to contain aflatoxin (Okello et al., 2011).

Groundnuts to be roasted in-shell and eaten by hand may be cleaned in two steps. The first consists of removing sand, dirt, stems, empty shells, stones, and other foreign material by screens, blowers, or hand inspection. This should leave only whole, sound nuts. The second cleaning insures a bright hull. The nuts are 'washed' in wet coarse sand which removes weathered stains and discoloration. The sand is screened out and reused, while the nuts are dried. Table 4.1 illustrates methods to reduce the incidence of foreign material in groundnuts.

Table 4.1 Methods to reduce the incidence of foreign material in groundnuts

Foreign material(s)	Best conventional method(s) of prevention	Best conventional method(s) of removal
Dirt	Harvest when soil is not too wet or dry. Control weeds.	Screening
Rock pieces	Avid planting on rocky or pebble-type soil	Specific gravity
Sticks/previous crop residue	Remove old crop residue before planting. When harvesting cut taproots as shallow as possible.	Screening
Immature pods	Harvesting at optimum maturity. Remove immature pods.	Screening and specific gravity.
Leaves, stems, and hulls	Harvest at optimum maturity	Screening
Weeds	Control weeds.	Screening
Metal	Maintain machinery in good condition.	Screening and magnetic separation.

Source: Nautiyal (2002)

4.6 Drying

Directly after being threshed, groundnut pods should be dried, either artificially or in the sun, until they attain a moisture content of 6-7 %. Delays must be avoided at all costs to reduce the risk of infestation by *Aspergillus flavus*, which rapidly increases. Under 9%, the creation of aflatoxin is retarded, but protection against storage pests, whose activities create aflatoxins, is only attained at levels under 7 %. For this reason, a moisture content of 6-7% is necessary.

Problems can often occur when the harvest is carried out during wet weather, and the produce insufficiently dried afterwards. Only at less than 6% will the seeds become damaged (they break during shelling). In cases of extreme sunshine and heat, it may be advisable to carry out the drying process under a roof. The weight loss during drying is compensated for by an increase in quality and a reduction of the risks involved.

Drying groundnut pods by spreading them in a thin layer on the soil is a common practice in many parts of Africa and this can be a major source of fungal contamination. Alternatively, woven matting or tarpaulin material should be used. In Uganda, where harvesting occurs largely in the wet season, a period of four to six weeks is given as the probable time taken for pods to dry to about 10 percent moisture content. A layer 3.8 cm. (1-1/2 inches) deep needs no stirring, while a layer 7.5 cm. (3 inches) deep needs stirring on alternate days. Two major disadvantages occur when drying groundnut pods by leaving them spread in a layer on the ground or on areas of concrete or on matting, etc. Initially, there is the problem of moisture in the ground in contact with the pods together with restricted air movement around the groundnuts. The second difficulty is the time and effort required to gather the pods together, cover them during a rain shower, and re-spread them as soon as possible to continue drying.

Aflatoxin management recommendation(s):

Do not dry groundnuts directly on soil. Use clean sheets, e.g. polythene sheets or tarpaulin or mats made of papyrus, cemented grounds or raised structures. Groundnuts should be dried as soon as possible (drying within 48 hours if possible). Also, do not dry diseased/infected groundnuts along with healthy ones (Okello et al., 2010).

Alternative methods to ground drying should be used—such as trays, platforms, sacks, and racks.

Trays

In some countries farmers are encouraged to spread groundnuts out on trays, which they leave exposed to sun-drying during the day and move under cover at night. In Uganda, for example, trays, which hold one hundred kilograms of groundnuts, consist of a metal mesh base and wooden sides with handles at both ends. These trays can be raised off the ground by supporting the four corners on sticks. The Government of Uganda subsidizes these drying trays for the farmers.

Platforms

Some pods, after removal from the plants, are placed on platforms to complete the drying process. Very often these pods are left on these platforms for an indefinite period of time and in some cases they are even stored there.

In sacks

When the moisture content of threshed unshelled and shelled pods is too high, groundnut pods are sometimes bagged. Each day the bags are brought out of the storeroom and left in the open. This is common practice at many agricultural stations in Africa but it can be problematic and attract mold.

