Review of pre- and post-harvest pest management for pulses with special reference to East and Southern Africa

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Contents

Executive Summary

Africa produces an estimated 8 million tonnes of grain legume seed from 17.7 million ha (FAO, 2000) accounting for 26.15% of the total global area of production. Nevertheless, production levels in North America and Europe are similar using one third and one fifth of the land area respectively. Legume production in Sub-Saharan Africa is dominated by groundnut (*Arachis hypogaea*), soybean (*Glycine max*) and cowpea (*Vigna unguiculata*) both in terms of area of cultivation and production.

Regional R&D focus on the production of legume crops and development of IPM packages in particular reflects the relative importance of particular legume crops. The International Institute for Tropical Agriculture (IITA) focuses on cowpea in West Africa and the International Centre for Research on the Semi-Arid Tropics (ICRISAT) focusing on pigeonpea in East Africa. Kenya, Malawi, Tanzania and Uganda account for 98% of pigeonpea production and yet the crop has considerable potential for cultivation in the dry savannah of West Africa. There is little emphasis on native legumes such as bambara bean, peas and other minor legumes that are locally important and have desirable triats such as the pest resistance of bamabara bean and yet they are being replaced by pest-susceptible cowpea.

Now some 200 million people in Africa are dependent on cowpea which represents a major source of protein for communities who can not afford animal products. Despite low bean yields, the importance of cowpea should not be underestimated; young leaves, pods and beans are used as fresh vegetables. Trading fresh and processed foods provides income for rural women and crop residues feed large and small ruminants and fertilise the soil. The short duration of legumes and cowpea in particular, make them ideal for cultivation in residual soil moisture after rice cultivation and this practice is promoted by many organisations. The drought hardy nature of deep rooted cowpea varieties enables the crop to be cultivated in semi-desert conditions of the African Sahel. Over 100 pest species have been recorded but their relative impact varies with season and location; heteropterans often cause more economic loss than the pod borer, *Maruca vitrata*, although the latter alone has been reported to cause up to 80% crop. Nevertheless, most recent research has been directed towards control of *M. vitrata*, and in particular development of a transgenic *Bt*-cowpea. While a welcome development, the *Bt* toxins will have no impact on insect pests of other Orders, notably sucking pests and Coleoptera storage pests will be unaffected and general release officially predicted by 2014 would appear to be optimistic given uncertainty about regulatory requirements and the prospect of seed companies having to bear the legal burden of farmer losses.

Conventional IPM technologies such as intercropping have yielded mixed results with little, if any, beneficial impact on pest populations in legume crops. Sex pheromones have been identified for key legume insect pests, notably *S. exempta*, *H. armigera* and *M. vitrata* (Cork, 2004). Although not fully optimised, the pheromone of *M. vitrata* has been successfully disseminated to farmers in Benin for use as an early warning tool of economically important larval damage. Research on floral attractants for attracting female *H. armigera* and *M. Vitrata* is on-going at NRI. A related product for controlling the former species in cotton in Australia has been developed and successfully commercialised (Magnet®) but dependent on a toxicant as the killing agent. Odour-baited traps have considerable potential for monitoring the movement of pest species given that *M. vitrata* is known to migrate northward with rain bearing winds in West Africa. The chemical ecology of a number of bruchid legume stored-product pests has been widely studied, notably *Callosobruchus maculatus*, but to-date the semiochemicals characterised have not been exploited for population monitoring or control.

IITA have developed cowpea varieties that are resistant to aphids, flower thrips and the parasitic weeds, *Striga gesnerioides* and *A. vogelii* and their breeding programme is focused on varieties that meet farmers' requirements for plants that yield significant quantities of fodder and can be grown as intercrops with cereals. FAO set up farmer field schools (FFS) for IPM on cowpea through technical cooperation projects (TCP) in Nigeria and Cameroon to promote a range of storage technologies including triple bagging, drum, ash and solar heating. Similarly, they are establishing a technical secretariat to facilitate communication as well as capacity building by identifying and assisting African scientists.

Natural enemies and parasitoids of *M. vitrata* have been extensively studied and although parasitism is typically less than 50% *Trichogrammatoidea eldanae* is thought to have value for control even in intercrops. Similarly, the recently discovered larval parasitoid *Ceranisus menes* has shown promise in the control of flower thrips *Megalurothrips sjostedti* in West Africa. *Bracon hebetor* has been found to attack *M. vitrata* in India and since the parasitoid can easily be reared on a small-scale there is considerable scope for use in control in areas where high pest pressures are common.

M. vitrata on cowpea, *S.litura* on groundnut and *H.armigera* on chickpea are all amenable to control with either *Bt* or viral biopesticides. In addition sucking pests such as *C. tomentosicollis* and thrips e.g. *M. sjostedti* may be susceptible to control with entomopathogenic fungi. Despite high levels of efficacy, *Bt*'s are currently relatively high cost and the short persistence in the field means that repeat applications are often needed. These constraints combine to make sprayed *Bt* generally too expensive a control technology for most poor African farmers to use on low value legume crops, and this has been one of the drivers for incorporation of *Bt* genes into legume crops. Unlike *Bt* nucleopolyhedroviruses are specific to their hosts and have been identified for *S. litura* (SpltMPV), *M. vitrata* (MaviMNPV) and *H. armigera* (HearNPV). However, in the absence of significant commercial exploitation in Africa, promotion and adoption remain elusive and unlikely within the next five years. Similarly, while *Beauveria bassiana* and *Metarhizium anisopliae* have both been reported to have activity against the eggs of the cowpea pests *M. vitrata* and *C. tomentosicollis* no fungal pesticides are commercially produced as yet in Africa apart from Green Muscle for control of locusts.

Phaseolus beans, notably the common bean, *Phaseolus vulgaris*, are particularly important sources of protein in East and Southern Africa (Pachico, 1993; Wortmann *et al*., 1998). *Zabrotes subfasciatus* and *Acanthoscelides obtectus* are the main post harvest bruchid pests. A wide range of IPM options have been identified for control including cultural methods such as leaving pulses in their pods, admixture with ash, soil, inert dusts, plant materials and oils and varietial resistance based on the lectin, areclin, which has been associated with strong suppression of *Z. subfasciatus* but with only sub-lethal effects on *A. obtectus*. Nevertheless, there is sufficient effect of arcelin on *A. obtectus* life history traits for it to be a component for a combined control strategy with parasitoids. Genetic resistance has been incorporated into commercial bean lines but the cultivars produced have not yet reached farmers in substantial quantities.

Local availability and low cost, botanical pesticides are particularly appropriate for use in developing countries where alternative methods of pest control are often not available and/or too expensive. Development and promotion of improved strategies for cultivation, harvesting and processing of pesticidal plants are needed to provide opportunities for rural smallholders as well as small-scale entrepreneurs to generate income by supplying approved botanical pesticides required by farmers, particularly in peri-urban areas where demand may be great but supply restricted.

Economics, availability, limited capacity and reliable information have meant that synthetic pesticides have not been used extensively in small-scale legume production in southern and eastern Africa thus far. However, the limited published information available, together with analogous experience in other crops, suggests that in some circumstances the cost-benefit ratio of controlling pests and diseases using inorganic pesticides is favourable if they are applied to a high standard of timing, dosing and targeting as part of an IPM strategy. In particular, newer more selective molecules such as imidacloprid, applied as a spray or seed dressing can be very effective at controlling sucking pests (and some disease vectors), with older moledules (principally pyrethroids) to control chewing and boring pests, and low cost old molecules for fungal disease control. Non-target impact on natural enemies and resistance management will be important considerations in any successful regime.

Given the range of successes and failures of IPM in an African smallholder context there has been considerable debate about its cost-effectiveness, and potential impact. The design of an effective IPM strategy for legumes depends on four key questions. These are: 1. *Supply and demand*: is IPM for legumes being driven by supply from researchers or by demand from farmers? 2. *Strategies*: what IPM strategies for legumes are available and are they appropriate for African smallholders? 3. *Systems*: how do these strategies complement the needs of the farming system and the farmer's objectives? 4. *Services*: how are these IPM strategies delivered or implemented at a regional or national level, and how cost-effective is this? Farmers will not invest in crop protection for crops that have low yields or limited market value leaving IPM supply-driven. However, farmers growing cowpeas purely for sale will grow a variety with a higher market value, invest in pesticides and spray more frequently than others. Demand for crop protection differs between field and storage pests. Generally, farmers will take steps to control storage pests, even for low value crops because they perceive a higher risk of total crop loss from storage pests, particularly from bruchid pests. Nevertheless, market price, technical change and farmer perception for change can influence demand for crop protection. Historically, the most successful IPM strategies have been host plant resistance (HPR) and classical biological control (CBC). The main reason for their success is that neither strategy requires any additional investment from the farmer. HPR is also problematic when yield losses are due to a complex of pest species, does not control all biotypes of a pest, and the seed is relatively expensive. While CBC has historically offered more sustainable solutions, many of the major pests of legumes are indigenous limiting scope for the introduction of exotic biological control agents.

Crop protection is rarely the farmers' top priority. Early maturing legumes are just as likely to be adopted because they are important for food security, since beans provide food earlier in the hungry season, than because they avoid loss from pests. Indeed successful adoption of IPM by subsistence smallholders may on reflection not be IPM projects *per se*, but general agricultural development projects which come to have an IPM component. Scaling-up has proved a key challenge for IPM. In Asia, the underlying assumption that classic farmer field schools (FFS) graduates would train others has been questioned, however, challenging farmers social norms on appropriate behaviour for dealing with pests and diseases is now thought to have had more impact. Market-led IPM strategies have the potential to achieve sustainable impact, but the big challenge is to develop the institutions that link smallholders with markets.

General Introduction

Integrated pest management (IPM) is the internationally recognized approach to pest and disease control. The concept of IPM has been practiced for over 50 years but the 6^{th} International IPM Symposium in Portland, Oregon, March 2009 decided that 'no unifying definition of IPM was possible'. Instead they concluded that IPM embraces diversity, is knowledge intensive, varies with crop, scale, and geographical location. Thus, while training manuals can be developed to provide guidance on best practice in IPM they would need to be tested and validated under local conditions. Nevertheless, all farmers practise IPM to some degree, including cultural control techniques that underpin all good farming practices.

In reality most farming practice is neither IPM nor non-IPM, but can be defined at a point along the so-called IPM continuum (Sorenson 1994) from chemically-intensive systems to bio-intensive systems. Chemically-intensive systems are those in which pesticides are applied, based on scouting and in accordance with economic threshold levels (ETL) and few, if any, biological approaches are incorporated, while bio-intensive systems utilise resistant varieties, biological control, crop rotation, plant health is maximized, reduced-risk pesticides such as biopesticides are applied and only then for therapeutic reasons. The historically low levels of pesticide use by smallholder farmers in Africa, in part because of poor access to these inputs and cost, has meant that organic production is a default position. This does not necessarily mean that IPM approaches would necessarily be embraced by African legume farmers, even with the promise of higher yields, but it does provide an ideal starting point for adoption of the principles of IPM in a low input system (Hillocks, 2002).

Africa produces an estimated 8 million tonnes of grain legume seed from 17.7 million ha (FAO, 2000) accounting for 26.15% of the total global area of production. Nevertheless, production levels in North America and Europe are similar using one third and one fifth of the land area respectively. Legume production in Sub-Saharan Africa was dominated by groundnut (*Arachis hypogaea*), soybean (*Glycine max*) and cowpea (*Vigna unguiculata*) both in terms of area of cultivation and production (Table 1).

Groundnut damaged by *Spodoptera litura*

Spodoptera litura moths in pheromone trap

The total area of cowpea harvested in 2006 has increased by 29% compared to 1995 and production increased by 90%, although this changed to 32% and 19% in 2007 because of a poor harvest in Nigeria which typically accounted for 64% of the total African harvest. Indeed Nigeria, Burkina Faso and Niger account for almost 90% of cowpea production between them. Similarly, Egypt, Nigeria, South Africa, Uganda and Zimbabwe produce over 90% of the soybean in Africa, with Nigeria accounting for 48%. While in contrast pea (*Pisum sativum*) is very important to smallholder farmers in Ethiopia, which produces 55% of the total, but is not common in other countries accounting for only 2% of the total legume produced, in common with pigeonpea (*Cajanus cajan*).

Table 1: Africa production of major legumes, FAOSTAT 2007

	Production		Area harvested		Yield
	tonnes	%	ha	%	kg/ha
Bambara bean	76,489	0.54	100,250	0.45	762.9
Cow pea, dry	2,996,452	21.00	11,011,182	48.96	272.1
Groundnut, with shell	9,156,545	64.18	9,157,118	40.71	999.9
Pea, dry	383,642	2.69	530,130	2.36	723.6
Pigeon pea	400,372	2.81	482,882	2.15	829.1
Soybean	1,253,879	8.79	1,210,374	5.38	1035.9
Total	14,267,379	100	22,491,936	100	

Regional R&D focus on the production of legume crops and development of IPM packages in particular reflects the relative importance of particular legume crops. The International Institute for Tropical Agriculture (IITA) focuses on cowpea in West Africa and the International Centre for Research on the Semi-Arid Tropics (ICRISAT) focusing on pigeonpea in East Africa. Kenya, Malawi, Tanzania and Uganda account for 98% of pigeonpea production and yet the crop has considerable potential for cultivation in the dry savannah of West Africa.

For many smallholder farmers cowpea (*Vigna unguiculata*) and bambara bean (African groundnut) *(Vigna subterranean)* are enormously important and while there is considerable interest in pigeonpea, perhaps to replace sea grass (*Lathyrus sativas*) in periods of drought, lablab bean (*Lablab purpureus),* yambean (*Pachyrhizus erosus*), locust bean (*Parkia biglobosa*), yardlong bean (*Vigna sinensis),* and marama (*Tylosema esculentum*) each have considerable potential for use by smallholder farmers under appropriate conditions but are not actively developed and promoted.

Acceptance or rejection of a legume crop by farmers may have nothing to do with pest management or indeed yields. Thus, in northern Ghana where many rural communities rely almost exclusively on sales of agricultural crops to obtain income, livelihoods are dependant on marketing high value yams and pulse grains. Bambara groundnuts and cowpea are cultivated in low fertility soils relying on nitrogen fixation by the legumes to enable the crops to grow. Bambara has several advantages over cowpea, not least resistance to field and post-harvest pests. However, for more than a decade bambara production has been in decline because of poor processing characteristics; it takes a lot of energy in the form of wood for fuel and large volumes of water to cook bambara groundnuts. In contrast cowpea is difficult to store and is susceptible to insect pests, and so is generally sold quickly after harvest. Despite bambara being a very high value crop and excellent source of protein cowpea cultivation is replacing bambara. Overall, the decline in bambara has led to a reduction in income generation as farmers can no longer take advantage of the high market prices that are available towards the end of the storage season which has put the food security of many farming communities in northern Ghana at risk. Paradoxically it may be that the natural traits of bambara that make it unattractive to farmers are the very ones that make it resistant to pests and diseases.

Status of cowpea, *Vigna unguiculata*, production

Cowpea provides a good example of a minor crop in terms of global production that is nevertheless, a crop of major importance to the livelihoods of millions in less developed countries. The African Agricultural Technology Foundation (AATF) estimate that approximately 200 million people in Africa consume the crop (Anonymous, 2009a). The crop is particularly important for communities in the dry savannah regions engaged in rain-fed agriculture. Notably, in Kebbi State, Nigeria, where more than 80 percent of the population are dependent on agriculture, cultivating food and cash crops such as cowpea (Anonymous, 2006). Cowpea is second only to cereals in importance as a source of protein for people in Kebbi State where the cost of animal protein is beyond the reach of the poor, and nearly 80 percent of vegetable protein intake comes from cowpea (M. A. Murna, personal comm.).

