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Review

Overview of groundnuts research in Uganda: Past, present and future

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The Groundnut Department at National Semi-Arid Research Resources Institute (NaSARRI) is mandated to conduct research on groundnuts (*Arachis hypogaea* L) in Uganda. It undertakes research aimed at cultivar development, maintenance and conservation through germplasm collection, characterization, evaluation, breeding, maintenance and generation of appropriate crop management technologies for sustained production. Most of the varieties traditionally grown by farmers in Uganda are landraces adapted more for survival than yield. Yields from such varieties average 800 kg/ha of dry pods yet yields of 3,000kg/ha have been achieved from on-station plots. Yields per hectare are low, because of a combination of factors such as unreliable rains, mostly non-irrigated cultures, traditional small-scale farming with little mechanization, outbreaks of pest infestations and diseases, the use of low-yielding seed varieties and increased and/or continued cultivation on marginal land. Political instability and the frequently unsupportive oilseed policies have also played their role in low groundnut productivity. Therefore, there is excellent potential for yield improvement. Research efforts have, since the 1920s, endeavored to breed varieties that are high yielding, resistant to major pests and diseases, tolerant to drought, high in oil content and have a short to medium maturity period, as well as to develop appropriate production packages. These efforts have resulted in the release of 14 varieties, the most recent being Igola-1, Serenut 1R, Serenut 2T, Serenut 3R and Serenut 4T. These varieties have helped to alleviate some of the production problems listed above. However, the market and field stability of those varieties, in light of emerging stresses, calls for continuous research while at the same time keeping crop improvement, quality and safety linked to practical applications. Emerging issues like aflatoxin, leafminers and biotechnology need to be addressed and incorporated into the research agenda. Deployment of novel breeding approaches like molecular breeding to complement conventional breeding would increase the efficiency of cultivar development. Additionally, to maintain or increase market share, producers and exporters need to adapt the type of groundnuts being cultivated to consumer requirements.

Key words: *Arachis,* Breeding NaSARRI, Uganda,

IMPORTANCE OF GROUNDNUT IN THE NATIONAL ECONOMY

Groundnut (*Arachis hypogaea* L.), also known as peanut, is the second most important legume after beans (*Phaseolus vulgaris L.*) in Uganda. The traditional groundnut varieties are of the red Valencia type, but of a very mixed nature ranging from large seeded manyema group e.g. Roxo to small seeded group e.g. Red Beauty (Busolo-Bulafu, 2004). In 2005, Uganda produced 140,000 metric tons of groundnuts from 250,000 ha with most of the crop being grown in the eastern and northern part of the country (Kaaya and Warren, 2005). Groundnut seeds contain 40 - 50% fat, 20 - 50% protein and 10 - 20% carbohydrate depending on the variety. With the costs of animal protein becoming increasingly prohibitive, groundnut is becoming an even more important source of protein. Groundnut seeds are also a nutritional source of vitamin E, niacin, falacin, calcium, phosphorus, magnesium,

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zinc, iron, riboflavin, thiamine and potassium (Savage and Keenan, 1994). A pound of groundnuts is 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 (Woodroof, 1983). Groundnut is consumed raw, roasted, blanched, as peanut butter, crushed and mixed with traditional dishes as a sauce or as *binyebwa,* a cooked paste. Groundnut is an excellent source of oil for cooking and groundnut cake and haulms (straw, stems) are commonly used as animal feed. Groundnuts thrive under low rainfall and as a legume; groundnuts improve soil fertility by fixing nitrogen. Therefore, the crop generally requires few inputs, making it appropriate for cultivation in low-input agriculture by smallholding farmers (Smartt, 1994). As a cash crop, it gives relatively high returns for limited land area and is well adapted to the hot, semi-arid conditions of Uganda. These multiple uses of groundnut make it an excellent cash crop for domestic markets as well as for foreign trade.

The returns for groundnuts greatly surpass those reported for soybeans and are less uncertain than those of sunflower (Laker-Ojok, 1996). A number of factors contribute to this. First, the area planted in groundnut far exceeds that of soybeans and sunflower. This increases the potential for large scale national benefits. Secondly, the markets for groundnuts are better established. Groundnuts are highly valued on the domestic market and its export market has been flourishing in recent years. Uganda can therefore save a lot of foreign exchange from the imports of sunflower and soybean vegetable oils if it can turn to wide scale oil extraction from groundnuts. Currently, vegetable oil extraction is mainly from sunflower yet groundnut is the most established oil crop and its production is continually increasing at a rate higher than all the other oil crops (sunflower, soybean and sesame).

HISTORY OF GROUNDNUT RESEARCH IN UGANDA

Groundnut is thought to have been introduced in Uganda by early traders and travelers around 1862 after its introduction into East Africa by Portuguese explorers (Tiley, 1972; Nalyongo and Emeetai-Areke, 1987). This was followed by slow spread and adoption of this new crop since there was scant knowledge on its production and utilization. Research on groundnut in Uganda started at Serere in 1930 with the collection of landraces and introductions followed by agronomic studies. The variety then grown was the pale-kernelled spreading type known under various local names (Itesot/Amasoga) at the time and has been grown ever since (Busolo- Bulafu, 1990). This landrace is still maintained by few farmers in Eastern Uganda (Teso and Busoga region). It is long term, low yielding, very susceptible to rosette, difficult to harvest by hand (needs digging by hoe) and the kernel colour is not preferred in the market. Groundnut is a very popular crop, especially in the Eastern and Northern regions of the country where it has become part of the people's culture (Mahmoud et al., 1991).