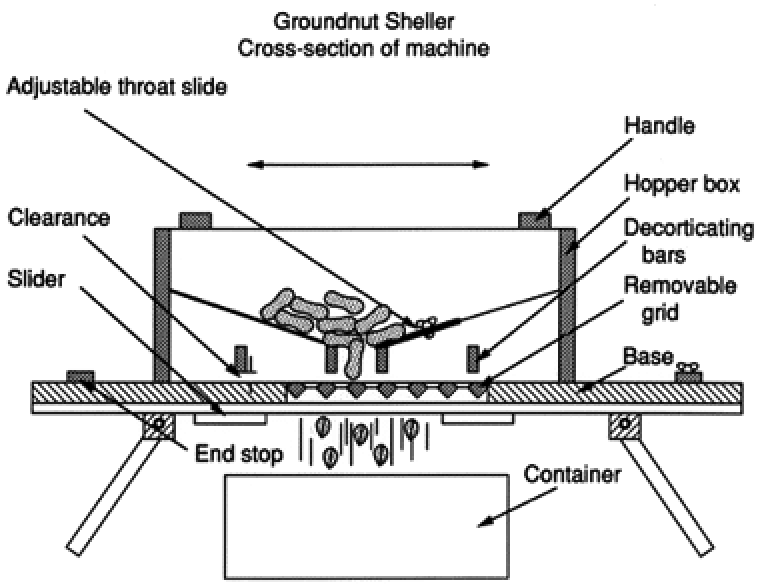
Racks

In Australia several trials have been conducted on the natural drying of threshed groundnuts in suspended bags. In the suspended bag trials, groundnuts of 30% initial moisture content in open weave bags were suspended vertically from a horizontal wooden rack supported at both ends by strong vertical posts. A galvanized iron roof provided protection from the rain. Staggered hanging bags at center distances of 56 cm. (22 inches), two bag rows deep, was reported to have safely dried groundnuts from approximately 30% moisture content to a safe storage moisture content in 10 days.

4.7 Decorticating or shelling

Groundnut shelling in Mozambique's smallholder sector, as in many other African countries, is often done by hand. While hand shelling keeps the rate of kernel breakage low, it is very labor intensive and leads to 'sore thumb syndrome' when large quantities of groundnuts are handled. In addition, the low productivity (1-3 kg./hour) of hand shelling puts enormous pressure on farmers, because they need to shell their groundnuts before the marketing season ends. It is, therefore, important to use a simple, efficient, low-cost machine to replace hand-shelling. See Figure 4.1.

Figure 4.1Universal nut sheller



Source: IDCR (2011)

The universal nut sheller was designed by the Farm Machinery Unit of Malawi, in conjunction with the Tropical Development and Research Institute, as the first hand-operated wooden universal nut sheller. Once the International Develop Research Centre modified the design, the universal nut sheller met market standards—90% average whole kernel efficiency or 10% visible kernel damage. The sheller has a shelling rate of 21-42 kg./hour and a larger model (twice as wide) can double the shelling rate of a smaller sheller.

Before shelling can begin, groundnuts need to be graded by size using grading sieves. The sheller is operated by two people, one at each end pushing the sheller back and forth. Groundnuts are placed in a hopper, fall through an opening called the throat, and settle into the gaps in the removable grid, which is placed in a slot in the base. The hopper is pushed against the resistance provided by the nuts, thereby shelling them. The broken shells and kernels fall through the grid gaps into a container placed under the base. Although the sheller has been designed and adapted for three local varieties, it is possible to use it with other varieties of similar size or to adapt it to new varieties (IDCR, 2011).

Aflatoxin management recommendation(s):

- Separate out immature pods as well as those infested with pests and diseases.
- Do not shell by beating or trampling on groundnuts in shells.
- Do not sprinkle water on dry pods while using a mechanical sheller. Instead, adjust (where possible) the space between the blades and the sieve according to pod size to reduce breakage.
- Remove shriveled, discolored, moldy and damaged groundnuts from the lot. Also remove dust and foreign material which can provide a source of contamination (Okello et al., 2010).

Groundnut farmers benefit from the time and labor savings associated with the universal nut sheller. Nutritionists, as well as organizations concerned with income generation such as extracting and selling oil, also find it useful. The sheller costs about USD35.00 to build and a manual for its construction and use is available by contacting: Farm Machinery Unit, Chitedze Agricultural Research Station, P.O. Box 158, Lilongwe, Malawi, tel: (265) 720968/720906; Fax: (265) 784184/741872; E-mail: icrisat-malawi@cgnet.com.