Estimates of production area are uncertain with Quin (1997) arguing an area of 12 million ha, and yields of beans typically 160 to 600 kg/ha, although even in the USA yields of 900 kg/ha are achieved (FAO, 1996). Fatokun (2009) suggested that the average yields of cowpea in Africa were 300 kg/ha in the 1990's and this has increased to an average of 470 kg/ha in West Africa in 2006 and 670 kg/ha in Nigeria, which is the largest producer and consumer of cowpea.

Despite low bean yields the importance of cowpea should not be underestimated; young leaves, pods and beans are used as fresh vegetables and in common with other legumes the beans contain high levels of protein (20-30%) and starch (50-70%). Trading of fresh and processed foods provides income for rural women and crop residues feed large and small ruminants and fertilise the soil. Indeed the sale of cowpea fodder at the peak of the dry season has been found to increase farmer incomes by 25% with yields of 2 to 4 t/ha being possible. In addition, nodal bacteria, *Bradyrhizobium* spp., produce 40-80 kg N/ha that is then available to help sustain the next cereal crop. Some cowpea varieties cause suicidal germination of *Striga hermonthica* (Braun, 1997) and the spreading low ground cover acts to improve soil and moisture retention. The short duration of legumes and cowpea in particular, make them ideal for cultivation in residual soil moisture after rice cultivation and this practice is promoted by many organisations. The drought hardy nature of deep rooted cowpea varieties enables the crop to be cultivated in semi-desert conditions of the African Sahel.

When new varieties are developed the importance of consumer preference should never be underestimated in order to achieve local adoption. Coulibaly (Terry *et al.*, 2003) found that the most important issue for consumers was bean colour and to some extent size; in some countries consumers' preferred red while others preferred white-seeded varieties.

PRE-HARVEST LEGUME PEST CONTROL

Cowpea, *Vigna unguiculata,* pest complex

In common with other legume crops cowpea is subject to a succession of insect pests from seedling through to storage. The palatability and protein content make cowpea liable to pest attack at nearly every stage of growth with over 100 pest species having been recorded. The most damaging pests of cowpea include those that occur during the flowering and podding stages. These pests include flower thrips, such as *Megalurothrips sjostedti* (Trybom) (Thysanoptera: Thripidae), pod borer, *Maruca vitrata* (Fabricius) (Lepidoptera: Crambidae) and pod suckers such as, *Clavigralla tomentosicollis* Stål (Hemiptera: Coreidae) (Adati *et al.*, 2007). In some regions of Africa beanfly, *Ophiomya* spp., *Amsacta flavicosta* (Hampson) (Lepidoptera, Arctiidae), and the weevils *Apion varium* Wagner (Coleoptera, Apionidae), and *Alcidodes leucocephalus* Fairmaire (Coleoptera, Curculionidae) are important. The biology of these pests are described by Cardona and Karel (1990) but their relative impact varies with season and location; heteropterans often cause more economic loss than *M. vitrata*, although the latter alone has been reported to cause up to 80% crop losses (Duke, 1981). Nevertheless, most recent research has been directed towards control of *M. vitrata*, and in particular development of a transgenic *Bt*-cowpea (see pages 26 & 29). While a welcome development, the *Bt* toxins will have no impact on insect pests of other orders, notably the sucking pests and Coleoptera storage pests.

Bambara groundnut, *Vigna subterranean,* pest complex

Bambara groundnut is generally considered to be pest resistant, nevertheless, six sucking bugs, *Agonoscelis versicolor* Fabricius, *Clavigralla tomentosicollis* Stål., *Mirperus jaculus* Thunby, *Locris rubens* Erich, *Macrorhaphis acuta* Dalm. and *Poophilus* spp. are prevalent pests during the reproductive stage of bambara groundnut (Dike, 1997) and when effectively controlled using insecticides the yields can be doubled compared to unprotected crops giving an average of 450 to 1,000 kg/ha. However, this was well below the yield potential of between 1,724 to 4,256 kg/ha with good management suggested by Johnson (1966). Good management alone may not be the primary reason for this variation in yields, Mkandawire (2007) suggests that symbiotic efficacy of native plant growth promoting rhizobacteria (PGPR), *Bradyrhizobia* spp. which nodulate this species can be important, as previously demonstrated by Dadson *et al.* (1988). Similar results have been found with other legumes, notably pigeonpea in India, where PGPRs isolated from different soils increased yields by between 27 and 47 percent (Swarnalaxmi and Singh, 2008).

Mkandawire (2007) lists a series of insect pests notably aphids (*Aphis* sp.), bruchids (*Callosobruchus* spp.), leafhoppers (*Hilda patruelis*) and termites. Of these, aphids were considered the most important, especially if the crop was planted late with a period of heavy rain followed by sunshine. Despite the wide range of potential diseases susceptibility to rosette virus (GRV; Genus, Umbravirus), transmitted by aphids, would appear to be a major constraint, as is root-knot nematode, *Meloidogyne javanica*, in some locations. Despite the potential of this crop, bambara remains an underutilised crop with little attention paid to production and, in particular, pest and disease management.

Pigeonpea*, Cajanus cajan,* pest complex

Pigeonpea is a native of Africa which has been in cultivation in the Nile valley for more than 4,000 years. The crop is very variable with tall, long season, short-day, and dwarf, day neutral varieties. The greatest numbers of cultivars are found in India and Pakistan. The crop is a woody perennial, living 3-4 years which bears well in the first year, profusely in the second and third years but less thereafter. The plant has a very long tap root making it ideal for production in semi-arid environments. Minja *et al.* (1999, 2002) conducted a systematic and thorough survey of pest incidence in pigeonpea, *Cajanus cajan*, in Malawi, Tanzania and Uganda during the mid 1990's. They found that key insect pests were pod sucking bugs (dominated by *C. tomentosicollis*), pod and seed boring Lepidoptera from the Noctuidae (*H. armigera*) and Pyralidae (*M. vitrata* and limabean pod borer, *Etiella zinckenella* Treitschke), and pod fly (*Melanagromyza chalcosoma* Spencer). Typical seed damage due to insect pests were on average 22, 15, 14, and 16% in Kenya, Malawi, Tanzania, and Uganda, respectively. Damage levels indicated that pod sucking bugs were more damaging in Malawi (69% of total seed damage) and Kenya (43%), while pod borers caused more damage in Tanzania (50%) and Uganda (54%). Pod fly caused more damage in Kenya than in the other countries. Pod borer damage was high in early maturing crops and pod fly in late maturing crops, while pod sucking bug damage was high regardless of crop maturity period. Warm and dry locations had less seed damage than warm and humid, cool and dry, or cool and humid locations in Kenya, Malawi and Tanzania, and this would favour production in semi-arid conditions where the crop is normally produced in South Asia for example. Interestingly, none of the farmers surveyed in Malawi, Tanzania, and Uganda used conventional pesticides on pigeonpea in the field but over 80% of those farmers used traditional methods in storage pest management. In contrast they found that 35 and 53% of farmers in Kenya had used conventional pesticides on long-duration pigeonpea genotypes in their fields.

Drought tolerant Pigeonpea, *Cajanus cajan*

Pigeopea pod, **www.permacultureliving.com.au**

Underutilized crops, pest complex

There are many underutilised grain-legume crops that have considerable potential in Africa (Fery, 2002). These include members of the genus *Vigna*, notably greengram, *Vigna mungo*, and blackgram *Vigna radiata*, which are highly prized and widely planted grain-legumes in South Asia. These short-duration crops are ideal as a cover crop, green manure or forage for cultivation in rice fields after harvest, requiring no inputs. The crop pest complex is similar to that of the related cowpea.

Among the subfamily Pailionoideae grasspea, *Lathyrus sativus* often referred to as 'poor man's meat' because it is cultivated by marginal farmers to secure access to a high-protein food for human consumption, animal fodder and improved soil fertility contributing to sustainable agriculture independent of external inputs. *L. sativus*, is the hardiest pulse crop, grown on 1 million ha throughout South Asia as a relay crop after rice. Ideal for resource-poor farmers, this drought tolerant crop thrives without external inputs. Traditionally used for food and a source of fodder, the protein rich legume is much enjoyed for its excellent flavour; an ideal crop for drought prone economies such as Ethiopia and dry savannah of West Africa. However, *L. sativus* produces small quantities of a neurotoxin, β-N-oxalyl –L-α-diaminopropanoic acid (ODAP), which, when consumed alone in large quantities, may cause lathyrism, an irreversible paralysis of the legs in humans. For this reason farmer cultivation to overcome this constraint is discouraged in many countries.

Drought tolerant grasspea, *Lathyrus sativus*

grasspea, *Lathyrus sativus* pod

Nevertheless, a number of centres are conducting research to produce varieties that do not produce ODAP. The International Center for Agricultural Research in the Dry Areas (ICARDA) is reported to have developed somaclones from Pakistani and Ethiopian land races. Another approach would be to use somaclonal variation to develop varieties with low ODAP content. This approach has been successfully used in India resulting in the release of 'Ratan' which has a low ODAP content (0.05%) and high yield potential. There is considerable potential for developing molecular markers for improving the speed and reliability of breeding programmes. Progeny from a segregating population can be examined using a range of marker technologies such as micro-satellite markers and AFLPs to identify markers that correlate most closely with traits of interest enabling the genes associated with the traits, such as those associated with production of ODAP, to be identified on genetic maps. Having developed suitable molecular markers, isolates that do not express ODAP can be identified in progeny without the need for conducting time-consuming field trials.

The natural vegetation of the Northern Guinea Savannah and the Sudan Savannah are characterised by open woodland with scattered, medium sized trees such as locust bean tree, *Parkia clappertoniana*. A member of the Mimosoideae, it is estimated that 0.2 million tonnes of protein-rich seeds they produce are eaten each year in Northern Nigeria alone. Yet very little is known about the biotic constraints, and pests in particular, faced by *P. clappertoniana* and the opportunity to grow these trees to improve and stabilise soils and provide much needed protein in these highly threatened environments is not promoted.

Chickpea, *Cicer arietinum*, is an ancient crop thought to have originated in Asia and although grown in Europe and Ethiopia is only a recent introduction to sub-Saharan Africa. Immature pods and young leaves can be used as vegetables and the grains eaten whole or turned into flour for the preparation of dal. Processing a long tap root the small herbaceous annual is an ideal short-duration crop sown after cereals. Particularly susceptible to grey mould, *Botrytis cinerae*, the crop is mainly affected by pod borers, such as *H. armigera*.

Chickpea, *Cicer arietinum*, and coriander grown as a relay crop after rice in Bangladesh

Chickpea pods are attacked by pod borers such as *Helicoverpa armigera*

Lablab bean*, Lablab purpureus,* pest complex

Lablab bean (often known as hyacinth or field bean) is a native of Africa but better known in South and South East Asia, notably southern India, where it is a major source of vegetable protein. This multi-purpose crop is grown as a source of pulses, vegetable and forage. The dry seeds can be used in various vegetable food preparations. The crop is capable of being grown in a range of climatic conditions including arid, semi-arid, sub-tropical and humid regions with temperatures ranging between 22°C–35°C, and a wide range of soil types varying in pH from 4.4 to 7.8. In common with other legumes *L. purpureus* as act as a cover crop and provide up to 170 kg/ha of nitrogen to soils and enrich the soil through their residues. However, *L. purpureus* prefers relatively cool season temperatures ranging from 14-28^{0}C and flowers indeterminately throughout a growing season. Improved varieties are photo-insensitive and can be cultivated throughout the year. Varieties such as Rongai, originally from Kenya is grown in Australia as a fodder crop. In Karnataka state, India seed yields of about 18,000 tonnes from an area of 85,000 hectares are typical, although 1.2 to 1.5 tonnes/ha are possible as a single crop and 0.4 to 0.5 tonnes/ha as an intercrop in 100-120 days. Green pod yields in India has been recorded to vary from 2.6 to 4.5 tonnes/ha. Young immature pods are cooked and eaten like green beans (older pods may need to be de-stringed). In addition flowers are eaten raw or steamed and the large starchy root tubers can be boiled and baked. However, dried seeds should be boiled in two changes of water before eating since they contain toxic cyanogenic glucosides.

Grown as a forage crop, *L. purpureus* can produce high seed and biomass yields. In northern Australia trials of the variety 'Highworth' consistently yielded over 1.5 tonnes/ha of seed as well as 5-11 tonnes/ha of forage (dry weight) with a protein content up to 22 percent (Anonymous, 2006).

Spraying *L. purpureus* with conventional pesticides for *M. vitrata (twice weekly in Bangladesh)*

L. purpureus bean pods, continuous cropping, high value for farmers

Lablab purpureus flower bud attacked

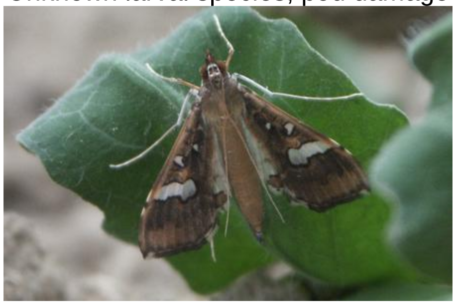
Lablab purpureus flower pod attacked

In common with other legumes *M. vitrata* is a major pest of *L. purpureus* as is *H. armigera* and a range of related pod borers, typically plume moth species. In Africa *C. maculatus* can be a significant pest species under field conditions.

Spodoptera spp. larval bud damage

Unknown larval species, pod damage

M. vitrata larva on *L. purpureus*



M. vitrata adult

Aphids attacking flower buds

Blue butterfly, *Lampides boeticus*


Anthracnose on bud


Leaf infected with mosaic virus

Semiochemicals for use in legume production

Semiochemicals or signalling chemicals (Law & Regnier, 1971) are divided into two groups, pheromones and allelochemicals based on whether the message is received by a member of the same or another species as the organism that produced the signal. Their use in agriculture has traditionally been associated with monitoring and control of insect pests. However, considerable efforts have been made in more recent years to understand and develop appropriate cultivation systems that utilise naturally-produced allelochemicals to achieve control. Notably, the push-pull system developed for control of maize stem borers and *Striga* spp. that intercrops attractive (pull) and repellent (push) non-hosts (Cook, *et al.*, 2007). Related systems are being developed in cereals where individual plants under attack release alarm compounds that stimulate the defences of neighbouring plants and the compounds can also act to recruit parasitoids in tritrophic interactions, however, no work has been undertaken on this approach with legumes.

1. Intercropping legumes and cereals

Many legumes are grown in intercrops with cereals, notably maize and sorghum. Legumes do not derive direct benefits from proximity to cereals, indeed they have to compete for nutrients and in particular light. Nevertheless, it has been argued that intercropping can reduce pest loads. This is not necessarily the case and depends on the intercropping species and pest complex since the micro-climate created can actually increase pest and disease problems for legumes. Jackai and Adalla (1997) suggest that many studies underestimate the impact of pests and diseases in intercrops because they focus on the constraints associated with only one of the two crops when overall damage levels may be comparable to mono-crops.

Host-plant resistance is an effective means of controlling insect pest damage in cowpea and there is no evidence to suggest that high levels of cowpea resistance has had an impact on natural biological control. The mechanisms of resistance can be complex and may or may not involve semiochemicals, notably repellents or antifeedants. In a particularly exhaustive study Bottenberg *et al.* (1998) compared susceptible *Vigna unguiculata* and a wild *Vigna* line, *Vigna vexillata* 'TVnu 72' as both mono-crops and intercrops with millet. They found that intercropping had no effect on flower and raceme infestation by larval *M. vitrata*, *Megalurothrips sjostedti*, and *Sericothrips* spp. were similar in crop mixtures and monocultures. *Empoasca* spp. populations and seedling infestation by beanfly, *Ophiomyia phaseoli,* were also similar in monocultures and mixtures as was pod damage by *M. vitrata,* but populations of *Clavigralla tomentosicollis* had no effect on cowpea yield. Parasitization rates of *M. vitrata*, *C. tomentosicollis* and *O. phaseoli* and predator–prey ratios of spiders and *Orius* spp. were similar across both cropping systems. Host-plant resistance in TVnu 72 drastically reduced insect populations and damage. Grain yield per hill was high in cowpea susceptible IT86D-715 and was not affected by intercropping with millet whereas grain yield of TVnu 72 was poor and reflected the low yield potential of that accession.