More recently, there is considerable concern over the apparent instability and decline in per capita production of groundnut over the past 30 years (Seruyange, 1991; Serunkuma et al., 1993). According to the Ministry of Agriculture statistics, the area planted in groundnut fell gradually during the early 1970s, followed by a dramatic collapse during the 1979 war that ousted Idi Amin's government. The situation worsened after the only operating seed company -The Uganda Seed project had its stores, equipment and records looted in 1979. Research activities came to a standstill and breeder seed could not be provided to the seed project. The Uganda Seed Project continued to multiply a limited quantity of certified seeds from contract farmers, but seed quality deteriorated rapidly as inspections and other quality control activities were suspended. This resulted in an overall decline in production of 8.8% per annum for the 1970 - 1980 period. The political instability in the Luwero Triangle in Central Uganda (1980 - 1985) led to the destruction of the Seed Scheme headquarters at Kawanda Research Station (10 km North of Kampala City in Central Uganda) with the eventual abandonment of the station in 1985. This seriously delayed implementation of the European Economic Community (EEC) project mandated to rehabilitate the Uganda Seed Scheme. While there was a gradual recovery of groundnut production throughout the 1980s, production in 1991 was just over 60% of the peak 1972 level (Figure 1). Even more worrying was the decline in national groundnut yields over the years (Laker-Ojok, 1996). The average national yield of 0.8 t/ha of dried pods was in stark contrast to the 3 t/ha yields reported by ICRISAT (1986) to be typical in developed countries. Yields of over 2.5 t/ha have been achieved in experimental plots, indicating the need for improved field production (Busolo-Bulafu 1990; 2004). Researchers identified the following factors as being major constraints to increased production in Uganda: groundnut rosette disease, early leaf spot (*Cercospora arachidicola* Hori), unreliable rainfall and drought in some areas, lack of high-yielding cultivars, storage diseases and pests.

Before 1960, research concentrated on the collection of local landraces and introduction of cultivars from other countries. In addition, some work was done on spacing and row cropping. Most trials were conducted on Valencia type varieties, but some Virginia and Spanish variety trials were also conducted. Studies on the groundnut rosette disease, a major constraint to groundnut production in Uganda, were started in 1949 (Figure 1). Selections were carried out in the 1950s that resulted in the development of Red Beauty, a Valencia type, which was constituted as a multiline in 1958. In 1963, Anthony Tribe initiated the actual breeding program aimed at

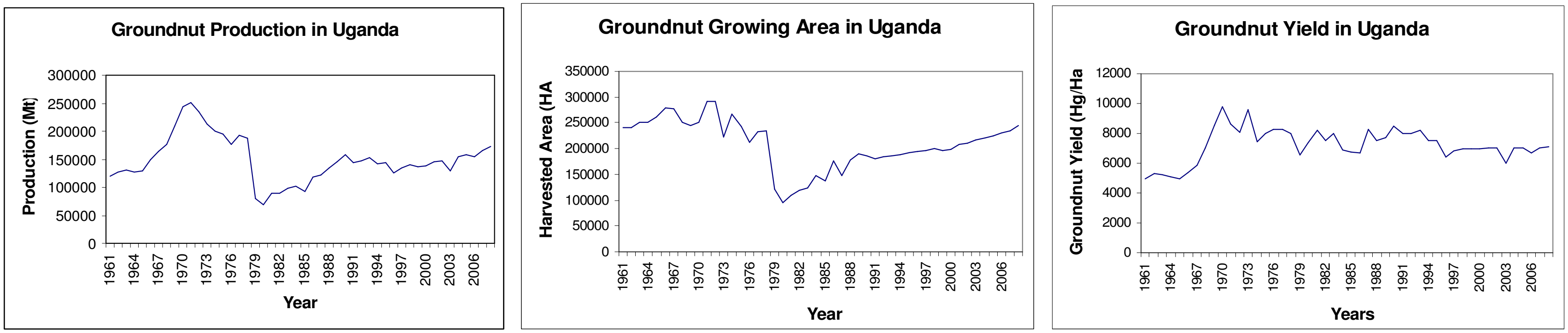

Figure 1. Groundnut (shell) production trend in Uganda 1961-2008. Source: FAO, 2010.

Reference: FAO. 2010. World Geography of Peanuts. Uganda . http://faostat.fao.org/site/567/default.aspx#ancor.

incorporating groundnut rosette resistance with some of the desirable characteristics in existing varieties. The reported objectives of this breeding work were:

1. To assemble and maintain a large germplasm collection to be used as a gene bank in the breeding program.
2. To breed for high yielding and “better quality” ground-nuts. Desired qualities listed included:

a) High oil content for crushing.
b) Large plump, tan kernels for confectionery.
c) Early maturing varieties.
d) Adaptability to a wide range of climate and edaphic conditions.