4.8 Storage

Groundnuts are semi-perishable. They may be held for five years under optimum conditions, but under unsuitable storage conditions they become inedible within a month due to mold, insects, discoloration, absorbing foreign flavors, staleness, or rancidity.

Groundnuts are normally held for a period between harvesting and consumption and experience has shown good packaging and refrigeration is most important. Storage during cool winter months is not a problem, but in warm weather groundnuts become rancid and insect-infested within a few weeks, unless refrigerated or otherwise protected. In general, the main factors which need to be observed in storing is a low moisture content of the seeds and low ambient temperatures. Room moisture content, coupled with high temperatures, is the main reason for the creation of aflatoxins. Prevention is achieved by:

- Sufficient air circulation;
- Regulation of the relative air humidity;
- Suitable cooling (Augstburger et al., 2002).

To successfully store groundnuts the following storage requirements should be followed:

Groundnuts should have high initial quality. That is to say, they should be free of mold, insects, rancidity, and off-odors. They should have the color and characteristics of the variety. The storage life of groundnuts begins in the field, including the degree of maturity, time and temperature of curing-drying, and method of cleaning. Ill effects of improper storage are cumulative and irreversible.

Ideally, the temperature should be low. In general, the lower the temperature the longer will be the expected storage life of groundnuts. At 21°C. (70°F.) unshelled groundnuts may be expected to retain edible quality for 6 months; when shelled, the time is reduced to about 4 months. Groundnuts at this temperature are subject to insect infestation, development of 'amber' coloring, staling, and rancidity. At 8.3°C. (47°F.) unshelled groundnuts may be stored for 9 months, shelled nuts for 6 months. Insects are 'arrested' at this temperature. At 0-2.2°C. (32-36°F.) the storage life of shelled groundnuts may be extended to 2 years, at -3.8°C. (25°F.) it may be for 5 years, and at -12.2°C. (10°F.) it may be 10 years. Storage life of in-shell groundnuts should be 50% longer.

Also the relative humidity should be low. High moisture in groundnuts is possibly the cause of more deterioration than any other single factor and may result in nuts becoming inedible within as short a time as two weeks. The control of moisture in groundnuts during storage is accomplished by circulating and control of the relative humidity of the air. Research has shown that at a relative humidity of 65-70% groundnuts equalize at a moisture content of about 7%. Above 70% relative humidity groundnuts are likely to mold and below this point they lose weight, become brittle, and may split during handling. Groundnuts with moisture above 8% will gradually lose moisture to a safe level, when the air is circulated throughout the storage room. On the other hand, groundnuts with moisture content below 5% will gain moisture. This happens because groundnuts having an oil content of 48%: if the oil content is lower the moisture content will be higher under the same temperature and relative humidity conditions.

The atmosphere should be free of odors and well-circulated. Groundnuts readily absorb odors and flavors from the surroundings. Imperfections in packaging permit odors from the storage room, the atmosphere, and other products to be absorbed, resulting in foreign flavors, odors or colors in the nuts. Even faint odors of wood, ammonia, paint, asphalt, and most fruits and vegetables may accumulate in the oil of the nuts and appear stronger than in the surroundings. Traces of ammonia, undetected by the human nose, can cause the skins of peanuts to blacken. The damage by ammonia is more severe to the appearance than to the flavor, while most odors degrade the flavor first. There is no practical way of deodorizing or restoring the color to groundnuts. Roasting frequently only intensifies the flavor and color.

The shelf-life of peanuts shelled, salted, and roasted or roasted in the shell is about three weeks when held at room temperature in transparent bags. It is extended by vacuum or with inert gas and by holding the low temperature. It is also extended by holding the moisture below 1%. Low moisture depresses rancidity.

Upon removal from cold storage, steps should be taken to prevent moisture condensation on the groundnuts. First, the groundnuts should be removed only on days when the relative humidity is fairly low. Secondly, transportation from refrigerated storage should be in insulated vehicles allowing the peanuts to slowly temper in transit. Thirdly, groundnuts may be removed to trucks or cars, and cooled to the same temperature as the storage room (Woodroof, 1973).

Often ideal conditions do not exist for farmers to store groundnuts in developing countries like Mozambique. Smallholder farmers then use earthen pots, mud bins, and other receptacles. These containers may be plastered over with mud with little or no use of pesticides. Daily storage of groundnuts in gunny bags or sacks is a common practice as well. Gunny sacks are then stored in or near farmhouses. Semi-underground storage of groundnuts has also been used in Africa.