Legumes can act as trap crops for some pest species, notably maize stem borers (Braun, 1997), and as oviposition preferences are mediated by semiochemicals among other factors, there is considerable potential in conducting research on intercrops and use of trap crops to reduce pest populations through tritrophic interactions that create the environment for implementing push-pull strategies. Similarly, augmenting parasitoid populations by providing nectar plants in field margins and other activities to increase biodiversity could provide valuable means of managing pest populations in low input cropping systems. Though many of these ideas are by no means new (Waage and Schulthess, 1989) little systematic progress has been made in implementing them in field legumes in Africa. In contrast extensive work has been conducted in Bangladesh to breed larval and egg parasitoids such as *Bracon hebetor* to *Trichogramma chilonis* commercially to control *M. vitrata* in lablab bean (S.N. Alam, *et al.*, unpublished). However, natural enemies are commercially produced in Egypt and Kenya and could be reared in neighbouring countries to use in smallholder vegetable and legume production systems but the economics of such an approach would have to be considered carefully with community support.

Legumes can act a summer bridges for polyphagous pest species such as American bollworm, *Helicoverpa armigera*, which feed on a large number of crop and weed species notably maize, sorghum, sunflower, tobacco, chickpeas, pigeonpeas and tomato. Indeed their preference for pigeonpea and chickpea means that these crops can be used as trap crops in their own right. African marigold, *Tagetes erecta*, is traditionally used for this purpose in India (Srinivasan *et al*., 1994) and the attractive compounds have been identified (Bruce & Cork, 2001) although the synthetic attractant was not effective in field trials in chickpea. It was assumed that the lack of attractiveness of the lure was due to the odour profiles of the synthetic attractant and chickpea flowers being too similar. Further work has now produced an odour-bait that is effective in a wide range of crops, notably cotton, chickpea and lablab bean (Cork *et al.*, unpublished) and is the subject of a patent application by the University of Greenwich. In related research Gregg and Del Socorro (2005) developed a control strategy based on a floral attractant for *H. armigera* for use in cotton in Australia (Magnet®), but this is dependent on a toxicant to kill the moths attracted.

2. Sex pheromone of *Maruca vitrata*

The most studied sex pheromone of a legume pest is that of the pan-tropical legume podborer, *Maruca vitrata* (F.) (Lepidoptera: Pyralidae) (Adati & Tatsuki, 1999; Downham *et al.*, 2001 & 2003). *M. vitrata* is a particularly important pest of cowpea (Jackai, 1995), pigeonpea (Shanower *et al.*, 1999), lablab (S.N. Alam *et al.*, unpublished) and beans (Abate & Ampofo, 1996). The larvae feed on flower buds, flowers and young pods (Singh and Jackai, 1985) and without control flower infestation rates in cowpea of up to 80% have been reported in West Africa (Afun *et al.*, 1991), and seed damage rates of 50% (Dreyer *et al.,* 1994). Downham *et al.* (2003) reported that the female sex pheromone was composed of (10*E*,12*E*)-10,12-hexadecadienal and two minor components, (10*E*,12*E*)-10,12-hexadecadien-1-ol and (*E*)-10-hexadecenal in the ratio of 100 : 5 : 5. In addition to male moths a significant number of female moths were also caught with the synthetic blend of these compounds. This result is unusual, but not unique, and although the basis of this effect is unknown traps baited with virgin female moths did not catch female moths suggesting that the effect is unnatural.

The synthetic sex pheromone of *M. vitrata* has proved to be effective for monitoring the pest species under field conditions in a number of West African countries in studies conducted in collaboration with IITA. Since 2002 around 500 farmers in 26 different villages in Benin and Ghana have been involved in testing and refining the use of pheromone traps in the control of *M. vitrata*. This work has confirmed the empirical observation that a cumulative catch of twelve moths from six traps placed throughout a village can provide an effective action threshold for insecticide application within three days of the threshold being exceeded. The researchers used deltamethrin for control together with a botanical pesticide prepared from neem leaf extract (http://www.nri.org/projects/maruca/). Recent research has resulted in the identification of two further components of the sex pheromone of *M. vitrata*, (*E*)-10-hexadecen-1-ol and (3*Z*,6*Z*,9*Z*)-3,6,9-tricosane which have significantly increased trap catches in Asia but has yet to be evaluated in Africa (Hassan, *et al.*, 2009).

3. Chemical ecology of bruchid beetles

Considerable research has been conducted on the semiochemistry of legume stored product pests, including the epideictic (Prokopy, 1981) or spacing pheromones which deter conspecific females laying eggs (Messina & Renwick, 1985) on the same bean. The long-range sex pheromone attractants of several stored product pests of legumes have been identified, most notably the bruchid beetles, *Callosobruchus analis*, *C. maculatus* (Cork *et al.*, 1991, Phillips *et al.*, 1996), *C. subinnotatus* (Shu *et al.*, 1996) and more recently the sex pheromone of *C. chinensis* (Shimomura *et al.*, 2008). However, in order for them to mate successfully male bruchid beetles require a copulation releaser pheromone, erectin, which has been chemically described for *C. chinensis* as consisting of a dicarboxylic acid and several hydrocarbons (Tanaka *et al.*, 1981).

Despite the sex pheromone of *C. maculatus* being composed of two relatively simple mono-unsaturated, (*Z*)-3-methyl-3-heptenoic acid and (*Z*)-3-methyl-2-heptenoic acid, and lures fully optimised in laboratory-based experiments (Shu *et al.*, 1996) they have not been used for either monitoring or control in storage facilities to-date. Research is on-going at NRI to look at the behaviour of *C. maculatus* in the presence of the sex pheromone with a view to developing a pest control strategy (Sam *et al.*, unpublished) and these studies will utilise a static air Petri dish bioassay with data recorded on EthoVision and a cutting edge motion compensator bioassay that was developed for bioassaying walking insects when presented with visual, auditory or olfactory stimuli, notably attractants or repellents (Tilborg, *et al.*, 2003). Related studies confirmed the optimum blends of compounds for attracting *C. maculatus* (Shu *et al.*, 1996) and *C. subinnotatus* (Shu *et al.*, 1999) and the high sensitivity of the insects to the compounds. Bioassays with *C. maculatus* are typically conducted at NRI with 10ng of compound. Mbata *et al*. (2000) found that in static air *C. maculatus* showed an increased latency period of response to the sex pheromone although male *C. maculatus* are quite capable of locating lures in the absence of a visual cue. This has been confirmed by studies at NRI which also showed that male *C. maculatus* will remain in contact with pheromone sources for long periods of time but are not arrested by the lure. They tend to leave the lure but return shortly after and search for a female again (Sam *et al.*, unpublished). Such persistent searching behaviour suggests that male *C. maculatus* could be readily trapped in odour-baited traps or killed through exposure to a toxic bait. *C. maculatus* is known to exist in two morphological forms. To-date no studies have been conducted on the response *C. maculatus* in field situations when initial infestations are thought to occur before crops are harvested and placed in storage.

4. Pheromones for monitoring insect pest movements

Semiochemicals, and in particular sex pheromones, have found application for monitoring insect pest movements as low cost and species-specific alternatives to light traps. Probably the best known network is that for the African armyworm, *Spodoptera exempta* that has been run on a regional basis from Tanzania to Ethiopia. The data collected has considerable predictive value when linked to weather forecasts allowing risk of outbreaks to be measured and early warnings released to farming communities. This process has recently been taken to a more local level enabling villagers to organise and maintain their own monitoring systems in Kenya (J. Holt personal comm.).

Many legume crops in West Africa are grown in dry savannah regions that have distinct and prolonged dry seasons. Thus in Kano, northern Nigeria the dry season lasts from October through to May during which time there are no field crops and herbaceous vegetation dies off. Nevertheless, each year cowpea grown by subsistence farmers as a low-density intercrop with cereals in the rainy season is heavily attacked by a wide range of pest species, and the aphid, *A. craccivora*, pod borer, *M. vitrata*, flower thrips *M. sjostedti* and pod-sucking bug *C. tomentosicollis* in particular (Singh *et al.*, 1990). Whereas cowpea grown in the dry season on residual moisture, it is rarely attacked by *M. vitrata* for example. Light trap monitoring and field sampling in Nigeria have shown that *M. vitrata* does not occur in the north in the dry season, but is abundant in the south. *M. vitrata* is thought to migrate to the north with the rain bearing winds. Similarly, flower thrips have been shown to cover large distances on prevailing winds reaching northern savannah regions at the beginning of the rainy season. In contrast foliar thrips species and aphids are present throughout the year being able to subsist during the off-season on groundnut and other leguminous plants.

In terms of IPM, sex pheromone traps and yellow sticky cards could be employed by farmers to determine the arrival of *M. vitrata* and aphids respectively; however, such information is only of use where remedial actions can be taken, notably the application of insecticides. In the rainy season legumes are only grown as low density intercrops with cereals and the cost of insecticide is not warranted compared to the low yields recovered. Despite that in some regions of northern Nigeria the persistent organo-chlorine pesticide DDT is still widely used to control *M. vitrata* (Ukaegbu, 1991). In contrast the low incidence of *M. vitrata* in the dry season and availability of aphid resistant varieties (Ansari *et al.* 1992; Ofuya, 1993) means that production in the dry season as a mono-crop can be highly productive where residual moisture can be exploited Bottenburg *et al.* (1998).

IITA cowpea breeding programme

Breeding for resistance is acknowledged as the major component of an IPM approach to future control strategies (Rubiales *et al.*, 2006). The world mandate for research on cowpea rests with the International Institute of Tropical Agriculture (IITA) since 1967. The major emphasis of their work has been on germplasm collection and breeding programmes. Apart from improving yield potential and drought hardiness they have combined resistance to several diseases and tolerance to key insect pests, notably aphids, thrips and bruchids and developed appropriate production strategies to maximise yields (Quin, 1997). However, IITA found that by 1987 relatively few farmers in West Africa were actually growing these improved varieties. Despite claiming insect pest resistance IITA advocated the use of insecticides while farmers preferred to use their own varieties without insecticides. Similarly, farmers intercropped their legumes with millet and or sorghum while IITA advocated monocrops. IITA have now changed the focus of their breeding programmes to develop varieties that can be grown as intercrops and yield fodder as well as grain without dependence on insecticides. Much of this work is now being conducted in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the International Livestock Research Institute (ILRI). This work have led to the development of new varieties that mature within 60 days from planting and have improved drought tolerance and resistance to aphids, flower thrips and the parasitic weeds, *Striga gesnerioides* and *A. vogelii*. According to Fatokun (2009) farmers do not need to apply insecticides so often with these improved varieties and production costs are reduced accordingly.

In order to develop pest resistant cowpea several accessions of *Vigna* species, including those belonging to *V. vexillata, V. davyi, V. oblongifolia*, and *V. luteola*, were screened by IITA. The results showed that some accessions of *V. vexillata* and *V. oblongifolia* have good levels of resistance to the insect pests that devastate land-races of cowpea. A phylogenetic study based on RFLP markers indicated that *V. vexillata* was the closest to cowpea (*V. unguiculata*) (Fatokun *et al.*, 1993). Embryos in pods obtained after pollination of cowpea with *V. vexillata* lines which served as female parents showed that these crosses did not develop beyond the globular stage. Given the intrinsic resistance of *V. vexillata* to key post-flowering pests and notably *M. vitrata* this research will no doubt continue but whether the very strong cross-incompatibility between cowpea and *V. vexillata* can be overcome remains to be established (Fatokun, 2000) and is likely to involve biotransformation.

Maruca-Resistant Cowpea Project

The international team led by African Agricultural Technology Foundation (AATF) are developing transgenic cowpea lines containing the cry1Ab gene that confers Maruca-resistance in cowpea. According to a recent project bulletin from some 3,000 individual transformed seeds 1,600 were selected and sent to Puerto Rico in August 2008 to assess their resistance to *M. vitrata*. The trials were reviewed in October by representatives from USAID, AATF, IAR, CSIRO, Rockefeller Foundation and Bill and Melinda Gates Foundation. Final yield and damage data were taken in December and discussed at the Donald Danforth Plant Science Centre in St. Louis, Missouri, USA, but final analysis is apparently ongoing.

Despite this promising start the Annual Cowpea Project Review and Planning Meeting held in Abuja, Nigeria in June 2008 suggested that while the development of Maruca-resistant cowpea varieties is the key objective in order to satisfy regulatory compliance, product deployment to smallholder farmers through communication and outreach programs can not be expected before 2014 when there will be pilot releases in Nigeria, Ghana and Burkina Faso.

While there is very reason to assume that an efficient product with appropriate agronomic traits can be developed, additional research is envisaged to address areas such as potential impact on non-target organisms, insect resistance management, and potential impact resulting from gene flow from *Bt*-expressing cultivated cowpea into wild relatives (Anonymous 2009a and b). Recently, Tamò (2009) reported that the effect of the *Bt*-toxin had been tested on the egg parasitoid, *Phanerotoma leucobasis*. The parasitoid has an unusual biology, laying eggs on the egg of *M. vitrata* but the larvae develop in the larvae of the host. Apparently the mortality of the parasitoid was not adversely affected by the *Bt*-toxin, but inevitably the death of *M. vitrata* larvae from the *Bt*-toxin would impact on parasitoid numbers, although the author concluded this would be less than had insecticides been sprayed.

FAO African legume projects

L.W. Kitch reported that FAO had technical cooperation projects (TCP) in Nigeria and Cameroon to set up farmer field schools for IPM on cowpea that dealt with improving seed production, insecticide use and storage technologies (Terry *et al.*, 2003). FAO believe that there are good insecticides but they are expensive and that sprayers and information on their use is not widely available. Farmers lacked market information suggesting that technology alone was not enough to enable farmers to benefit from cowpea enhanced production. In common with FAO's belief to provide farmers with Technology Packages (Terry *et al.*, 2003) a range of storage technologies was to be promoted (triple bagging, drum, ash, solar heater) (discussed on pages 64-86).

FAO on GMOs

FAO has funding to establish a network in Africa on biotechnology (Terry *et al.*, 2003). Some of the activities will include, establishing a technical secretariat to facilitate communication as well as capacity building by identifying and assisting African scientists. The secretariat will provide access to good quality information on crop improvement and biotechnological tools, assist countries to develop TCPs on biotechnology and crop improvement activities, establish an information system on biosafety risk assessment methods for GMOs, resource allocations, breeding and biotechnology in African countries.

Biological control of *M. vitrata*

Considerable efforts have been undertaken to assess the impact of biological control agents to control *M. vitrata* and determine the species involved. Recent efforts have been directed at assessing whether the level of parasitism is different in wild host plant species and agro-ecological zones in an effect to understand the factors that might limit their impact. As might be expected the level of parasitism is influenced by the host plant *M. vitrata* is feeding on and the agroecological zone. However, in legume crops the impact of natural enemies and parasitoids is typically low and erratic. In order to identify highly efficient biological agents it is assumed that they are most prominent in the geographical region where *M. vitrata* originated. In case of pan-tropical species such as *M. vitrata* this is hampered by uncertainty over the origin and original host range.

Nevertheless, considerable progress has been made in recent years to understand the range of natural enemies and parasitoids that impact on *M. vitrata* in Africa. Notably, the parasitoids that impact of *M. vitrata* in herbaceous plants would appear to be quite different from that found on host tree species. Thus the main parasitoid recovered from woody plants such as *Pterocarpus santalinoides* was *Phanerotoma leucobasis* Kriechbaumer (Hymenoptera, Braconidae). In contrast the predominant parasitoid on herbaceous legumes was *Braunsia kriegeri* Enderlein (Hymenoptera, Braconidae) and indeed was the most commonly reported parasitoid of *M. vitrata* on cowpea, however, the level of parasitism achieved by *B. kriegeri* on cowpea was less than half the levels than achieved by *P. leucobasis* on woody plants, typically 5-10% (Tamò *et al.*, 2000).