3. To develop disease and pest resistant varieties.

By 1976, the collection assembled at Serere had reached 900 accessions, the largest in East Africa, but by 1990 had fallen to only 350 due to civil strife. The following varieties were officially released by the Ministry of Agriculture and were multiplied commercially at least briefly: Red Beauty, Roxo, Manipintar and Makulu Red. Red Beauty (B1), selected at Serere Research Station from among 15 local cultivars, was the variety most extensively produced by the Uganda Seed Scheme. The characteristics of these released varieties are presented in Table 1. Three additional varieties, 710 (Brazil), 534(Venezuela) and Congo Red (Israel) were recommended for release in 1983, but no action was taken. Of the released varieties only Red Beauty and Roxo are being actively maintained by the research program. Furthermore, out of the 9 varieties, only Roxo was included in the variety trials conducted under the World Bank-funded research programme under International Funds for Agricultural Development (IFAD). Between 1983 and 1987 ICRISAT India was germplasm source and a lot of materials were under evaluation until the insurgents destroyed trials and looted the germplasm bringing the research to halt. Groundnut department and Staff were shifted from NaSARRI Serere to National Crop Resources Research Institute (NaCRRI) Namulonge (located 30 km North East of Kampala City in Central Uganda). In 1990, ICRISAT established a regional center at Chitedze, Malawi. This became the source for NaSARRI Serere germplasm up to now. The immediate objective was introduction of advanced breeding lines for fast evaluation and release. This led to the release of the Serenut 1R, Serenut 2, Serenut 3R and Serenut 4T as a short term goal. We have made crosses among these introductions, cultivars and landraces and generated our local adapted line. This hybridization is routine agenda in our breeding plan as along term sustainable groundnut improvement goal at NaSARRI Serere. However, maintenance and evaluation of germplasm introductions from ICRISAT is ongoing and we are members of the regional ICRISAT groundnut germplasm trials benefiting from any new groundnut technology developed.

PRESENT RESEARCH PROGRAM

Presently, groundnut research efforts at the National Semi-Arid Research Resources Institute (NaSARRI) is focused on providing clients with

Table 1. The Characteristics of Groundnut Varieties Released in Uganda between 1966 - 2002.

Variety	Maturity (days)	Yield (kg/ha)	Year of release	Other remarks
Red Beauty[1]	90 - 100	1900 - 2500	1966	Multiline of Red Valencia
Acholi white[1]	80 - 90	1900 - 2500	1966	Valencia
Roxo[1]	100 - 110	2000 - 2700	1969	Red Manyema, Venezuela
Tatu[1]	100 - 110	1900 - 2400	1969	Spanish
Manipintar[1]	110 - 120	2600 - 3600	1969	Virginia
Bukene[1]	90 - 100	1800 - 2600	1970	Spanish
Mwituude[1]	100 - 110	2000 - 2400	1970	Virginia
Makulu Red[1]	110 - 120	2000 - 2800	1970	Virginia
Amasoga[1]	110 - 120	1800 - 2300	NA	Local
Igola - 1[2]	125 - 130	3000 - 3500	1995	Virginia
Serenut 1R[2]	100 - 110	2500 - 3700	1998	Virginia, Red Seeded
Serenut 2[2]	100 - 110	2500 - 3500	1998	Virginia, Tan
Serenut 3R[2]	90 - 100	2500 - 2900	2002	Spanish, Red Seeded
Serenut 4T[2]	90 - 100	2500 - 2900	2002	Spanish, Tan

Sources: [1]Undated memo report entitled, "Groundnut Improvement Programme, Serere." Apparently post-1982.
[2:] NaSARRI Groundnut Breeding Department. NA = information not available.

varieties with high yielding potential, high quality, resistance to major pests and diseases, short to medium term maturity periods and tolerance todrought, together with improved production packages (Busolo-Bulafu, 2004). Specifically the groundnut breeding programme continuously breeds for varieties with resistance to rosette and Cercospora leafspots, large seeds for confectionery purposes, high oil content for oil extraction, tolerant to drought, short to medium maturity as well as development of improved agronomic practices that are feasible and economically viable. This is mainly done through evaluation of advanced ICRISAT germ-plasm introductions for generation of short-to-medium maturing resistant varieties in addition to limited hybridi-zation for future cultivars and lines. Uganda is particularly endowed by having three known rosette hotspots at on station NaSARRI in Serere (Soroti), Nakabango (Jinja) and Iki-Iki (Pallisa). These hotpots areas are becoming a regional hub for testing advanced lines and parentals for rosette resistance in the SubSaharan Africa. In addition to these varietal developments, research also develops production, harvesting, drying processing packages that will maintain the full potential of inherent characteristics bred into new varieties. Through genetic improvement, selection and multi-locational testing across different ecological zones, a number of additional varieties have been released. These varieties are superior in various attributes, which have contributed to their better productivity, such as disease resistance to groundnut rosette, early maturity and high yield. Table 1 shows varieties released since 1966.

Serere Agricultural Research Station (currently known as National Semi-Arid Resources Research Institute-NaSARRI), serving the generally drier and less fertile short grass areas north and east of the River Nile, is located about 350 km northeast of Kampala and 30 km southwest of Soroti.