Aflatoxin management recommendation(s):

- Properly dry groundnuts to a safe storage moisture level.
- Use new/clean gunny sacks or polybags to store groundnuts. Only put clean sorted kernels into bags. Bags should not be placed directly on the floor.
- Do not heap groundnuts in shells/pods on the floor/ground instead the storage facility.
- Maintain proper storage facilities (well-ventilated, dry and low relative humidity) and take care not to expose groundnuts to moisture during transport and marketing.
- Control insect and rodents during storage.
- Do not mix new with old groundnut stock (Okello et al., 2010).

Throughout history reasonable success has been achieved in storing various foods underground. In the 1980s various semi-underground storage models were explored. A small semi-underground warehouse was constructed by waterproofing and placing a 7.6 cm. (29.9 inches) thick pre-cast concrete tank measuring 304.8 cm. (120 inches) long by 152.4 cm. (60 inches) deep in the ground with the top of the tank at ground level. Two levels of 20.3 cm. (8 inches) concrete blocks were installed above the walls and the warehouse was covered with a sheet-metal gable roof with a 45° slope. The warehouse had a groundnut storage capacity of approximately 10.2 m^3. A fan located in the south gable changed the headspace air once every two minutes. Thermocouple and relative humidity sensors placed at various locations throughout the warehouse indicated temperatures and relative humidity at these locations. Temperatures were found to be more uniform in the underground warehouse than a conventional warehouse, offering the potential for maintaining groundnut quality in this type of storage (Smith & Sandras, 1987).

4.8.1 Storage pests

Groundnuts are stored both as unshelled pods and as kernels for different reasons. Both forms are vulnerable to attack by a plethora of insect pests after harvest. However, groundnut kernels are more susceptible to insect attack than pods in storage. The amount of damage inflicted by insect pests during storage depends on several factors such as:

- the moisture content in the product;
- the way in which groundnuts are stored;
- the level of maturity at harvest;
- the sanitation of the storage space, and
- the quality of the groundnuts themselves.

In addition, the type of storage structure also influences the rate of deterioration through its physical environment. Post-harvest processing of groundnuts (threshing, drying and cleaning) has significant influence on insect behavior and infestation during storage. Mature pods are less susceptible to insect pests than immature pods. Damage to pod shells also increases susceptibility to insect pests. In most cases, manual hand picking is safe because it avoids damage to the groundnut shells.

Excessive drying in the sun can also affect the viability of the nuts; therefore, care should be taken to ensure that groundnuts are dried either under shade or at the appropriate temperature. Undamaged unshelled groundnuts can be stored for long periods without insect pest damage provided the moisture content is below 7%, as discussed above (Rao, Rao, & Nigam, 2010).

More than 100 insect species are known to live and feed on stored groundnuts. The most commonly reported pests affecting stored groundnuts worldwide are listed in Table 4.2.

Insect infestation in groundnuts is well known for causing direct loss, but indirect loss in terms of the quality of the product also impacts its use and trade. The heat and moisture generated by a large insect population in storage also increases the risk of mold growth, which indirectly spoils the quality through mycotoxin contamination, rendering the stock unfit for human and animal consumption.

Table 4.2 Important insect pests of groundnuts during storage

Latin name	Common name
Abasverus advena **(Waltl.)**	Foreign grain beetle
Alphitobius diaperinus **(Panzer)**	Lesser mealworm
Araecerus fasciculatus **(De Geer)**	Coffee bean beetle
Attagenus megatoma **(L.)**	Black carpet beetle
Carpophilus dimidiatus **(F.)**	Corn sap beetle
Caryedon serratus **(Olivier)**	Groundnut bruchid
Corcyra cephalonica **(Stainton)**	Rice moth
Cryptolestes pusillus **(Schoenherr)**	Flat grain beetle
Dermestes lardarius **(Linnaeus)**	Carpet beetle
Elasmolomus sordidus **(F.)**	Pod sucking bug
Ephestia cautella **(Walker)**	Almond moth
Lasioderma serricorne **(F.)**	Cigarette beetle
Latheticus oryzae **(Waterhouse)**	Longheaded flour beetle
Liposcelis **sp.**	Booklouse – several species
Necrobia rufi pes **(De Geer)**	Checkered beetle
Oryzaephilus mercator **(Fauvel)**	Merchant grain beetle
Oryzaephilus surinamensis **(L.)**	Saw-toothed grain beetle
Plodia interpunctella **(Hubner)**	Indian meal moth
Sitophilus oryzae **(L.)**	Rice weevil
Stegobium paniceum **(L.)**	Drugstore beetle