A single egg parasitoid species has been identified attacking *M. vitrata*, *Trichogrammatoidea eldanae* Viggiani (Hymenoptera, Trichogrammatidae) in West Africa (Tamò *et al.*, 1997). Because of the minute size of egg parasitoids and the difficulty of observing them in nature sentinel eggs laid on cowpea where placed in host plants and parasitism estimated in the leaves returned to the laboratory (Arodokoun, 1996). Parasitism levels of typically 50% were observed in the wet season. Importantly *T. eldanae* has been reported to attack eggs of cereal stemborers *Sesamia calamistis* Hampson (Lepidoptera, Noctuidae) (Bosque-Pérez et al. 1994) and *Eldana saccharina* (Walker) (Lepidoptera, Pyralidae) (Conlong and Hastings 1984) suggesting that in traditional intercrops the polyphagous habit of *T.?eldanae* could enhance efficacy.

The larval parasitoid *Ceranisus menes* attacks a second important legume pest, the flower thrips *Megalurothrips sjostedti*, but overall parasitism rates are low. However, the related parasitoid, *C. femoratus*, was recently discovered in Cameroon which has shown a higher level of efficiency in parasitizing *M. sjostedti* on important host plants, including cowpea. The potential of this new parasitoid as a biocontrol candidate in West Africa is currently being assessed through experimental releases in Benin and Ghana (Tamò *et al.*, 2000).

A recent study in pigeonpea in India (Mohapatra *et al*., 2008) showed significant natural parasitism of late instar *M. vitrata* larvae by the ectoparasitoid, *Bracon (Habrobracon) hebetor* with the total life-cycle being completed within 8 to 10 days. Each larva produced between 5 and 9 parasitoid cocoons. Commercial rearing of *B. hebetor* in Bangladesh is economically viable for use in control of the eggplant fruit and shoot borer, *Leucinodes orbonalis*. Initial studies have been conducted in lablab bean (S.N. Alam, personal comm.) which suggest that *B. hebetor* may well be suited as a component of an IPM strategy for control of *M. vitrata*, however because it is a larval and pupal parasitoid the crop could still sustain significant damage and farmers would not accept them in the absence of technology for control of other life stages, notably adults and eggs.

Microbial pesticides

Key pests of legumes grown in Africa that could be amenable to effective microbial control include *M.vitrata* on cowpea, *S.litura* on groundnut and *H.armigera* on chickpea all of which could be controlled with either *Bt* or viral biopesticides (Lingappa & Hegde 2001). In addition sucking pests such as *C.tomentosicollis* and thrips e.g. *M. sjostedti* may be susceptible to control with entomopathogenic fungi.

The most broad spectrum and most available microbial pesticide is *Bt* which in its *B.t. kurstaki* form, widely used in commercial *Bt* spray formulations, is very effective against *M.vitrata* and *S.litura,* though probably less so against *H.armigera*. *Bt* formulations are registered in many African countries, mainly for controlling chemically resistant pests such as Diamond back moth, *Plutella xylostella*, in high value vegetable production. However *Bt*'s drawback is the relatively high cost of commercial formulations and the short persistence which means repeat applications are often needed. These constraints combine to make sprayed *Bt* generally too expensive a control technology for most poor African farmers to use on low value legume crops. There have been attempts to produce *Bt* in Africa e.g. by ICIPE in Kenya as a means to lower cost but as yet these have not resulted in the appearance of any commercial products. The issue of higher cost in scaling up use of sprayed *Bt* to poor farmers is indeed behind the initiatives reported above to capture the IPM benefits of *Bt* more economically and sustainably in the form of GM varieties incorporating *Bt* genes.

The viral control agents the nucleopolyhedroviruses specific NPVs have been identified against *S.litura* (SpltMPV), *M. vitrata* (MaviMNPV) and *H.armigera* (HearNPV). All these NPVs are specific to their hosts and do not control other insect pests or even other Lepioptera, a major drawback to their use especially by subsistence farmers. The SpltNPV (Sachithanandam *et al.*, 1989) and HearNPV (Cherry *et al.*, 2000, Arora *et al.*, 2002, Grzywacz *et al.*, 2005) have been widely evaluated in Asia and shown to be very effective in controlling their respective pests on some legumes. The MaviMNPV is at a much earlier stage of development and has been identified and characterised but not yet evaluated in the field (Lee *et al.*, 2007). Both SpltNPV and Hear NPV are produced and sold as commercial pest control products in India (DBT., 2008) and China (Sun & Peng, 2007). However, neither of these has yet been registered in Africa, though a local company Kenya Biologics set up in Kenya is intending to register a HearNPV product (Van Beek, 2007) and has received DFID funding to do this in 2008, as yet however no product has emerged or completed registration. IITA have access to the Asian MaviMNPV and were intending to evaluate this for cowpea IPM (M. Tamo, pers comms.). So while NPV options for some key pests of legumes exist none are likely to become available in Africa in the short to medium term (<5 years) and their suitability for general smallholder use will depend crucially on price.

The entomopathogenic fungi have a long history of research into their potential use as crop protection agents and from them a number of commercial pest control products have been developed from the seven species that have been commercialised (Lacey *et al.*, 2001; Shah & Pell, 2003). The ability of fungi to penetrate the insect cuticle and initiate infection in contrast to the oral route required by *Bt* and NPV gives them a strong potential advantage especially for the control of sucking and boring pests whose feeding habits make per os infection challenging.

Beauveria bassiana and *Metarhizium anisopliae* have both been reported to have activity against the eggs of the cowpea pests *M. vitrata* and *C. tomentosicollis* in the laboratory by African Researchers (Ekesi *et al.*, 2002). Other work has suggested that *M. anisopliae* is a potential candidate for the management of thrips *M. sjostedti* on cowpea (Ekesi *et al.*, 1998). However, while these entomopathogenic fungi show some promise as biological control agents none appears to be under further active commercial development in Africa. Indeed apart from Green Muscle produced in South Africa no fungal pesticides are commercially produced as yet in Africa and capacity to commercialize them in Africa is very limited as yet in sub Sarahan Africa (Langewald & Cherry, 2000; Grzywacz *et al.*, 2009).

In conclusion while the technical constraints to developing and scaling up microbial control of some key legume pests are not great, the limited capacity in applied research, production and registration in Africa as well as the high costs of using microbials on smallholder farming systems in particular do not make microbial control currently a viable option in the near future unless these capacity issues are addressed and cheaper production models developed.

Pesticidal Plants and botanical insecticides

1.0 Introduction

Subsistence farmers comprise some of the poorest and marginalized people across Africa and also the most vulnerable to malnutrition. Their principal needs are simple: food security in terms of production and storage. For most people in southern Africa, maize provides the staple food but cowpeas (*Vigna unguiculata*) and common beans (*Phaseolus vulgaris*) are also very important as sources of protein, micronutrients and essential vitamins particularly for poor households and are arguably staple crops themselves. Despite this, legume crops remain a relatively low priority for crop improvement programs at national and international institutions and at government organization. This is despite the fact that legumes are relatively high value so are a high cost for farmers who can not produce enough themselves and for those who can, provide a rare opportunity for farmers to raise themselves out of poverty through the sale of excess produce. Legume crop yields are, however, chronically low, often <400kg/Ha, largely attributable to insect pests and disease or extreme weather conditions. While, productivity is limited by numerous biotic and abiotic constraints, insects are arguably the most important. This is because they are often the most destructive constraint so their effects are often easily visible to farmers, they present a chronic problem and the majority of farmers have some knowledge about them (identification, seasonal occurrence, specific crop damage effects etc). Even the poorest can have some direct control. What is of course very clear is that if left unmanaged insects' present very severe consequences and for the production of some legumes intervention to manage insects is essential.

Current approaches to pest control on legumes. Commercial insecticides are usually effective, but they come with some severe constraints to their use.

i) *Cost.* Most commercial products are, not surprisingly, priced to be as affordable as possible to as many farmers as possible although this still requires some considerable outlay from farmers. A full year's supply of Actellic Super™ dust (Pirimphos/Pyrethroid) applied once every 3 months), an effective stored product protectant against maize and legume insect pests, can cost as much as 10% of the product value in Malawi. If damage levels are minimized using solarisation to kill off pre-storage infestations and appropriate storage containers are used then the cost benefit margins for synthetic products become finer. The costs are high when one considers all the other essential inputs required throughout the 'seed to store' growing process. Insecticide subsidies can alleviate the burden of cost but in Malawi for instance these subsidies are available for grain crops such as maize but there is no equivalent subsidy for legumes so these are often left untreated.

ii) *Adulteration*. This is surprisingly common as few African countries have the infrastructure to produce chemicals locally so import in bulk and simply provide the packaging input – at which point adulteration is fairly straight forward. The frequent use of adulterated products exacerbates insect pest problems since they result in products being used at sub optimal (ineffective) concentrations that do not kill the insect and encourage the development of pest resistance.

iii) *Health and Safety*: Health and safety in Africa is a low priority. Most commercial products are invariably applied without protective clothing despite known toxicity (Fig 1.) and there are few mechanisms to ensure food safety for consumers while little is known about their long term effects since low acute toxicity results in health and safety complacency. Many of the products commonly found in Africa are considered too toxic in developed countries and there are thought to be as much as 50,000 tonnes of pesticide dumped across Africa including, endosulfan, flumeturon, atrazine, malathion and methidathion and DDT (PAN Africa, 2009; PAN UK 2009). This is not altogether surprising since disposing of chemicals is expensive and the only alternative option may be to sell out dated products which could result in similar consequences to those described for adulteration above.

iv) *Poor labelling* (Fig 2.) Accurate labeling is very important and often overlooked as a priority but even where labeling is accurate they are still of no use to illiterate farmers or farmers who only speak local dialects or languanges when national languages or English are the language used for labels.

v) *Environment*: Commercial insecticides also have well documented impacts on wildlife, pollinators and natural enemies; so many farmers avoid these products.

Farmer surveys carried out in West Africa have highlighted these problems, and have led to farmers avoiding commercial products altogether (Belmain & Stevenson, 2001) and, instead, moving to the use of plant-based products. More recently surveys in Malawi and Zambia in 2007/2008 (Nyirenda & Kamanula, pers comm., www.nri.org/sapp) reported that farmers were knowledgeable about plant materials as environmentally benign, safer and cost effective alternatives to synthetic pesticides and recognize pesticidal plants as reliable and if collected or produced themselves, that their cost can be calculated in terms of time rather than in cash. However, despite a wide knowledge of which plants are effective and how to use them surprisingly few farmers in these countries were doing so and the study concluded that there was a need for research to optimize their use.

Fig 1. Endosulphan: instructions for use

Fig 2. Health and Safety is a low priority for users and consumers

2.0 Pesticidal plants as alternatives to synthetic products.

The use of plants, plant material or crude plant extracts for the protection of crops and stored products from insect pests is probably as old as crop protection itself (Thacker, 2002). In fact, before the successful emergence of commercial synthetic insecticides from the 1940s, botanical insecticides were the major global technology for insect pest control (Isman, 2008). In Africa the technology still has a major place in the arsenal of farmers despite its decline elsewhere in the world. A comprehensive review of pesticidal plants is provided by Prakash and Rao, (1997) who list and describe the biological activities and practical applications for 150 species with some agricultural potential. Stoll (2005) provides an excellent practical tool for a wide variety of different tropical pests and crops. Commercially (and primarily in North America and Western Europe) there are four major types of botanical products used for insect control (pyrethrum, rotenone, neem, and essential oils), along with three others in limited use (ryania, nicotine, and sabadilla). Additional plant extracts and oils (e.g., garlic oil, *Capsicum oleoresin*) see limited (low volume) regional use in various countries (Isman, 2006). Here we only consider pesticidal plants that comprise crude plant materials (leaves, stem bark, roots, fruits, seeds) that are effective for pest control but require only rudimentary preparation and are more appropriate for small holder farmers across Africa. This might include simply drying crushing and admixing with stored products (Belmain & Stevenson, 2001) or making crude extracts, usually with water, to provide a product that can be applied using a brush or knapsack sprayer (Stoll, 2005). The level of processing required is critical in that the less processing required the more universally appropriate the plant material. As mentioned above the term botanical insecticides usually refers to more processed materials, extracts, fractions or even semi-purified chemicals.

If one considers the relatively low market share for pesticidal plants in the developed nations and the limited commercialisation of plant products it is easy to argue that they be of greatest benefit in developing countries, particularly those in tropical and subtropical zones not least of all because of the long standing indigenous knowledge that resides there even if not practised so much anymore. In a recent survey of farmers in Malawi and Zambia we determined that almost all farmers were aware of at least one plant materials that was useful for pest control but less than half in Malawi and less than 20% in Zambia actually used them. Clearly the materials must be effective, however, one argument that has always hindered serious investment in the commercialization or wide promotion and uptake of plant based products is the relatively low efficacy of some materials compared to synthetic products. This is in many cases a matter of fact; however, it also helps illustrate the relevance of plant materials. In short, for many African farmers some efficacy even if only moderate is enough, provided that there is some perceivable reduction in damage that can be of quantifiable and of economic benefit to them. Of course there is scope to optimize efficacy and this is discussed below and the principal purpose of some new projects funded through the EUs Africa Caribbean and Pacific Science and Technology Program.

Another facet of pesticidal plants that makes them particularly attractive alternatives is their low cost. Indeed some materials such as *Tephrosia vogelii* are already cultivated under soil improvement programs so it's possible with some materials for farmers to grow their own. This provides some scope for the poorest farmers to provide some additional income from the preparation and sale of excess material to other farmers. For others that are collected from the wild, farmers can cost their products in terms of time rather than cash, although this can make them decidedly unattractive so the scope to develop the most basic commercial processing may have potential to increase the extent of their use.

While economic benefits from the use of pesticidal plants are encouraging, the greatest benefit from their use may be in terms of human health. The majority of acute human poisonings from pesticides occur in developing countries; in some regions they are a major cause of mortality (a relatively rare event in western Europe or the United States) (Forget, 1993; Ecobichon*,* 2001). In the past 20 years despite the agrochemical industry producing newer synthetic insecticides with dramatically reduced health and environmental impacts, public perception remains strongly tied to the damaging products of the past, such as DDT. In contrast plant products are relatively safe but this cannot be assumed. Plants produce some of the most toxic substances known to man e.g., aconitine and ricin and some such as nicotine and rotenone that have acute mammalian toxicity constitute active components in some popular plant based pesticides (Isman, 2008). In reality, however, the human health risks associated with these compounds are largely mitigated through the use of crude plant preparations in which the concentrations of the substances are typically very low. Ideally, local production of plant extracts would be standardized and regulated to ensure product safety and efficacy, but this may be an unrealistic expectation in many of the poorer regions of the world. Fortunately there is some level of regulation for use of some of the best known materials elsewhere in the world and these standards may be adopted. Furthermore, many natural pesticides have a natural tendency to breakdown, particularly in sunlight e.g., azadirachtin and pyrethrum and in all cases owing to their very nature breakdown ultimately into environmentally harmless products. Public opinion is certainly on the side of pesticidal plants and like the organic producers themselves accept them as organic which highlights another important contemporary benefit of these materials compared with synthetic products. They are suitable for organic growers, an increasingly important market share in agricultural produce.

From a resource poor farmers perspective pesticidal plants are appealing because they cannot be adulterated (at least if they are collected by the farmer), and are cost effective. Although they do require time to collect and prepare on top of the input required to apply them. However, their efficacy can vary across seasons and locations and the application procedure is not always as efficient or effective as it could be. This then highlights the importance of understanding the chemistry of their activity to optimize their application. Nowhere is this demonstrated more emphatically than with Neem although other species are now benefitting from increased knowledge about their activity.

Numerous species, many with only local use and known to farmers, can be discovered through surveys (Fig. 3), and a recent survey in Malawi and Zambia has identified the following list as useful species. Curiously several of these (indicated with an asterisk) are virtually unknown in the literature for the reported applications and present interesting new research and development opportunities.