PRODUCTION ENVIRONMENT

Groundnut is grown mainly in the Northern, Eastern and Southern parts of the country although the eastern region has the highest production volume. In the North and Eastern Uganda groundnut is produced mainly on light, loose and sandy loams, but in Southern Uganda it is also grown in clay loams. In Uganda, groundnuts are primarily grown as a rain-fed crop. In the Southern region which has two rainy seasons, the crop is grown during both the rainy seasons, with most of the production done during the first rainy season. The first rain crop is harvested during dry periods in July and the second crop is harvested in the November - December dry season. The first rainy season, which lasts from March to June, has more reliable rain than the second rainy season lasting from August to September. Most of the crop is grown as inter-crop with maize and cassava. While both bunchy and spreading types are grown, recently there is more of a tendency to grow bunchy types because they are usually early maturing and because they are easier to harvest (Nalyongo and Emeetai-Areke, 1987). In Uganda, groundnuts are primarily grown by small scale farmers.

PRODUCTION CONSTRAINTS

Groundnut production in Uganda fluctuated greatly over the last decade and yields per hectare are low. Groundnut production in the country is constrained by various factors such as:

Low level of inputs

As groundnut is grown mostly by small-scale farmers, the production is limited by low levels of inputs. For example, national fertilizer consumption fell from 1.4 kg/ha in the 1960s to 0.2 kg/ha in the 1990s (Laker-Ojok, 1996). The figure has dropped even more as a result of the insurgency (between 1986 up to now) in the major groundnut production regions (Figure 1). With such low levels of inputs used by farmers, the potential yields often recorded on station are never realized on farm.

Pests and diseases

Groundnuts are exposed to pests and diseases that reduce yield and quality and increase the cost of production wherever the crop is grown. Major diseases in Uganda include rosette, early leaf spot (*C. arachidicola*), late leaf spot (*Phaeoisariopis personata*), Rusts (*Puccinia arachids*) and aflatoxin (caused by *Aspergillus niger*, *Aspergillus flavus*). Important pests are aphids (*Aphis craccivora* Koch vectors of groundnut rosette disease, leafminer (*Aproarema modicella* Deventer), thrips (*Thrips palmi* Karny, *Frankiniella schultzie* Trybom, *Scirtothrips dorsalis* Hood and *Caliothrips indicus) and* termites (Isoptera). Thrips and aphids are considered more important as vectors of viruses than as causing direct damage to groundnut. The groundnut leaf miner (*A. modicella* Deventer), a defoliator from the order Lepidoptera, has become an important pest on groundnut in the major groundnut producing regions in Uganda (Mukankusi et al., 2000). These pests can be held to tolerable levels if the growers can employ Integrated Pest Management (IPM) involving a combination of cultural practices, management techniques and pesticides. If well employed, IPM is likely to lower costs, keep pests below economically damaging levels and provide growers with greater profit.

Rainfall or soil moisture

Rainfall is the most significant climatic factor affecting groundnut production, as 70% of the crop area is under semi-arid tropics characterized by low and erratic rainfall. Low rainfall and prolonged dry spells during the crop growth period were reported to be main reasons for low average yields in most of the regions of Asia and Africa (Camberlin and Diop, 1999; Reddy et al., 2003).

Seed supply

The groundnut seed sector is faced with many constraints; primarily limited supply of breeder seed, poor seed quality control, poor demand estimation and inadequate distribution systems (Okello and Nalyongo, 2007). Secondary constraints include the often long testing process before a new variety is released and registered, limited consideration of farmers' preferences in variety development and lack of established grades and standards. Physical factors also constrain seed supply such as: groundnut has a low seed multiplication rate, seed is delicate, bulky, sensitive to heat and moisture and susceptible to pest attack. Thus, seed production, storage and quality control pose problems at all stages of the seed production chain.

Sustainability of research funding

Macro-level constraints on the productivity and sustainability of the research system have not yet been fully overcome. The Ugandan government's inability to raise sufficient revenues to timely finance an adequate programme of investment in the agricultural sector leaves the fate of agricultural research largely in the unpredictable hands of donors. Perhaps most corrosive to research productivity has been the uncertainty and lack of control over operating funds. It is very difficult for researchers to develop and implement an efficient and productive research program under such conditions. Continuity of funding is absolutely essential to the achievement of the research impact predicted by the return to research.

Political instability

As a result of political instability and poor macroeconomic policies from 1972-86, Uganda underwent a dramatic reversal of the agricultural and structural transformation process it had achieved in the 1960s. By the time Uganda opened up again to the international community, its economy was on the verge of total collapse and it had suffered a near total breakdown of agricultural research, seed multiplication, output markets, input distribution networks and extension services. National fertilizer consumption fell from 1.4 kg/ha in the 1960s to 0.2 kg/ha in the 1990s. Worse, many productivity enhancing technologies fell into disuse during this period, leaving Ugandan yields much lower than those of other developing countries with similar agroecologies. Farmers in Eastern and Northern Uganda, where animal traction had been well established for 50 years, suffered tremendous losses of livestock as a result of the political instability and were suddenly forced back into hand hoe cultivation. The result has been a vicious circle of low input/low productivity agriculture that has proved very difficult to break. Much of the groundnut germplasm and research results were lost or destroyed during the political insecurity in Northern and Eastern Uganda between 1987 - 1989 (Laker-Ojok, 1996).

Breeding methods used to curb the constraints

Groundnut/Peanut 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 (Coffelt, 1989). The groundnut breeding department at NaSARRI applies conventional breeding techniques deploying Pure line Selection, Mass Selection, Pedigree Breeding, Single Seed Descent and Backcross Breeding methods. Biotechnology and genomic breeding techniques are not yet used.