***Tenebrio molitor* (L.)**	Yellow mealworm
***Tenebroides mauritanicus* (L.)**	Cadelle
***Tribolium castaneum* (Herbst)**	Red flour beetle
***Tribolium confusum* (Jacquelin du Val)**	Confused flour beetle
***Trogoderma* sp.**	Khapra beetle
***Trogoderma inclusum* (LeConte)**	Larger cabinet beetle
***Typhea stercorea* (L.)**	Hairy fungus beetle

Source: Rao, Rao, & Nigam (2010)

Four of the most important species of pests that attack groundnuts in Africa are the groundnut bruchid, the red flour beetle, the rice moth, and the pod sucking bug (Nautiyal, 2002):

Groundnut bruchid (aka groundnut borer or weevil), *Caryedon serratus* (Olivier)

The groundnut bruchid is found throughout India and Africa. It breeds on common tree legumes and harvested groundnuts. It is the only species that can penetrate intact pods to infest the kernels. Infestation of the harvested groundnuts can occur while the crop is being dried in the field or stored near infested stocks or crop residues.

Adult females attach their eggs to the outside of pods or kernels. When the first larva hatches it burrows directly through the pod wall to reach the kernel, where the larva feed and develop. A single larva can make a large excavation in the cotyledons, but no sign of damage is visible externally at this stage. Mature larvae emerge partially or completely from the pod and construct an oval papery cocoon. The egg to adult development period is about 42 days under optimum conditions of 30°C. (86°F.). The adult is 4 to 7 mm long, with small black markings.

Red flour beetle, *Tribolium castaneum* (Herbst)

The red flour beetle is found throughout the tropics and is regarded as a major pest of shelled groundnuts. Female beetles lay about 450 eggs at one time. These eggs hatch into cylindrical larvae, which, like the adult, feed on groundnut kernels. Pupation takes place inside the food without a cocoon and adult beetles may live for 18 months. The developmental period from egg to adult is about 20 days under optimum conditions at 35°C. (95°F.). The role of the red flour beetle in the deterioration of shelled groundnuts has been assessed as loss in weight (4.5%) and loss in germination (73%).

Rice moth, *Corcyra cephalonica* (Stainton)

The rice moth has the ability to develop at low humidity (<20 percent RH). The adult is brown and 12 to 15 mm. (0.47-0.59 inches) long with its wing folded. The head bears a projecting tuft of scales. A female rice moth lays up to 150 eggs within a few days of emergence from her cocoon. Her larvae are mobile and feed upon and within the kernels. Infestation causes aggregation of kernels by the presence of webbing. The development period's optimum temperature—about 28-30°C. (82.4-86°F.)—is 4-5 weeks. The larvae are capable of damaging intact kernels and feed both on the surface and within seed. They spin a tough silky fiber, webbing together the kernels. Rice moths appear in particularly severe unhygienic storage conditions.

Pod sucking bug, *Elasmolomus sordidus* (Fabricius)

This pest is also widespread in India and Africa. It appears on pods left for drying in the field and in storage. The adult is dark brown, approximately 2mm wide. In the field, females lay their eggs in the soil or on groundnut stalks, but in storage facilities, eggs are laid loosely among the groundnuts or in sacking. The first nymphs have a bright red abdomen; later they become progressively darker. All stages feed on kernels, perforating the pods. This causes the kernels to shrivel and increases the free fatty acid content of the oil, producing a rancid flavor.