• Indigenous species list	• Non-indigenous species
• *Aloe ferox* *	• *Tithonia diversifolia* *
• *Bobgunnia madagascariensis**	• *Azadirachta indica* – Neem.
• *Dolichos kilimandsharicus* *	• *Tagetes minuta*
• *Euphorbia tirucali* *	• *Cymbopogon* spp.
• *Lippia javanica*	• *Mucuna pruriens**
• *Neorautanenia mitis* *	
• *Solanum panduriforme*	
• *Securidaca longepedunculata*	
• *Strychnos spinosa*	
• *Tephrosia vogelii/candida*	
• *Vernonia* (spp.) *	

Fig. 3. Farmer surveys and discussions beneath a Neem tree. Farmers are an important source of knowledge and experience about new and established plant materials.

Fig. 4. Small neem tree, Zambia.

***Azadirachta indica* (Neem) Meliaceae**

Neem is almost legendary in its potential value to agriculture and is particularly noteworthy as a pesticidal plant since there is so much work on this species and along with essential oils is the only plant-based agricultural product to have been successfully commercialised in the last 20 years. It is a fast-growing tree (Fig 4) which is native to the Indian subcontinent, where its medical and insecticidal properties have been known for centuries. It is now widely distributed throughout Southeast Asia, East and Sub-Sahelian Africa, Fiji, Mauritius and parts of Central America. It grows well in climates from semi-arid to semi-humid and will thrive even in places with less than 500 mm of rain per year. However, its distribution can be restricted locally so it is not universally appropriate. For example in Malawi, it grows well in parts of the south but in the northern parts of the country it doesn't grow so well or at all and certainly does not flower and thus does not produce the seeds which are the best source of biologically active compounds. That said, soil requirements for neem are modest and it grows equally well on poor, shallow, sandy or stony soil. The trees fruit when they are 4-5 years old, yielding 30-50 kg per tree. The oil content of the seeds is between 35 and 45%. The effective ingredients are present in all parts of the tree but are most highly concentrated in the seeds. The neem tree is used in pest control in more than 50 countries but has historic use in Asia over many centuries. A very comprehensive review is provided by (Prakash and Rao, 1997). The insect deterrent or toxic substances; are primarily azadirachtin A (Fig. 5) and B. In addition, neem contains a number of other chemical substances such as Salannin and Meliantriol, which have primarily repellent effects, and Nimbin/Nimbidin, which have anti-insect and anti-viral effects.

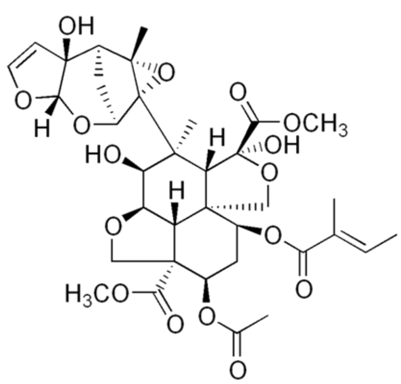


Fig 5. Azadirachtin A

Practical and specific information

Kernels: The seeds should be dried well so that they do not become contaminated with *A. flavus* and the toxic aflatoxins which impair their pest control properties and which are highly toxic to humans. When harvesting neem seeds, the outer fruit colour should be yellow not green or brown. Greenish yellow fruits are not fully mature and are low in azadirachtin content. Greenish centres are OK though and characteristic of higher content. Fruits can be collected by spreading a plastic sheet or cloth under the tree and the seeds do not come in contact with the soil and the danger of fungus attack and aflatoxin contamination is reduced. After the fruit pulp is removed the seeds are then dried for one day in the sun, and the following three days in well aerated shade, during which they are regularly stirred. Seeds between 3 and 8-10 months after harvest have the highest quantity of azadirachtin. Germination of neem seeds will decrease about one month after harvest and if exposed to temperatures higher than 45ºC.

Leaves: The advantage of using Neem leaves lies in the fact that leaves are available all year round and do not have to be processed for storage. It is reported that a mature tree of about 8-10 m in height can produce about 360 kg of fresh leaves per year. However leaves have very much lower azadirachtin content.

Target organisms: The activity is broad based including insecticidal, repellent, antifeedant, acaricidal, growth-inhibiting, nematocidal, fungicidal, anti-viral. The compounds are most effective against Coleoptera, Lepidoptera and Orthoptera although it has reported activity against most insects as indicated from the following list.

Some insects with reported susceptibility to Neem

American bollworm	*Helicoverpa armigera*
Bean pod borer	*Maruca testulalis*
Bruchids	*Callosobruchus* spp.
Cutworms	*Agrotis spp.*
Desert locust	*Schistocerca gregaria*
Diamondback moth	*Plutella xylostella*
Fall armyworm	*Spodoptera frugiperda*
Gram pod borer	*Clavigralla tomentosicollis*
Leafhopper	*Empoasca jlavescens*
Leaf miner	*Liriomyza spp.*
Mexican bean beetle	*Epilachna varivestis*
Migratory locust	*Locusta migratoria*
Termites	*Coptotermes jormosanus*
Thrips	*Heliothrips spp.*
Whitefly	*Bemisia tabaci*
Cowpea weevil	*Callosobruchus maculatus*
Khapra beetle	*Trogoderma granarium*
Lesser grain borer	*Rhyzopertha dominica*

*Effects on non-target organisms***:** Spiders, ants and birds are apparently not affected although ladybird beetles have been found to suffer some mortality of 3% under field conditions. Bees sometimes are unable to hatch or have crippled wings. Rice fields treated with neem products house more natural enemies than untreated fields. Earthworms do not like to penetrate into soil treated with neem, but if they do, they grow better and have higher fertility. IRRI reported that neem was relatively non-toxic to most parasitoids and predators of rice pests which suggests that they should have similar low levels of toxicity against non target organisms of legumes. In Neem has no known direct toxicity to humans although the fungus *Aspergillus flavus* develops rapidly on seeds with high moisture content which can produce produce carcinogenic aflatoxins and thus posing a health hazard to humans.

*Preparation and application***:** Azadirachtin is required at about 30 g Ha^{-1} in field applications and it occurs at between 2 and 9 mg/g in seeds. This variation therefore presents an important issue for ensuring correct application rates so ideally the seeds needs to analyzed, where possible, in order to use optimum extracts. Azadirachtin is also highly sensitive to ultraviolet light. Therefore spraying in the evening is recommended.

Pure azadirachtin is poorly soluble in water, but it is almost completely dissolved in water extracts of seed powder, due to the action of co-solvents. Hot water extracts help optimise extraction of Neem as well as other materials. Therefore, water extracts can be as effective as a commercial neem extract. As general guidelines, the following quantities are recommended.

Basic neem formula	**Low incidence or highly susceptible pests, g/ltr water**	**High incidence or moderately susceptible pests, g/ltr water**
Seed powder:	15 - 30	40 - 60
Kernel power:	10 - 20	30 - 40
Seed cake powder:	15 - 30	40 - 60
Kernel cake powder:	10 - 20	30 - 40

Extracts should always be mixed with liquid soap at a 0.1%.

*Neemoil/emulsion***:** Neem oil can control sucking insects like aphids, whiteflies and stemborers (e.g., the bean stem maggot). 30-40 ml of neem oil is added to 1 litre of water, stirred well and then an emulsifier added, e.g. liquid soap at 1 ml per litre. Some plant species may provide suitable surfactant properties e.g., *Sapindus emerginatus*. It is essential to add the emulsifier and mix properly. It should be used immediately otherwise oil droplets start floating. A knapsack sprayer is better for neem oil spraying than a hand sprayer. Per hectare ca. 500 l of the finished liquid is required.

Neem cake extract: 100 g of neem cake is required for 1 litre of water. The neem cake is put in a muslin cloth and soaked in water overnight. It is then filtered and liquid soap is added as emulsifier at 0.1%.

Neem leaf extracts: Neem leaves should be used before flowering occurs and extracts require large quantities of dried leaves (20% by weight) but is effective against leaf-eating caterpillars, grubs, locusts and grasshoppers and upto 35% for thrips (*Megalurothrips sjoestedti*), the bean pod borer (*Maruca testulalis*) in beans and the American bollworm.

Neem seeds - storage insects: Most stored grain pests are reportedly susceptible to neem, except the saw-toothed grain beetle (*Oryzaephilus surinamensis*), which curiously breeds well on neem. However, field trilas in Zambia have shown it to be much less effective than expected against bruchids on cowpea although it is not yet known whether this was due to the age of the material used. There are three methods to apply neem in storage protection: 1. neem seed powder 2. neem seed slurry 3. neem oil. Applying plant powders as slurry preparations is more effective against the larger grain borer (*Prostephanus truncatus*) than the powder preparations. An explanation of the superiority of the slurries over the powders is that with the slurry treatment, the grains are more thoroughly coated. With the powder treatment, the powders tend to settle at the bottom of the container.

Neem oil can be made by hand but only using dried decorticated kernels. Outer husks can be freed from the inner seed in a mortar and then removed by winnowing and then the kernels pounded until they form a brown, slightly sticky mass. A little water helps form a workable paste which forms an almost solid ball which is kneaded for several minutes over a bowl until oil collects on the surface. Then it is firmly pressed and the oil emerges in drops. 100-150 ml of oil can be extracted from one kg of neem kernels using this method which constitutes about half the oil content. Results of experiments conducted in Thailand suggest that admixing neem oil to mung bean seeds at a rate of 2-5 ml/kg mung beans can effectively control cowpea weevils (*Callosobruchus maculatus*) for up to 8 months with a damage of less than 15%.

***Tephrosia vogelii* (and *T. Candida)* Leguminosae**

T. vogelii was probably introduced and not native anywhere in Africa despite being widespread in the continent. The species has been extensively cultivated and found near cultivated land for use as a fish poison and is clearly introduced in many of its present localities so that the extent of its native area is now obscured. It is now widely discouraged from being grown near water courses. Despite this, in surveys of hundreds of farmers conducted in Malawi and Zambia, *Tephrosia* was, by far, the pesticidal plant most reported by farmers. It is a shrubby plant used as a fallow plant to improve soil fertility and to reduce erosion, particularly in higher areas. A related species, *T. candida* is widespread in parts of Asia, e.g. in Vietnam where it is used as a green manure and cover crop and this is being increasingly used in Africa since it is considered to be more effective at soil improvement than *T. vogelii*. This immediately presents a problem in that farmers, who know about the insecticidal properties of *T. vogelii,* now assume the same of *T. candida* although this species is not well studied. *Tephrosia* spp. may grow as rapidly as 2-3 metres in 7 months although *T. candida* usually produces greater biomass than *T. vogelii*. *T. vogelii*, after 5 months of growth, produces about 27-50 tonnes of green material per hectare. This is equivalent to about 110 kg of nitrogen. Plants can also be planted as a hedgerow at a distance of 1 metre or as a relay crop with maize. Leaves of *T. vogelii* contain at least four isoflavonoids with biological activity; these are collectively known as rotenoids (Fig. 8.). The highest concentration of the active compounds is found in the leaves. The main compounds are tephrosin and deguelin and the often cited component rotenone occurs either in only very low quantities or is completely absent (Figs. 6 and 7). Since much of the flag waving about the value of *Tephrosia* rests on its content of active rotenoids, and that rotenone is the only one that has been evaluated in laboratories much work still needs to be done in evaluating the other components to determine optimised applications. While much ‘grey’ literature cites rotenoids in the leaves of *Tephrosia* to be insecticidal, surprisingly there is no published work to corroborate this and indeed the bioactivity of *T. vogelii* against bruchids and weevils was even reportedly not associated with rotenoids (Koona & Dorn, 2005). The active components at least against *C. maculatus* are deguelin and rotenone although the latter occurs only at low concentrations in the leaves (Stevenson unpublished). Tephrosin, the other major rotenoid is not toxic despite having very similar structure to deguelin so the relative proportions of these components should be monitored in different cultivars distributed for soil improvement and in pesticidal plant use.

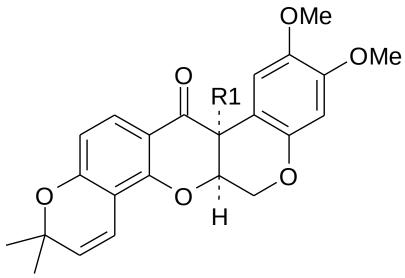


Fig. 6 Deguelin R1 = H;
Tephrosin R1 = OH

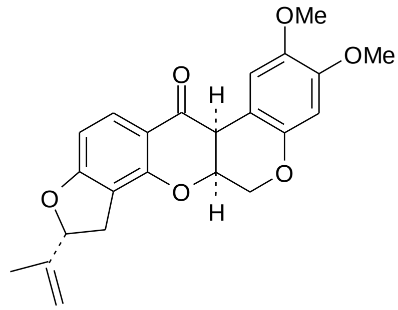


Fig 7 Rotenone

The active components are generally reported to be in the leaves and roots and the reported effects are anti-feedant, insecticidal, acaricidal, ovicidal, icthyotoxic and as a contact and stomach poison to insects. A range of field pests and stored product pests are susceptible but recent work shows them to be particularly effective against bruchids (Stevenson unpublished) but less effective against red spider mites and aphids of beans than less well studied species including *Tithonia diversifolia* and *Vernonia amygdalina*.

Preparation and application: Most 'rough guides' to using *Tephrosia* recommend using dried powdered leaves particularly in storage and as such it appears to be much more effective than if used as an extract in storage. Of course, great care must be taken with *Tephrosia* treated materials to avoid consumption. In experiments in Zambia, *Tephrosia* leaf powder admixed at a rate of 0.1% (w/w) with cowpea seeds proved highly effective in controlling the bruchid, *Callosobruchus rhodesianus*, which is an important pest on cowpea seeds. This treatment was more potent than the officially recommended Malathion. Germination was also much better on the *Tephrosia* treated material. As with most pesticidal plants control effects last about 3 months so the stored product needs to be retreated. This however, is no different to instructions for the use of synthetic actellic dusts. For field uses the leaves must be extracted in water at a rate of about 5% by weight to make extracts that are suitable for foliar spraying. This relatively higher quantity is required since the active compounds are non-polar so are not extracted efficiently in water. In this case it may be more effective to use fresh leaves since the rotenoids are already in an aqueous environment and be more susceptible to solubilisation. Unpublished work indicates that the addition of liquid soaps can greatly optimise the efficiency of extraction (Stevenson unpublished) of rotenoids. For example, 5% teepol extracts 8 times more rotenoids from dried leaves than water which is almost as efficient as using 100% methanol. If concentrated extracts are made using 5% liquid soaps these can then be diluted prior to spraying so that soap concentrations are more appropriate for field applications e.g., 0.1%. The incorporation of soaps early on in the process may help to ensure that surfactants are ultimately used when sprayed to help disperse the active chemicals on the plants – an inclusion that is all to often overlooked by farmers using pesticidal plant extracts or commercial products.

Fig 8 and 9. *Tephrosia vogelii* is the most well known pesticidal plant in Malawi and Zambia where it has been promoted widely to improve soil nutrition.

Bobgunnia madagascariensis **Fabaceae**

Usually a small deciduous tree, 3-4 m in height. The plant part used in insect control is the pod which is cylindric, up to 30 cm, dark brown to black when ripe, indehiscent (Fig. 10). Generally found in deciduous woodland and wooded grassland, often on sandy soils throughout tropical and southern Africa. A typical species of Miombo and while common occurs sparsely. Although it is not clear what the effects are there are high concentrations of saponins in the pods which like with *Securidaca* (below) may be responsible for the effects. Its traditional use is as a fish poison.