Sources of germplasm

The bulk of the breeding materials (Over 90%) come from International Center for Research in Semi-Arid Tropics (ICRISAT). We have recently received seventy five core collection accession of Valencia from U.S.A. Landraces reflecting the cultural identity of the people and harbouring a diversity of traits that is of interest for future breeding work, as well as for developing new farming systems and products have largely been excluded in earlier breeding goals. This probably explains why some farmers are still growing these landraces despite various options from recently released improved varieties. Landraces still widely grown includes Acholi white (best for peanut butter and sauce) and Gwerinut (confectionery type).

EMERGING ISSUES

Diseases

Some diseases not previously addressed are now requiring immediate attention, the most notable are *A. niger* and *A. flavus* infections, which result in aflatoxin contamination and Sclerotinia blight (*Sclerotinia minor* Jagger). Aflatoxins are of economic and health importance because of their extreme toxicity and because they are one of the most carcinogenic compounds known. Depending on environmental conditions (e.g. drought), groundnut can become particularly susceptible to *Aspergillus*, resulting in aflatoxin contaminated groundnut, which is used for human consumption and animal feeds

Pests

The most important pest threatening groundnut production in Uganda is groundnut leaf miner (*A. modicella* Deventer), a defoliator from the order Lepidoptera. The hosts of this leafminer are primarily legumes and groundnut and soybean are among its most important crop hosts. Populations of leafminers increase during the rainy season and may become severe pests during the pod-filling stage. Problems caused by this pest may intensify when groundnut production extends beyond the rainy season into the dry season. Moths then move from fields with mature plants to fields with immature plants, which are particularly susceptible to damage by this species (Kokalis-Burelle et al., 1997). In Uganda, it was first reported in Kumi in 1997 then later in the Eastern and Northern districts of Apac, Lira, Kumi, Pallisa and Soroti. Presently, groundnut leaf miner is well established in Kumi and Soroti districts, where it occasionally reaches epidemic levels in Kumi. This species has only been reported before in Southern Africa and Southeast Asia. It is regarded the most serious pest of groundnuts in India (Kokalis-Burelle et al., 1997). As far as can be ascertained, this is the first record of this species in Africa, although there have been recent reports of Groundnut Leaf Miner appearing in Malawi in April 2000 and in South Africa in 2002 (Epieru, 2004). In Uganda, total crop losses have been reported by some farmers. No resistant variety is yet available in Uganda. The recommended chemical control is too expensive for the resource poor farmers. There is need for research into the role of natural enemies, cultural practices, use of pesticides and resistant breeding. There is also need to educate farmers about this pest since it’s new in the Ugandan cropping systems.

Drought

Drought is a complex problem involving three main factors, timing, intensity and duration of water deficit, all of which vary widely in nature. Drought is an inevitable recurring feature of world agriculture and despite improved ability to predict their onset and modify their impact, drought still remains a major abiotic stress that poses a threat to agricultural production in many parts of the world (Nigam et al., 2005; Altmann, 1999). The unpredictability of drought implies that improved groundnut genotypes should perform well not only under water limited conditions, but also when rainfall is adequate. Groundnut plants cope with drought through escape (by having appropriate phonologies to fit the most appropriate growing season e.g. earliness), avoidance (lessen evaporatory water loss or increased water uptake through deeper and more extensive root system) and tolerance (maintaining cell turgor or enhancing cellular constituents that protects cytoplasmic proteins and membrane from desiccation) where most other food legumes will not produce a crop (Holbrook and Stalker, 2003; Maarten and David, 2003; Specht et al., 1986). However, insufficient water at the time of flowering and fruiting will significantly reduce yield. Breeding for drought tolerance is most durable and sought after mechanism in mitigating drought stress in groundnuts. With the ever changing weather patterns, more attention will be focused on drought tolerance.

Participatory plant breeding

Participatory plant breeding (PPB) that is, a breeding process in which farmers and plant breeders jointly select cultivars from early segregating populations under target environment, should become a permanent feature of formal breeding programs. The fundamental rationale for PPB program is that joint efforts can deliver more than when each participant works alone. Previous research efforts are characterised by lack of adoption and uptake of technologies developed by researchers alone. This participatory approach provides for stakeholders consultation and participation in technology development and dissemination. Participatory plant breeding improves with time, in the sense that through their continuous interaction, scientists and farmers know each other better and better and the increased understandings of each other's skills, interests, motivations, problems, limitations translate into a gradually more equitable collaboration. Participatory plant breeding should however, be linked both with the formal breeding system which can provide a continuous flow of novel genetic variability and with the informal seed supply system which can spread new varieties in the farmers communities without the unnecessary requirements of the formal seed system.