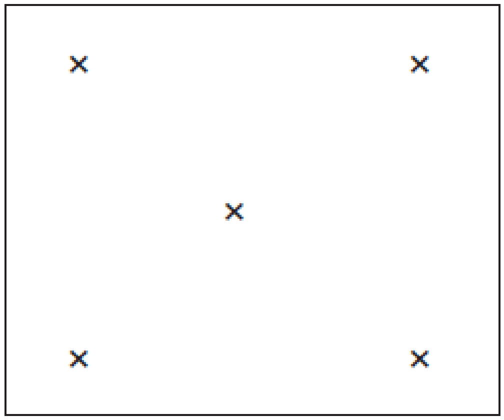
4.8.2 Monitoring insects

It is important to regularly monitor (once every two weeks) insect populations in storage areas so that remedial measures can be taken as soon an infestation is noticed. Crop handling also has a bearing on predisposing insect attacks during storage. That is to say, while harvesting a groundnut crop, damage to the pods should be avoided. Although insect traps (sticky traps, light traps, and pheromones) are effective in detecting and capturing insects, it is difficult to estimate insect populations from a trap catch. In some cases insects do not move from their feeding sites on the groundnuts so they cannot be trapped.

To estimate the loss caused to groundnuts in storage by insects, it is not practical to examine every bag or pod. Instead, it is recommended that damage be assessed from a representative sample from the lot. Since insect infestations are not uniform or even randomly distributed within a storage facility, a sample that gives a true indication of infestation or loss must be used to ensure appropriate evaluation.

In a large storage facility, the condition of storage may vary among the sacks; for example, the temperature at the center of the stack may differ from the surface of the stack. These differences need to be taken into account by following a stratified sampling procedure. To make it easy and effective, the division of a single stack into a number of layers, each containing the same number of sacks will help in drawing representative samples. In a given number of sacks in each layer, samples must be drawn at random without bias. See Figure 4.2.

Figure 4.2 Sampling procedure in each layer of stack



Source: Rao, Rao, & Nigam (2010)

If there are ten sacks or less, sample each sack. If there are 11 to 100 sacks, sample 10 sacks at random. To obtain a representative sample, the stack must be dismantled, which will involve disturbing the normal insect movement in the storage facility. When stacks are broken down while sampling, the sacks should be replaced in their original position, so that the disturbance within the stack is minimum. If the samples are taken only from the most accessible sacks, the measurement of pest damage represents only that part, and not the entire stock (Rao, Rao, & Nigam, 2010).

4.8.3 Prevention of infestation

<u>Commercial storage</u>: Good warehouse management and hygiene are key to preventing insect infestation in stored groundnuts. Groundnuts must be processed properly after harvest and dried to bring the seed moisture level below 7%. Before shifting groundnuts to a storage facility, they should be thoroughly cleaned and free from crop residues. If old gunny sacks are used they should be checked first for any infestation before filling them with newly harvested groundnuts. The filled sacks should be placed on wooden pallets away from the facility walls to protect them from moisture from the ground and to provide proper ventilation around the stacks.

<u>Pod storage</u>: Insect pests that attack groundnuts after harvest prefer kernels as they are unable to infest intact pods. Keeping groundnuts in pods for as long as possible is an effective strategy in limiting pest damage

<u>Kernel storage</u>: Groundnuts are sometimes stored as kernels to economize storage space, to reduce transportation costs, and for export purposes. Groundnuts meant for confectionary use are often shelled soon after harvest so that the damaged and shriveled kernels can be discarded. Applying any insecticide to kernels is discouraged because of possible residues in the kernel if not used for seed (Rao, Rao, & Nigam, 2010).

4.8.4 Infestation management

On farms groundnuts are often stored as pods and it may not be possible for smallholder farmers to provide high quality storage conditions. In such cases, pods should be stored in polythene lined gunny sacks or in some other safe storage structures (e.g. small seed bins, earthen pots, or metal drums) in a well-ventilated and rodent free room. For example, in Asia well dried pods are stored in earthen pots of 20-25 kg capacity lined with dried banana leaves. The top of the container is filled with a thin layer (one cm depth) of rice and then sealed with mud. This facilitates effective storage against insect pests without affecting the groundnuts' viability. See Figure 4.3.

Figure 4.3 Ceramic pot used for groundnut storage in Vietnam

Source: Rao, Rao, & Nigam (2010)

Only undamaged, well-dried clean pods should be stored to avoid fungal and insect attacks. After 2–3 days of drying in the field, in exceptionally high temperatures (40-45°C./104°-113°F.) at the time of harvest, the pods should be stripped immediately and dried under shade to maintain seed viability for a longer period.

Storage containers should be thoroughly cleaned and exposed to sunlight for a couple of days before storing groundnuts.

Storing groundnut kernels with dried neem leaves (about 500 grams of leaves for every 10 kilos of kernels) in any sealed container can be effective against some pests (Rao, Rao, & Nigam, 2010).

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