Farmers in southern Africa report this species to be useful primarily in stored products although its efficacy is not straight forward. Recent data (Stevenson, Sola and Mvumi unpublished) has shown that this plant material is ineffective at controlling C*allosobruchus maculatus* on cowpea or

Sitophilus oryzae on maize in farm trials but is highly effective at controlling *Acanthoscelides obtectus* on dry beans in laboratory trials. It is very important to collect the pods when they are dry otherwise they add moisture to grain and then exacerbate infestation and can result in greater damage to stored grain than without doing anything at all. Pods are collected, shade dried and pounded to a powder which is admixed with stored grain at a concentration of about 5% by weight – so quite a lot. Work is currently underway to develop a micropropagation technique for its multiplication but the distribution of seeds with instructions for germinating them should provide greater local production of this tree to ensure easy availability of material.

Fig 10. *Bobgunnia* (*Swartzia*) *madagascariensis* (Snake Bean Tree)

Fig 11. *Tithonia diversifolia* (Mexican sunflower)

Tithonia diversifolia **(Mexican sunflower) Asteracece**

T. diversifolia is an annual or perennial herb or shrub to 3 m. The flower buds are reportedly the most active but leaves are also effective against mites and aphids (Fig. 11). The herbivory activity of plant material is thought to be associated with sesquiterpene lactones secreted by the glandular trichomes on the leaf surface. There is a considerable seasonal variation in the occurrence of the active compounds which could hamper the successful use the material unless it is collected at the optimum time. In the southern hemisphere the highest level of the main metabolite tagitinin C occurs between September and October and the lowest was from March to June. A 10% extract is made by boiling the flower buds or leaves in water.

Securidaca longepedunculata **Polygalaceae**

This is a small tree up to about 6 m. or shrub that is very variable in size and shape. Flowers are pink or purple (Fig 12) sometimes variegated with white, sweet-scented giving it the common name of violet tree. Found in various types of woodland and wooded grassland across sub-Saharan Africa it is typical of African drylands. It's rarely gregarious but variable in habit and morphology such that it has been subdivided by various authors into a number of varieties. An infusion of the roots is used as a remedy for snake-bite and is commonly used as a medicine in many parts of Africa for the treatment of rheumatic conditions, fever, headache, and various other inflammatory conditions (Oliver-Bever, 1986; Assi & Guinko, 1991). Powdered dried roots are also used in pest control against insect pests in stored grain (Belmain *et al.*, 2001; Boeke *et al.*, 2001).

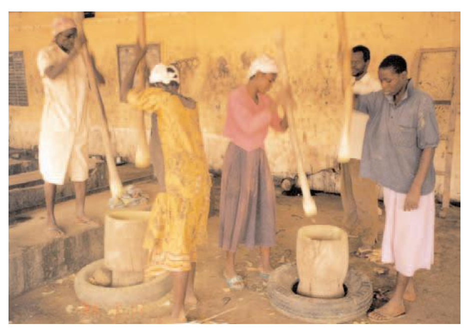


Fig. 12 From Top left clockwise, *Securidaca* seeds, flowers, pounding root bark, stripping bark from roots, collecting roots.

Historically it was used as a fish poison but also has various medicinal uses and even some molluscicidal properties. Most relevant to this review is its use recorded in Ghana against stored product pests. While it is most effective against *Sitophilus oryzae* and *zeamais* it also has some activity against bruchids so has potential to be of value in bean storage (Jayasekera *et al.*, 2003). The activity has been attributed to a volatile terpenoid methylsalicylate (Fig. 12) (Jayasekera *et al.*, 2005) and several saponins (Stevenson *et al.*, 2009). This has led to successful attempts to optimise its use by making water extracts that can then be used to soak the grain or beans prior to storage which makes more efficient use of the relatively scarce plant material. This coats each grain with the active saponins but along with the solarisation after dipping in the extract helps to kill pre storage infestation.

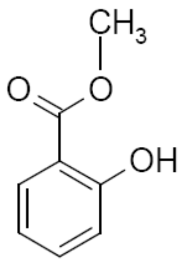


Fig 12. Methyl salicylate

Fig 13 Treating grain with water extracts of *S. longepedunculata*

Tanecetum (Chrysanthemum) cinaerifolium **Compositae Pyrethrum**

Pyrethrum actually originates in the Dalmation mountains but is now cultivated across the world and particularly in East Africa although it is restricted to higher altitudes to ensure good flowering which can last up to 10 months with an optimal 100 flowers per plant. The flowers contain the highest concentration of active ingredients (up to 20% by weight) and these are the origins of the synthetic pyrethroids that are of considerable importance worldwide in the commercial agrochemicals sector.

Pyrethrum is potently insecticidal, with some repellency and contact toxicity. One great attribute is there is almost instant knockdown particularly of flying insects which impresses farmers but it is as effective at killing non-target species as the pests themselves. Having said this, its activity is only effective for about 12 hours and is particularly sensitive to sunlight so bees can be spared if used in the evening. Although some people show allergic reactions in the main Pyrethrum is largely non-toxic to mammals.

Pyrethrum refers to the oleoresin extracted from the dried flowers of the pyrethrum daisy, *Tanacetum cinerariaefolium* (Asteraceae). The flowers are ground to a powder and then extracted with hexane or a similar non-polar solvent; removal of the solvent yields an orange-colored liquid that contains the active principles. These are three esters of chrysanthemic acid and three esters of pyrethric acid. Among the six esters, those incorporating the alcohol pyrethrolone, namely pyrethrins I and II, are the most abundant and account for most of the insecticidal activity. The need to extract with hexane illustrates the polarity of the chemicals and one of the reasons why Pyrethrum is less appropriate for small holders; they only have water to extract with.

The toxicity of Pyrethrum is enhanced with the addition of small quantities of rotenone (*Tephrosia, Lonchocarpus* or *Derris*) or nicotine (Tobacoo) and indeed the combination of materials may prove to be the real winning formula for pesticidal plants generally as weaknesses imparted on pests with one material increases susceptibility to others. This is a very underutilised strategy in pesticidal plants and while more complicated is likely to be a very much more effective use of the materials.

***Tagetes minuta* (African marigold) Asteraceae**

T. minuta is an introduced garden ornamental, native to Central America, widely planted in public and private gardens. Nowadays it is found as an escape in fields and along riverbanks, even at elevations above 600 m. It is an erect annual herb, branching above, growing up to ca. 90 cm high, rooting at the lower nodes. Leaves usually are alternate, deeply divided with toothed leaflets which are linear-elliptic. Plant parts with insect-controlling properties include leaves, flowers, seeds and roots. The mode of action is repellent, insect-controlling and with efficacy against aphids, bean pod weevil, caterpillars diamondback moth, leaf beetle, leafhoppers and grasshoppers. A 2.5% extract of the dry leaves in water is reported to be effective. In granaries fresh material is advised placing them about 2.5 cm thick on the bottom and a similar layer on top.

***Euphorbia tirucalli* Euphorbiaceae**

An unarmed, succulent shrub up to 5 m, or a small tree to 12 m, with brittle succulent branches, c.7 mm thick, green with fine longitudinal white striations (Fig. 15) that exudes white sap when broken that is typical of euphorbes but can be quite irritant to applicators. Found in open woodland; very frequently planted and naturalising near habitation. Plant parts with insect-controlling properties are the succulent branches with toxicity to a range of insect species including aphids, termites and cutworms.

A fresh mature branch of the plant is pounded finely. This paste is dipped into 10 litres water and allowed to extract for some time. The solution is filtered and ready to be sprayed. In fact to control cutworms 10 drops of oozing sap from a cut branch are collected, added to 1 litre of water and ready to use. For general grain pests, branches are burnt to obtain its ash. One teacup full of ash is mixed with 20 litres of grain.

Fig 15. *Euphorbia tirucalli*.

Neorautanenia mitis **(A.Rich.) Verdc Leguminosae.**

Sub-shrubby highly variable erect climbing stems to 2m from a large tuberous root stock (Fig 16) that can reach 12kg or more in weight. It is this part of the plant that contains the highest concentration of biologically active material. It occurs on grassland, bushland and open woodland of African dry lands. The foliage is reportedly browsed by goats although seeing as the plant is generally fairly poisonous it is likely that this is rare or that the leaves are low in toxins.

Historically it is known to be used by the Wahehe and Sukuma as an insect control agent against *Sitophilus zeamais* and scabies although it appears to be little known more widely across Africa and was not mentioned in recent surveys in Malawi and Zambia.

Recent studies of this plant root which was from an old collection of material indicated activity against bruchids that was similar to that for *Tephrosia vogelii*. Analysis of the root showed the presence of rotenone and deguelin among numerous other rotenoids.

The toxicity of the plant can also be questioned when one considers that the fruit was consumed by Sukuma people as a famine food.

This species is an underexploited material that would benefit from much more work to determine its value in crop protection. While it is not rare it is not abundant where it grows so efforts to propagate them would help realize their potential for farmers.

Fig 16 Neorautanenia mitis.

Plant Essential Oils (*Rosmarinus officinale, Eucalyptus globus, Syzygium aromaticum, Thymus vulgaris*).

Steam distillation of aromatic plants yields essential oils, used as fragrances and flavorings in the perfume and food industries and more recently in aromatherapy and as herbal medicines (14, 26). Plant essential oils are extracted primarily from the mint family (Lamiaceae). The oils are composed of complex mixtures of monoterpenes, phenols, and sesquiterpenes such as 1,8-cineole, the major constituent of oils from rosemary (*Rosmarinus officinale*) and eucalyptus (*Eucalyptus globus*); eugenol from clove oil (*Syzygium aromaticum*); thymol from garden thyme (*Thymus vulgaris*); and menthol from various species of mint (*Mentha* species). A number of the source plants have been traditionally used for protection of stored commodities, especially in the Mediterranean region and in southern Asia, but there is scope to introduce their use more widely in Africa. The rapid action against some pests suggests neurotoxic activity. While some of the purified terpenoids are moderately toxic to mammals products based on oils are mostly nontoxic to mammals, birds, and fish (Isman, 2000). However pollinators and natural enemies are vulnerable to essential oil based products. Essential oils are volatile so have limited persistence under field conditions; therefore, although natural enemies are susceptible by direct contact, predators and parasitoids that invade a treated crop one or more days after treatment are unlikely to be poisoned by residue contact as often occurs with conventional insecticides. The scope to develop products based on essential oils is buoyed by the fact that most of the active components are already components in foods and as such are considered safe by regulatory authorities and can avoid the costly process of toxicology. There is surprisingly little evidence of use of these species in pest control in southern Africa although we did record use of *Ocimum americanum* in Ghana (Belmain and Stevenson, 2001).

3.0 Optimizing use

There has been a huge amount of information published in the scientific literature and elsewhere on pesticidal plants but still farmers struggle to apply this technology as a genuinely competitive alternative to synthetic products. This may be because there is a tendency of scientists to conduct sporadic research and move on once the extent of their own scope has been reached. In African institutes this often occurs at the point when plant chemical analysis is required and particularly the structural elucidation of unknown products is required. Chemical knowledge can help provide optimized solutions for the extraction or application of some materials as illustrated above. A network of scientists working towards the same goals but with diverse range of skills is required to ensure that all the efforts are focused and have the scope to provide all the required information. It will then be possible to not only validate materials on farm and in the laboratory but also determine the mode of action the active compounds and specific range of activities of materials to apply this to the farmers needs. It is at this point that their application, preparation and harvesting can be optimized to impact on livelihoods along with the development of approaches to improve health and safety of their use and reduce the human exposure to materials. For wild species especially those that are less common some information on their distribution and habitats is required to ensure any promoted use is sustainable and that conservation is promoted alongside the use of wild species. Guidelines for harvesting from the wild are required for most species and where possible to cultivate materials. This is clearly a possibility for *Tephrosia* spp. since they are already cultivated but other species can be grown locally for the sole purpose of using as pesticides which can reduce pressure on wild populations but also save farmers time collecting. Some efforts are underway to develop micropropagatative methods for *Securidaca longepedunculata* and *B. madagascariensis*.

Where possible there may be scope to strengthen market potential for some materials. Government subsidies ensure in some African nations that pesticides are affordable for the so called staple foods like maize. However this is often not the case with legumes on which synthetic pesticides may generate significant tax revenues. In which case, government recruitment to promote activities through their extension services may be less popular operations than those which promote the use of pesticides. The best way to promote the use of optimized pesticidal plant technologies is through the development of market opportunities for SMEs. As long as someone is making some money from the process then it will be promoted through normal channels of business thus a great deal of emphasis needs to be placed on opening up market potential for these materials and scientists need to back stop the development of marketable materials.

Farmers may perceive the use of pesticidal plants as somewhat crude and unsophisticated. Therefore it may help promote their use if they can be packaged into a technology product. One idea that will be investigated on a new McKnight project is the potential to develop a delivery system of effective pesticidal plant materials through filterbag technology. This involves optimizing the concentration of a plant material in a sachet similar to a tea-bag that will allow the extraction of the active components without contaminating the apparatus with particulate matter that might block sprayers. The amounts required can be predetermined by the supplier – so for example 4 bags for a 20l knapsack sprayer extracted overnight. These 'tea bags' can be impregnated with soaps to optimize extraction as described for *Tephrosia* above and essentially provide a low cost product that is effective and appeals for all the reasons explained above.

Ultimately efforts need to be implemented to improve knowledge about pesticidal plants to increase their consistency (efficacy), improve harvesting (sustainable), achieve higher yields and ultimately increase profits

4.0 Commercialization

Current commercial products: There is a vast quantity of literature reporting the effects of plant chemicals on insects with much of it published in the past 30 years but despite this between 1980–2009, only neem products and essential oils were registered for use in the United States and parts of Europe as agrochemical products. Having said that biocontrol has seen a 15% increase annually in products but this is still the domain of SMEs and cottage industries. While there are numerous examples worldwide of biocontrol agents only 26% are natural products (Neem and essential oils) with the remainder being macrobials (predators/parasites/nematodes) and microbials (fungi, bacteria, virus) (http://www.ibma.ch/) and of this less than 3% of the industry is represented by the continent of Africa.

Product development. For those products that have found some commercial potential the rewards can seem tempting. The example of a contemporary botanical pesticide, Neem Azal produced by Trifolio-M GmBH illustrates the investement. A brief analysis of the development indicates that while the cost is a fraction of that for a synthetic product (<10%), the costs are still high and the time investment sufficiently long to make the likelihood of a similar process succeeding in most African countries to be small. Development takes 10 years to registration with an overall cost of around £12 million. Chemistry and formulation costs around £2million and takes 2-3 years, with biological screening in glass houses and then field taking 5 years at a cost of 2 million but it's the risk assessment that contributes the highest cost at 8 million and– toxicology and ecotoxicology taking 2-3 years. This contrasts with about 250 million for a synthetic product although the market return for the latter is likely to be equally inflated.

The real scope for the commercialization of pesticidal plants in Africa probably lies with community based organizations or small enterprises. These could be established with the input from development programs to help establish them up with technical backstopping but the analytical requirements could always prove to be a hurdle for continued success. This has been born out in attempts to establish cottage industry production for nucleopolyhedrovirus in India. Shortly after the scientific backstopping was withdrawn the product had become Without the continuous quality assessment of the product efficacy reduces and with it the confidence of the farmers in the product.

There is considerable scope for developing novel approaches to optimize application that are appropriate for small holder African farmers and may be suitable for uptake by local CBOs or small enterprises but will require some scientific investment based largely on fully understanding the nature of biological activity and the validation of materials against specific pest species to emnsure that materials are not used randomly. The regulatory processes must be observed and these may require two or three seasons of field evaluation under observation from the relevant authorities. Some examples have already been touched upon above and include the use of 'teabag' technology and liquid soaps to simplify qualitative control and optimize extraction, particularly for field use of plant materials that require spraying. Similarly there is scope for developing approaches to using plant materials for storing food pulses as well as seed material by keeping the plant materials separate from the seeds. For example, where stored in plastic tubs or pots a trap layer of seed laid on the top of the grain and treated with a relatively high concentration of plant material would allow the majority of the store to remain untouched and this would also simply the retreatment at periods during the year. Alternatively, where farmers use sacks for storage there is scope for investigating whether the treatment of the storage sacks themselves might allow for the protection of the seeds using potentially harmful materials without them being in direct contact with the plant material. Recent studies show that although the insects take longer to die, contact of *Callosobruchus maculatus* with extracts of *Tephrosia vogelii* and *Neorautanenia mitis* incapacitates females almost immediately and drastically reduces oviposition despite no killing the insects immediately like the powdererd plant material.