OUTLOOK, RECOMMENDATION AND CONCLUSION

Future work will continue to seek early maturity and resistance to pests and diseases. Because of changing weather patterns, attention will also be focused on drought tolerance. Interest has been expressed by some organizations, such as IDEA, in confectionery groundnuts for export. Therefore, suitable varieties will be identified from the existing stock, germplasm from U.S.A., as well as from the ICRISAT collection. The requirements of the confectionery trade include: large, bold seeds of uniform shape and size and usually, but not necessarily, tan coloured. Other future goals in groundnut breeding activities will include:

Vegetable oil production

Uganda once had a vibrant private sector driven edible oil industry. The economic turmoil of the 1970s and '80s however brought the sub-sector to its knees. With the right macro-economic policies now in place, the sub-sector has made a huge turn around. The edible oil industry is now one of the leading sustainers of the 6% annual economic growth rate Uganda has enjoyed for the last fifteen years. Uganda's demand for vegetable cooking oil is growing at a rate of 3% per annum. The national demand for edible oil was projected at 80,000 MT in 2005 up from 42,000 in 1999. National production stands at 16,000 MT making Uganda a net importer of edible oil. More importantly, Uganda's central location in the East and Central Africa region makes the country a good springboard to the Common Market for Eastern and Southern Africa (COMESA) market with population estimate of 370 million people. Presently, sunflower is the major source of vegetable oil in Uganda. Other sources of locally produced vegetable oil will be required if the present drain on the country's foreign exchange resources for vegetable oil imports is to be substantially reduced. The cost of imports and the risks associated with imports through another country, make domestic vegetable oil production an attractive alternative. Better still; the return to research on groundnut far outweighs that of soybean and sunflower. Research in groundnut technologies for oil extraction need to be supported.

Embracing biotechnology and genomics in groundnut breeding

During the next decade, traditional breeding approaches will be greatly aided by DNA marker selection enabling rapid generation of new cultivars for the small landholders in Africa and across the developing world. Innovative plant breeders are changing their *modus operandi* in order to develop objective marker assisted introgression and selection methods that increase the efficiency of their genetic improvement programmes and allow them to address new goals. To achieve success in this new endeavor, cheap, easy, decentralized and rapid marker screening procedures will be required. Uganda is among the 27 African countries that have ratified the Cartagena Protocol on Biosafety to date. In 2004, the Uganda Government allowed the introduction of GM products for food consumption only. The Uganda National council for Science and Technology, the branch of government in charge of Biosafety issues has drafted National Bio-safety Regulations and Guidelines that would regulate both research into GM crops and the release of GM organisms. This document has been submitted to the cabinet, prior to being voted on in parliament. Both physical and human capacity in biotechnology and genomics is urgently needed for leverage in international peanut research and development. Additionally, Uganda needs to have Biosafety laws, intellectual property right (IPR) laws and breeders' rights in place if it is to benefit from the global peanut genome initiative research and international drive to enhance groundnut productivity, crop protection and product quality through genetics and molecular biology. This is true in the light that:

a) Some of the materials to be exchanged with global partners have patent rights and many of the gene sequences and tools required for producing transgenic plants are subject to patents owned by industry.

b) Some of the genetic resources required to mitigate peanut production and utility constraints are transgenics.

c) Additionally, since the Convention on Biological Diversity in 1993, international seed exchange has become significantly more tedious and restricted (Williams and Williams, 2001). Germplasm obtained prior to 1993 at the CGIAR Centers, including ICRISAT which has a mandate to preserve *Arachis* genetic resources, is freely available; but germplasm obtained since then is subject to the terms of the Convention on Biological Diversity requiring stringent Material transfer agreements.

The government of Uganda has developed the national biotechnology and biosafety policy in line with principles and objectives of other related policies that provide for promotion of research, development and application of science and technology for national development. The Uganda National Council for Science and Technology (UNCST), as the lead national co-ordinating agency for science and technology development in the country initiated this Biotechnology and Biosafety policy formulation process in the year 2002. Guidelines for conducting research involving genetic modification both at laboratory and confined field trial level have been developed: Confined field trial Guidelines developed in 2006 and Guidelines for Containment with Genetically modified organisms and microbes were developed in 2007. Crops that have undergone containment studies include banana and cotton. Currently, there is no clear demarcation of stakeholder and sectoral roles in the development and application of modern biotechnology. The efforts in research and development are fragmented and in the interest of individual funders. The definition of government agencies that are supposed to address the concerns of the stakeholders and the public in the development and application of modern Biotechnology is not clear. Inter and intra-institutional linkages in the areas of biotechnology training, research, product development and commercialization in Uganda are currently weak. This policy therefore, provides an implementation framework that defines responsibilities of different agencies at the national level (Rou, 2008).

Broadening germplasm base through judicious hybridization of contrasting donors/parents

Trait mining and introgression from wild relatives

We are fortunate to be living at a time when genetic engineering holds much promise for modifying crop performance. However, most of the advances thus far in genetic engineering have been directed toward traits other than yield, largely because of the complexity of this trait. The wide repertoire of genetic variants created and selected by nature over hundreds of millions of years is contained in our germplasm banks in the form of exotic accessions. More than 50 years ago (Tanksley and McCouch, 1997) predicted the value to agriculture of collecting and maintaining the wild relatives of crop plants in gene banks. Owing to the advent of molecular mapping and the ability to scan the genomes of wild and cultivated species for new and useful genes, we may now be in a position to unlock the genetic potential of our wild and cultivated peanut germplasm resources for the benefit of society (Tanksley and McCouch, 1997). Although there is considerable morphological, biochemical, physiological diversity among varieties and land races of groundnuts, genetic diversity and variability for some important traits of agronomic interest are low. The lack of variability at the genetic level is often cited as one of the reasons for little progress in genetic enhancement of the crop (Suvendu, et al., 2007; Norden et al., 1982). The low level of polymorphic variation in cultivated groundnut (*A. hypogaea* L.) is attributed to its origin from a single polyploidization event that occurred relatively recently on an evolutionary time scale. The resultant amphidiploid, viz. an allotetraploid plant (with two different genomes that behaves genetically as if two separate diploids are in the same cell) would have had hybrid vigor, but be reproductively isolated from the wild relatives (Dwivedi et al., 2007; Suvendu, et al., 2007; Kochert et al., 1996; Young et al., 1996; Pattee and Young, 1982). This evolutionary event that gave rise to *A. hypogaea* imposed a severe genetic bottleneck at the origin of the crop and the genetic diversity in cultivated germplasm today results from some 4,000 years of mutation and selection (Dwivedi et al., 2007). In addition, a second genetic bottleneck has been imposed by modern breeding programmes, which so far have used only a tiny fraction of the variation within *A. hypogaea* (Upadhyaya et al., 2002). In crosses between wild and cultivated groundnuts, alleles that were “left behind” during the domestication process may be reintroduced into the cultivated gene pool (McCouch, 2004).

This infusion of new genes could renew and invigorate modern groundnut cultivars in surprising and interesting ways. It is not uncommon for some of the inbred progenies derived from these crosses to perform better than the better parent (Frey et al., 1975; Rick 1976, Tanksley and McCouch, 1997). Current cultivars therefore have a very narrow genetic base and the allelic combinations available from working with elite germplasm are limited, hence the urgent need to broaden the genetic base of the cultivated peanut germplasm through incorporation of germplasm into breeding programmes. The reproductive isolation of cultivated groundnuts from their wild relatives has frustrated such work. In order to surmount reproductive barriers, the species *A. hypogaea* needs to be resynthesized from wild species, in a way that mimics the original speciation event as closely as possible. New peanut varieties incorporating wild *Arachis* genes will have improved resistances to biotic stresses and tolerance to abiotic stresses together with allelic combinations for enhanced yield potential and increased quality profiles that would never have been possible through conventional approaches.

Creation of genebank to house diverse accessions

Germplasm banks-living seed collections that serve as repositories of genetic variation-need to be established as a source of genes for improving groundnuts and future conservation. Wild relatives and early landrace varieties have long been recognized as the essential pool of genetic variation that will drive the future of plant improvement (Bessey, 1906; Burbank, 1914). Early plant collections made by people such as Nikolai Vavilov (1887-1943) or Jack Harlan (1917 - 1998) inspired the international community to establish long-term collections of plant genetic resources that provide modern plant breeders with the material they need to creatively address the challenges of today (McCouch, 2004). Uganda Government therefore, needs to invest in a functional genebank for the future of groundnut and Agriculture for the country in general.

Increased aflatoxin research

Information on the impact of aflatoxin on health status of humans and animals in Uganda is inadequate (Kaaya and Warren, 2005). Aflatoxins, toxic metabolites of *A. flavus* and *Aspergillus parasiticus* fungi, are naturally occurring contaminants of food (Pettit and Taber, 1973; Griffin and Garren, 1974) and are associated with both acute and chronic toxicity in animals and humans including acute liver damage, liver cirrhosis, induction of tumor and teratogenic effects (Samuels, 1984; Stolof, 1985). Toxicity of groundnuts also lowers market value (Abdalla et al., 2005). Hence, it is a problem to groundnut producers as well as consumers. Liver cancer and Hepatitis B virus cases are on the increase in the country especially among the immuno-compromised patients and the underlying causes have not been studied adequately, yet aflatoxins have been strongly implicated in these health conditions elsewhere in the world (Williams et al., 2004). Aflatoxin content of food has been associated with hepatoma (liver cancer) frequency in Uganda (Kaaya and Warren, 2005). No strategies for controlling aflatoxin contamination of food and food products in Uganda have been reported. At the moment, the established standards on aflatoxin contamination of food in Uganda are based on Kenyan standards, not on the actual aflatoxin content in Ugandan foods. Susceptible produce like groundnuts are not visually inspected by qualified personnel at buying points to separate good quality produce from contaminated produce. Thus, when the produce reaches the retail markets, sorting may be done, but contaminated produce is sold to unsuspecting consumers at low prices (Kaaya and Warren, 2005). There is need for full participation of government through the Ministries of Health (MOH) and that of Agriculture, Animal Industry and Fisheries (MAAIF) together with the Uganda National Bureau of Standards (UNBS) to put into practice regulations for monitoring susceptible produce from buying points to retail markets. Strict appropriate post-harvest measures for drying, sorting, packaging, storage and proper handling of produce should be introduced and monitored. Adaptive research in the area of quantification of contamination levels, management and elimination urgently need to be supported

Bridging the gaps between conventional breeders and molecular biologists through:

1. Collaborative research.
2. Routine training of conventional breeders in novel tools in molecular biology/genetics.
3. Deployment of routine Marker assisted introgression in breeding programmes.

The new tools of molecular biology/ genetics enable researchers to understand better and faster the full potential of the genetic potential of a crop, to preserve this genetic heritage and to develop improved plant materials. The identification, isolation and cloning of new genes controlling specific characteristics will also facilitate the development of a more stable, diversified germplasm with improved resistance to diseases and pests, stress tolerance, better food quality and higher productivity.