5.0 Going forward

Investment must be focussed on actions that support African countries to develop collaborative multidisciplinary teams with the appropriate knowledge and scientific skills to optimise and promote the use of pesticidal plants to reduce the reliance on synthetic pesticides. These networks need to assist the development of policies related to the regulation of indigenous knowledge, bio-diversity conservation, health & safety directives and commercialisation of pesticidal plants and natural products. Equally there needs to a focus on strengthening basic research and technology across Africa in the field of pesticidal plants by ensuring that the generation of knowledge is appropriately focussed on current constraints and strongly linked to the needs of end users, civil society and enterprise. Once established these networks should strengthen institutional and policy levels across Africa by encouraging debate and consensus over best practice guidelines, and the need for formal regulatory frameworks regarding the protection and utilisation of indigenous knowledge, bio-diversity conservation, health & safety and the commercialisation of pesticidal plants.

These networks will assist in the coordination of applied research activities on pesticidal plants at a range of institutions (universities, NGOs, government research institutes, extension agencies, policy makers) to catalyse discussion and promote collaborative research cooperation. Constraints to widening promotion and uptake and knowledge gaps can be formulated and reinforce research quality by consulting and involving a wide diversity of stakeholders. Improved management of research activities is also important aspect and can be provided by training workshops and seminars that focus on enhancing research responses to knowledge gaps identified by the networks.

Strong partnerships across African institutions will facilitate teams to bid effectively for competitive funding calls by fielding diverse multi-disciplinary teams to comprehensively address knowledge gaps. Ultimately this capacity building fosters the critical mass of expertise which becomes increasingly self-sustaining as programmes develop.

Development and promotion of use of effective and safe botanical pesticides in an appropriate manner will increase yields of legume field crops and stored products by rural smallholders and hence increase their incomes. Their local availability and relatively low cost make botanical pesticides particularly appropriate for use in developing countries where alternative methods of pest control are often not available and/or expensive. Development and promotion of improved strategies for cultivation, harvesting and processing of pesticidal plants are needed to provide opportunities for rural small holders as well as small-scale entrepreneurs to generate income by supplying approved botanical pesticides required by farmers, particularly in peri-urban areas where demand may be great but supply restricted.

To date, research in Africa on pesticidal plants has been fragmented, relatively small-scale and largely laboratory-based. These networks will enable new, lasting partnerships between institutions across Africa including academic and government laboratories, NGO's and farmer organisations. Ultimately it is envisaged that the outcome will be better and more meaningful research attaining wider readership and having greater overall impact; NGO's will have more and better information to disseminate to their beneficiaries and farmer organisations will have more reliable and optimised materials for their members to increase productivity and incomes.

Pesticide application

1. Introduction

Pulse crops such as cowpeas (*Vigna unguiculata*) - staple food and an important source of protein for over 200 million people and chickpeas (C*icer arietinum*) – the third most important legume in the world, are important sources of food in sub-Saharan Africa. The production and productivity of chickpea has remained stagnant over the past five decades because of several biotic and abiotic constraints. Lentils are an under-exploited pulse in African countries, with Ethiopia being the exception. For all pulses, major losses can be experienced due to pests such as the legume pod borers *Helicoverpa armigera* and *Maruca vitrata/testulalis,* aphids (*Aphis craccivora*), flower thrips (*Megalurothrips sjostedti*), and various pod sucking bugs. In addition to direct damage, aphids can spread virus diseases such as leaf roll virus. Published estimates of pre-harvest losses vary but taking a potential yield for cowpea of around 3 tonnes per hectare (Rusoke and Fatunlat, 1987), the typical yield of 400 kg reported by Omongo *et al* in 1997 indicates that much of the potential is missed. Insect pests and diseases such as fusarium wilt, various viruses and blights are very important in reducing output although factors such as variety, low fertiliser use and irrigation are also responsible for low yields. Indeed the pulses are typically grown with relatively low inputs, either because they tend to be grown on drier or less fertile lands or because pulse growers do not have the finance for more intensive production. For pest management, use of varieties that are resistant to pests and diseases is often the favoured option and aside from post-harvest, use of insecticides and fungicides is limited. The work described below indicates that there is a role for insecticides both to control pests and the virus diseases they can transmit.

2. Use of pesticides in pulses

Pesticide use has typically been low on smallholder pulse production due possibly to cash flow constraints on their purchase, limited availability and low levels of information on product choice, best practice and cost benefit of their use. Where they have been used, application is usually in the form of emulsifiable concentrate or wettable powder formulations, mixed with water and applied by lever operated knapsack sprayer using hydraulic cone nozzles. However, application of concentrated oil based formulations of insecticides and fungicides through controlled droplet application (CDA) devices such as the Micron Micro Ulva and the Electrodyn to cowpea, pigeon pea and groundnuts in Nigeria has also been reported by Micron Sprayers Ltd (2005) and in India by Sharma (1998).

There is a limited amount of published data on the efficacy of pesticides for pest and disease control on small scale legumes in southern and eastern Africa, although there is additional material from other regions and continents. Ajeigbe and Singh (2006) showed experimentally that under Nigerian conditions two to three insecticide sprays gave good cost benefit ratios with improved varieties of cowpea and a single spray of a mixture of dimethoate and cypermethrin applied at flowering time increased the value of yields by US$100 per ha with a cost benefit ratio of 15. Makkouk and Kumari (2001) reported that imidacloprid used as a seed treatment reduced transmission of several virus diseases in various legume crops and significantly improved yields of moderately resistant and susceptible lentil types. Nabirye *et al*. (2003) studied integrated pest management technologies in Uganda to control insects attacking cowpea. Targeted pests included *Aphis craccivora*, flower thrips (Megalurothrips sjostedi), legume borer *Maruca vitrata and* a range of bugs that attack pods. Combining cultural control practices such as intercropping and time of planting with three applications of pesticides (dimethoate and cypermethrin) at budding, flowering and podding stages was more effective than the standard weekly spraying regime and gave the highest yields of 791 kg/ha. This is a 51% increase over farmers' traditional practice. Mallikarjunappa and Rajagopal (1991) studied action thresholds for initiating insecticide sprays based on peak egg laying and pod borer damage on field bean, concluding that an initial spray at peak egg laying and tender pod stage, followed by sprays to maintain 0.5 flat pods damaged per inflorescence reduced pod and seed damage and maximized the yield and net returns. The strategy also resulted in fewer insecticide applications than calendar-based sprays.

Ward et al (2002) used partial insecticide applications (i.e. some areas untreated) on cowpea. The results showed that the presence of insecticide-treated plants (carbofuran or furathiocarb) reduced the level of leaf damage on untreated plants. The greater the percentage of insecticide-treated plants the greater this reduction on the untreated plants. Meanwhile, the number of flowers found on the untreated plants increased suggesting the foliage pest damage reduced flower production. Karungi et al (2000) looking for a cost-effective pest management strategy for cowpea growers in Uganda found that planting cowpea at the onset of rains gave good yields when insecticides were applied. A single spray at budding, flowering and podding had the highest marginal returns (3.12) in comparison to spraying throughout the season (1.77) and at seedling, flowering and podding stages (2.18). Grain yields and marginal returns from plots receiving combined control measures were higher than those from plots receiving only cultural or chemical control measures, providing evidence that a few well-timed sprays in combination with cultural practices are not only effective but also very profitable. Afun et al. (1991) compared monitored (decisions made on the basis of scouting for pests) and calendar spray applications in Nigeria to determine whether it was possible to reduce the number of insecticide applications without compromising yield. The study focused on cowpea aphid (*Aphis craccivora*), legume bud thrips (*Megalurothrips sjostedti*), legume pod borer (*Marcua testulalis*) and pod-sucking bugs. These pests damage cowpea at various stages of growth. The trials were carried out at three locations and one of two calendar schedules were used (7 or 10 day spray intervals) whereas the monitored spray treatment had only two spray treatments. Differences in insect pest numbers were not significant, neither were there differences in grain yield, although the calendar schedules recorded lower infestation/damage by aphids, flower thrips and pod borers than monitored spraying. They concluded that decision-based spraying was a better way to manage cowpea pests.

Tanzubil *et al*. (2008) conducted trials in the Sudan Savanna zone of Ghana to evaluate the potential of integrating host plant resistance with chemical control in the management of key insect pests of cowpea, *Vigna unguiculata*. None of the improved varieties tested showed significant and consistent resistance to the key pests and there were no significant interaction effects between varieties and spray regime. Spraying the crop with lambdacyhalothrin during the reproductive phase produced better results than with neem extracts but both levels of neem increased yield significantly. Kamara *et al*. (2007) working on insect pests of cowpea in Nigeria, evaluated the response of diverse cowpea genotypes to different schedules of spraying with an insecticide. Flower thrips, the legume pod borer (*Maruca vitrata*) and a range of pod-sucking bugs were the major insect pests. Application of insecticides once at flowering increased grain yield by 75%. Application at both flowering and podding stages, significantly reduced insect pest population and increased grain yield by 126%. Improved cultivars recorded a higher grain yield than the local checks at all spraying regimes. Marko (2000), working on chickpeas in the northern Guinea savanna zone of Ghana looked at effect of three sprays of lambdacyhalothrin insecticide at 12 g active ingredient per ha at different stages on crops planted at different dates. The results indicated that early planting did not have any effect on insect damage. His results, based on damage scores for *Mylabris pustulata* and *Helicoverpa armigera* indicated that effective insect control should start at floral bud initiation stage.

Ambang *et al*. (2009) working with cowpea, *Vigna unguiculata* - an important food crop widely grown in the Soudano-sahelian region of Cameroon - used an integrated disease control approach involving insecticide treatment and plant host resistance to control virus-induced diseases, which are the most yield-limiting factor. Cyperdim 220 EC (cypermethrin + dimethoate) insecticide was applied at different doses (1.75, 1.25 and 0.95 l/ha). Severity of cowpea viral diseases including Sterility Mosaic Virus Disease (SMVD), YMVD, ABMVD and GMVD, was assessed as was population of thrips (*Megalurothrips sjostedti*) and larvae of *M. vitrata*, the two main vectors of cowpea viral diseases. Both viral diseases and the population of vectors reduced with combined treatment consisting of the less susceptible cowpea variety VYA and the highest insecticide dose (1.75 l/ha). This treatment combination also produced the highest cowpea grain yield (29.5 t/ha), a yield that was almost 3 times higher than the control (10.2 t/ha).

In the US Javaid *et al*. (2005) looked at the effect of insecticide spray applications, sowing dates and cultivar resistance in diverse cowpea genotypes in Delaware, Maryland and Virginia in the United States. A mixture of cypermethrin and dimethoate was applied in the first experiment and the number of spray applications ranged from two to six. The second experiment had two sowing date treatments and received four spray applications of endosulfan. There was a 30% increase in cowpea seed yield as a result of spraying the mixture of cypermethrin + dimethoate insecticides. The damage to cowpea pods was also significantly reduced in the sprayed treatments. The first and second sowing dates of cowpea sprayed treatments gave 30% and 45% increase in the seed yield over the first and second unsprayed dates of sowing cowpea treatments, respectively. The first sowing date treatment gave significantly higher seed yield than the second sowing date treatments. There were significant differences in the number of some major insect pests and also on pod damage among the ten diverse cowpea genotypes.

Singh *et al.* (2009) evalutated the effectiveness of IPM modules against grain pod borer, *H. armigera* on chickpea (*Cicer arietinum L.).* Amongst the various methods evaluated were pheromone traps @ 20/ha, bird perches @ 20/ha, endosulfan 35 EC @ 0.07% a.i. and chlorpyriphos @ 0.05% a.i. Highest yields were correlated with highest dose rate and although the population of natural enemies was low the cost benefit was highest with highest dose applied. Wightman et al (1995) studied the influence of the density of larval *H. armigera* (instars 4-6) on the seed yield of chickpea plants growing in large cages. Their work indicated that one larva per plant was a critical density. Larval feeding activity during the first 2 weeks of flowering had no effect on yield. There was also no evidence of compensatory growth following insect attack during the flowering stage. These data were used to set action thresholds in a large (0.8 ha) field experiment that was designed to investigate the economics of insecticide application. *H. armigera* had a marked effect on the yield of the two pest-susceptible varieties, both of which would have made a loss unless protected by insecticides. Helicoverpa-resistant ICC 506 did not achieve as high a yield as the other two varieties when treated with insecticides but did make a profit when no insecticide was applied. Three insecticide applications during the following season resulted in a greater than threefold increase in yield (from 0.65 to 2.2 t ha-1). Karel and Ashimogo (1991) evaluated the effectiveness of dimethoate in protecting common bean (*Phaseolus vulgaris L*.) and soybean (*Glycine max L. Merrill*) against insect infestation. Without the use of insecticides, higher seed losses were recorded in common bean than in soybean. Common bean had losses of 37, 36 and 47% for plants unprotected before flowering, after flowering, and during the entire period of growth, respectively. The corresponding losses for soybean were 22, 10, and 32%. Although failure to protect soybeans from insect pests led to relatively lower seed losses than in common beans, seed yield increased remarkably as a result of insecticide application in both legume species. The study suggested that at least two insecticide sprays can significantly reduce seed losses caused by insect pests.

Adipala *et al*. (2000) concluded that for the diverse cowpea pest complex, a single control strategy is unlikely to produce satisfactory control. Ekesi (1999) reported resistance in *M. vitrata* on cowpea in two locations (Shika and Samaru) to cypermethrin, dimethoate, and endosulfan. When compared with a susceptible reference strain, resistance ratios ranged from 17- to 53-fold for cypermethrin, 27- to 92-fold for dimethoate, and 15- to 37-fold for endosulfan. Low level of tolerance to lambda-cyhalothrin (3-4-fold) was observed in Samaru. He recommended non-chemical approaches or the use of chemical insecticides only when necessary to prevent or delay the development of resistance to insecticides.

3. Impact of pesticides natural enemies

One important factor in decision making on the use of inorganic pesticides for legume crop protection is the damaging effects of specific pesticides on biodiversity. Any unwanted reduction of environmental biodiversity is an important criterion because in the absence of insecticide, predators and parasites help to suppress pest numbers and killing ‘beneficials’ exacerbates the control problem.

Important species of natural enemies vary from crop to crop and from country to country. They include predators such as bugs, lacewings, syrphids (hover flies), beetles (including ground beetles and ladybirds), wasps, ants and spiders (Hajek, 2004). Also important are parasitoid flies and wasps that lay their eggs in or on eggs. Pathogens such as nuclear polyhedrosis virus and Mermithid nematodes have also been observed killing larvae of *H. armigera* (Bell, 1995), so need to be considered within an IPM programme.

An analysis of natural enemy impact on *H. armigera* populations was carried out by Dobson and Russell (2005 – unpublished). Studies in Kenya (van den Berg *et al.,* 1993) indicate that Anthocorid bugs (mainly *Orius* spp.) and ants (*Pheidole* spp., *Myrmicaria* spp. and *Camponotus* spp.) play the most important natural regulatory role on *H. armigera*. Parasitoids were also present, particularly the egg parasitoid *Trichogrammatoidea* spp. and the Tachinid larval parasitoid *Linnaemya longirostris*, but their impact was generally low. In contrast, in northern Tanzania, parasitism was the major cause of bollworm mortality on sorghum, cotton and a weed (*Cleome* sp.). The importance of the different species of parasitoids varied with host plant (van den Berg *et al.*, 1990) and in India, Ichneumonid wasps such as *Campoletis chlorideae* have been found to be important (Gopal and Senguttuvan, 1997) for *H. armigera* suppression.