Exploring novel industrial uses of groundnuts

Groundnut is rich in protein, oils, minerals (calcium, magnesium, phosphorous and potassium) and vitamins (E, K and B1) (Savage and Keenan, 1994). The American and some Western diets are highly fortified with essential nutrients to provide nourishment to the consuming public. However, it is known that certain nutrients are more readily absorbed in natural form than as supplements. On the basis of this information, it is recommended that groundnut be bioengineered to contain appreciable quantities of the following nutrients (folate, flavanoids, sterols, vitamin A, arginine and vitamin E).

Groundnuts are high in protein but much of it is not digestible. It is thought that biotechnology holds the key to unlock this door and making groundnut protein more useable.

Another area of novel use of groundnut is in biodiesel. With the rapid depletion of fossil fuels, environment impacts of using fossil fuel and potential health hazards there is a need to develop environment friendly forms of fuels from renewable resources. Groundnut oil is one such option for being explored for biodiesel by increasing its oil concentration plus higher oleic acid (BBC, 2007; USDA, 2006). Biodiesel has a lower environmental impact than conventional fuels and can be grown and processed locally.

Enhancement of the above mentioned compounds in groundnut will greatly improve the nutritional and economic value of groundnuts.

Policy and market interventions

There is considerable potential to increase groundnut productivity in Uganda through a strategy that combines technological innovation, policy and institutional reforms and improved support services. Structural adjustment policies have eliminated subsidies on inputs. In some cases, this has reduced market access and worsened production incentives. Mechanisms to allow emerging private sector enterprises to become active stakeholders in the seed industry are urgently needed. It is important to have a clear national policy on seed production so that stakeholders have clearly defined roles. Uptake of improved varieties is hampered by lack of efficient product market. There are large transaction costs in remote villages, where farmers are sparsely distributed. It is critical that farmers have easy access to markets. It is essential to establish sustainable systems driven by the private sector. Development of institutions with clearly defined roles, operating in a flexible legal environment, is likely to increase uptake of new varieties. These institutions could include village-level seed schemes under which more efficient farmers or groups of farmers are encouraged to multiply and sell seed of improved varieties.

Complementarities between the formal and informal seed sectors

Seed is one of the critical inputs in groundnut production. Dissemination of improved seeds to farmers is an efficient way to increase production of the crop in Uganda. Although both the formal and informal seed systems operate side-by-side, the informal seed sector is much more important, supplying the majority of groundnut seed in the country. This situation, which is reflective of low economic activity and lack of professionalism among the operators of the seed sector, can be improved if there is a complement between the formal and informal seed sectors. This will encourage capacity building in the development of technical and entrepreneurial skills and management strategies among stakeholders in groundnut seed production. Support from government agencies, seed companies and non-governmental organizations are needed to create awareness about availability and potentials of improved varieties. The integration of formal and informal seed Systems in Uganda will guarantee improved seed supply to the groundnut farmer.

Awareness campaign targeting business communities

There is need for awareness creation among the groundnut market chain so as to improve the quantity and quality of groundnut for consumption and trade. Farmers, seed producers and distributors, groundnut processors and traders, agricultural credit banks, as well as government officials in charge of agricultural and trade development need to meet to discuss practical ways to improve the quantity and quality of their groundnuts products and to adapt exports to increasingly stringent import market requirements. There is need for increasing exports of edible groundnuts matching end-user needs; implementing integrated aflatoxin management programmes; encouraging regulatory measures to control the flow of contaminated shipments in national and international trade and technical information and training in aflatoxin control and prevention; establishing certified national quality control laboratories, in charge of issuing export quality certificates; promoting exports through market prospecting and generic promotion of national products.

Adding value to groundnuts for exports

This aims at improving income levels of groundnut producers and exporters in the Uganda by encouraging business communities to become more efficient and focus on edible groundnut production for export. The groundnut sector needs to do the following: market development and promotion missions in target import markets and the participation in specialized trade fairs; training in export quality control, management and certification; development of export labeling and generic promotion campaigns for products with specific origins and; technical support to selected enterprises in quality assessment, quality and yield payment systems adapted to specific local conditions, forecast of output and efficient groundnut selection.

Gains in groundnut productivity through research advances in genetic enhancement will help to achieve sustainable food security, poverty alleviation and environmental protection in the semi-arid tropics. Operational genebanks housing diverse accessions of groundnut need to be created soon as this will provide first line of long term defense against biotic and abiotic stresses and house germplasm for future research. The application of the tools of biotechnology offers a new means to achieve this mission in regions where rainfall and biotic stresses are the major constraints for increasing and stabilising groundnut crop productivity. Therefore, there is need to complement conventional breeding with the new molecular tools. Fortification of groundnut with essential nutrients will greatly improve the nutritional image of groundnuts. National Agricultural Research managers therefore need to enforce the issues of Biosafety Laws, Intellectual property rights, Indigenous knowledge rights and Breeders rights to embrace and reward innovative groundnut research.

Abbreviations

ICRISAT, International crops research institute for the semi-arid tropics; **EEC,** European economic community; **IFAD,** international funds for agricultural development; **NaCRRI,** national crop resources research institute; **IPM,** integrated pest management; **PPB,** participatory plant breeding; **IPR,** intellectual property right; **GM,** genetically modified; **UNCST,** Uganda national council for science and technology.

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