The impact of parasitoids on the seasonal abundance of *H. armigera* is still poorly understood and few quantitative details were available, other than of percentage parasitism. Egg parasitoid effects can be significant. Intermediate rates of parasitism have been recorded for some of the *Tachinidae*, but these generally occur too late in the larval stage to reduce host damage. Reviews have been produced by King and Jackson (1985) of European and a number of Asian countries, for Africa by van den Berg *et al.* (1993), and for Sri Lanka and Australia by Waterhouse and Norris (1987). In most regions, species of *Telenomus* and *Trichogrammatidae* (*Trichogramma* and *Trichogrammatoidea*) are important egg parasitoids, and larvae are parasitized by at least one species each of *Braconidae*, *Ichneumonidae* and *Tachinidae*.

The review by Dobson and Russell (2005 – unpublished) assessed published information on the impact of specific insecticides on natural enemy populations. The data on non-target effects are summarised in Table 1, largely using the SelecTV system of scoring impact. SelecTV is a database developed at Oregon State University that rates the effect of about 400 pesticides on over 600 species of natural enemies. Scores are an average of many individual data on a wide range of natural enemies and crops. Numbers approaching five indicate a profoundly harmful effect on beneficial organisms. Any score over 4 indicates at least 30% mortality. This apparent systematic bias towards apparently low natural enemy mortality is because even small reductions in predators/parasitoid numbers can trigger rapid expansion in numbers of their prey/host numbers, i.e., the crop pests. An alternative ranking system developed by the company Koppert was also incorporated in which three species of beneficials, a parasitoid (*Trichogramma* spp) and two predators (*Chrysoperla carnea* and *Orius* spp.) were used as indicators.

Table 1. Rated effect of individual pesticides on beneficial organisms in crops

Active ingredient	**Impact 1 – 2.9***	***Active ingredient***	**Impact 3 – 3.9**	**Active ingredient**	**Impact 4.0 - 5**
NPV (Bio)	1.0	phosalone (OP)	3.4	fenvalerate (Pyr)	4.0
azadirachtin (Bot)	2.0	endosulfan (OC)	3.5	fenthion (OP)	4.0
Bt products (Bio)	2.2	amitraz (Am)	3.7	triazophos (OP)	4.0
thiodicarb (Carb)	2.5	acephate (OP)	3.7	beta-cyfluthrin (Pyr)	4.0
teflubenzuron (BU/IGR)	2.5	phenthoate (OP)	3.7	cyfluthrin (Pyr)	4.0
diflubenzuron (BU/IGR)	2.6	carbofuran (Carb)	3.8	biphenthrin (Pyr)	4.0
lufenuron (BU/IGR)	2.7	phorate (OP)	3.8	spinosad (Bio)	4.0
fluvalinate (Pyr)	2.8	fenpropathrin (Pyr)	3.8	emamectin benzoate (Ave)	4.0
		DDT (OC)	3.9	flucythrinate (Pyr)	4.0
		carbaryl (Carb)	3.9	phosphamidon (OP)	4.0
		chlorpyrifos (OP)	3.9	BHC (OC)	4.1
		dichlorvos (OP)	3.9	monocrotophos (OP)	4.1
				fenitrothion (OP)	4.1
				dimethoate (OP)	4.1
nimbolinin B and ohchinolide-A, (Melia azedarach) (Bot)	no data			methomyl + fenvalerate (Carb+ Pyr)	4.2
chlorfenapyr (Pyr)	no data			deltamethrin (Pyr)	4.2
				cypermethrin (Pyr)	4.3
				malathion (OP)	4.3
				methidathion (Carb)	4.3
				methyl parathion (OP)	4.3
				methomyl (Carb)	4.3
				quinalphos (OP)	4.4
				EPN (OP)	4.4
				methamidiphos (OP)	4.5
				profenofos (OP)	4.5
				imidachloprid (Neon)	4.5
				cyhalothrin (Pyr)	4.7

- Toxicity ratings: 1 = 0%, 2 = <10%, 3 = 10-30%, 4 = 30 – 90%, 5 = >90%

4. Conclusions

Economics, availability and limited capacity and reliable information has meant that pesticides have not been used extensively on small-scale legume production in southern and eastern Africa thus far. However, the limited published information available, together with analogous experience in other crops, suggests that in some circumstances the cost benefit ratio of controlling pests and diseases using inorganic pesticides is favourable if they are applied to a high standard of timing, dosing and targeting as part of an IPM strategy. In particular, newer more selective molecules such as imidacloprid, applied as a spray or seed dressing can be very effective at controlling sucking pests (and some disease vectors), with older moledules (principally pyrethroids) to control chewing and boring pests, and low cost old molecules for fungal disease control. Non-target impact on natural enemies and resistance management will be important considerations in any successful regime.

POST-HARVEST LEGUME PEST MANAGEMENT

Introduction

There have been several reviews documenting postharvest pest management of pulses in sub-saharan Africa; cowpea (Huis van, 1991; Leinard and Seck, 1994; Singh *et al.* 1997; Kitch and Sibanda, 2001; Murdock *et al.*, 2003; Gomez , undated) and common beans (Giga *et al.*, 1992; Abate and Ampofo, 1996; Jones, undated). There have been no specific reviews relating to pigeon pea, bambara, groundnut or soya bean. Of these four, soya is so rarely affected by postharvest pest problems that it will not be mentioned in this review.

All relevant areas of pest management are included in this review, at least in as far as they relate to the postharvest activities of small-scale farmers/traders and although coverage is not exhaustive at least most important examples are quoted. The section on current research and extension activities offers only two examples, this may subsequently found to be deficient so that later additions may need to be made to this document.

Context of pulse postharvest activities

In sub-Saharan Africa, pulses are produced mostly by small-scale farmers. The chain of postharvest activities is broadly similar irrespective of the type of pulse concerned. Once the crop has reached physiological maturity, plants are pulled from the ground and left in heaps or rows to dry in the sun to a moisture content suitable for storage; in common beans, cowpea and pigeon pea this would be in the range of 14-15% or for groundnuts about 8% moisture content; the difference is due to the high oil content of groundnuts. In East and Southern Africa, such ideal moisture contents are not always achieved, resulting in some fungal growth (Giga *et al*. 1992). The whole plants are then brought to the homestead where they are threshed, usually by beating the pods with sticks. The harvested pulses will then be stored. Storage structures vary from sacks made of jute or polypropylene, to traditional granaries of various sorts to plastic or metal drums that can be sealed. Most farmers retain some of their crop for seed, the remainder would be for household consumption or sale; the different proportions varying according to season, marketing system, price and cash need. In many cases the pulses are sold as soon as possible to avoid pest attack, otherwise the pulses are stored for varying periods but usually less than one year.

The design and implementation of pest management to protect pulses may require changes to current practice and so account must be taken of the ability and willingness for adoption by subsistence farmers. Furthermore, to understand pest management opportunities it is important to understand the biology of the pest involved.

Postharvest insect pests of beans and their biology

Pulses in sub-Saharan Africa are attacked by a variety of postharvest insect pests (Table 1 and Fig. 1). All the listed pulses are attacked by beetles of the family Bruchidae while groundnuts may be attacked by other pests, especially further along the marketing chain in large-scale stores; details of these other pests are not be given in this review which will focus on farm storage. A guide to the identification and biology of tropical bruchid postharvest pests is given in Haines (1991).

a) ***Callosbruchus maculatus*** b) ***Zabrotes subfasciatus*** c) ***Acanthoscelides obtectus***

Figure 1: Some of the main insect pests of stored pulses

Bruchid beetles commence attack on the physiologically mature crop in the field, laying eggs on the seed pods or seed coats. In the case of bambara and groundnuts, which have subterranean seeds, attack by postharvest pests can only commence once they are lifted from the ground.

When female bruchid beetles lay their eggs on pulses they either glue them firmly to the seed coat (*Callososbruchus*, *Zabrotes*) and/or the seed pod (*Callosobruchus*), place them in crevices or scatter them (*Acanthoscelides* or *Caryedon*). When an egg has been firmly glued to the seed coat or pod, the emerging larva burrows directly from the egg into the substrate using the adhering egg shell as a brace; this causes the egg to fill with frass and change to colour to that of the pulse cotyledons. If the egg was not glued to the surface then the larvae will hatch and wander over the surface of the pulse until it has found a suitable site for penetration. Nevertheless, the larva still needs to brace itself to penetrate the seed coat and so will wedge itself in the narrow gap between the pulse to be attacked and an adjacent surface which may be another pod/pulse or the storage container (Quentin, 1991). Larval development usually takes place entirely within the pulse (Fig. 2) and just prior to pupation the last instar larva creates a weakened 'window' of seed coat through which the adult will push to emerge from the pulse. Adult bruchids are pollen feeders and usually live for only 10 to 12 days.

Table 1: Postharvest insect pests of pulses in sub-Saharan Africa

	Cowpea	Pigeon pea	Bambara groundnut	Common beans	Groundnut
Coeloptera – Bruchidae					
Callosobruchus maculatus	+	+	-	-	-
Callosobruchus rhodesianus	+	-	-	-	-
Callosobruchus subinnotatus	-	-	+	-	-
Callosobruchus analis	+	+	-	-	-
Callosobruchus chinesis	+	+	-	-	-
Callosobruchus phasoli	+	-	-	-	-
Acanthoscelides obtectus	-	-	-	+	-
Zabrotes subfasciatus	+	-	(+)	+	-
Careydon serratus	-	-	-	-	+
Coleoptera – Dermestidae					
Trogoderma granarium	-	-	-	-	+
Coleoptera - Tenebrionidae					
Tribolium castaneum	-	-	-	-	+
Lepidoptera - Phycitidae					
Ephestia cautella	-	-	-	-	+
Plodia interpunctella	-	-	-	-	+

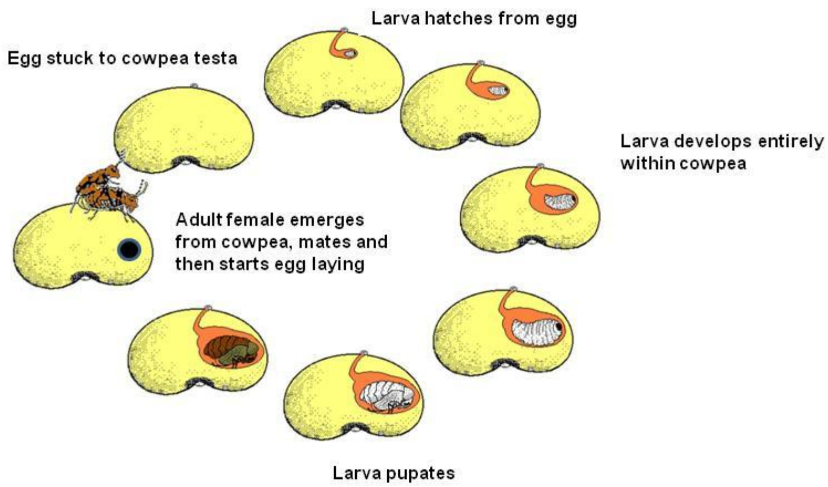


Fig. 2: Typical lifecycle of a bruchid beetle infesting a cowpea or other pulse (source NRI)

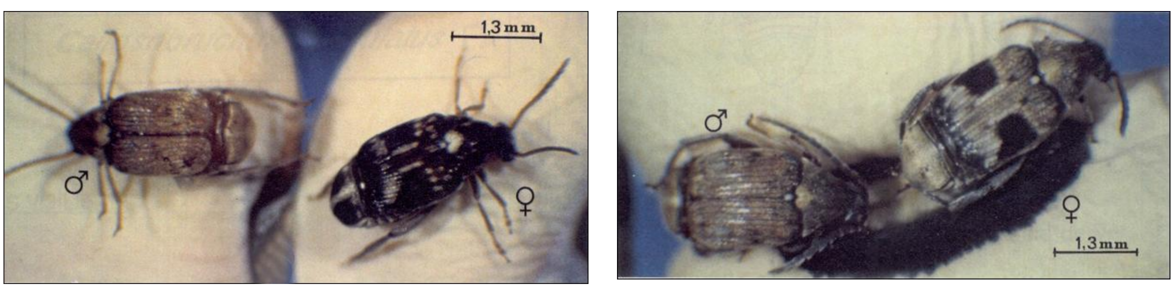
Cowpeas are attacked mainly by *Callosobruchus* spp and by *Zabrotes subfasciatus*. In southern Africa the dominant pest of cowpea is *C. rhodesianus* (Giga, 2001) while *C. maculatus* is found throughout Africa and is dominant in West Africa. *Callosobruchus maculatus and Callosobruchus chinensis are* common on pigeon peas, which may also be infested on other *Callosobruchus* species. Apparently *C. chinensis* is dominant on pigeon peas in Uganda (Silim Nahdy *et al.*, 1998). Bambara groundnuts are a substantial crop in West Africa but in East and Southern Africa there is only minor production; bambara are attacked specifically by *Callosobruchus subinnotatus*. Common beans fall prey to *Acanthoscelides obtectus* and *Z. subfasciatus* (Fig. 3). The two species have distinctly different altitudinal ranges in South America (Schoonhoven and Cardona, 1986) and in Uganda, Tanzania and Zimbabwe there is a difference in prevalence according to agro-climatic zone (Giga *et al*. 1992; Nchimbi-Msolla & Misangu, 2001). Generally, *A. obtectus* infestations appear earlier in the season in East Africa when temperatures are lower and its eggs may be scattered on the ripe pods or on the pulses. Whereas *Z. subfasciatus* glues its eggs only onto the pulse seedcoat (Fig. 3) so that infestation typically occurs only after threshing, especially in storage, and becomes more noticeable later in the season when temperatures are higher.

Figure 3: Common beans damaged by *Zabrotes subfasciatus*, showing adult emergence holes and egg shells filled with frass, visible as white dots (Photo NRI)

Caryedon serratus is the major storage pest of groundnut especially in West Africa (Sembene, 2004) but may be found in other parts. It breeds on common tree legumes such as *Terminalia indica* L. as well as on harvested groundnuts. It is probably the only species that can penetrate intact groundnut pods to infest the kernels. Larvae bore inside seeds making a large hole in the cotyledon (Fig. 4). Pupation may take place inside or outside the kernel in paper-like cocoon attached to the pod.

Figure 4: Damage to groundnut due to *Caryedon serratus (Photo ICRISAT)*

Adult bruchids are unusual in that they may occur in two distinct types; 'normal' morphs and 'active' morphs. Normal morphs are relatively sedentary and highly fecund while active' morphs may suspend reproductive activity and are adapted to dispersal by flight. The differences are both morphological – varying body size, elytral colour, wing dimensions etc (Fig. 5) and physiological – varying pre-maturation period, fecundity and adult longevity. Development on pulses in storage typically leads to the production of normal morphs while the active morph is typically found under field conditions. This phenomenon has been described for *C. maculatus* (Utida, *1972)*, *C. chinesis (*Silim Nahdy *et al.* 1999), *Z. subfasciatus (*Panji, *1986) and C. subinnotatus* (Appleby and Credland, 2001).



'Normal' type **'Active' type**

Figure 5: The two morphs of *Callosobruchus maculatus (Photos* A.P. Quedraogo*)*

The reproductive behaviour of bruchid beetles is mediated by chemicals released by the insects (Table 2). Female *Callosobuchus* spp. and *Z. subfasciatus* are known to release a sex attractant pheromone and in the case of *Callosobruchus* spp. also a contact sex pheromone that elicits copulation behaviour in males. *Acanthoscelides obtectus* differs as in this species the male produces a pheromone to attract females. Not surprisingly there is a difference in pheromone production between the normal and active morphs. In *C. maculatus* the normal morphs are sexually mature at emergence and release pheromone on the first day following emergence while the active morph shows no sexual activity at emergence and delay the emission of pheromone, but this can eventually be stimulated by the presence of host seeds (Lextrait *et al.*, 2008).

Host selection is the task of females and closely linked to oviposition behaviour as eggs are specifically laid on the host. It would appear that females can detect the volatiles generated by developing larvae, at least those at the fourth instar, and avoid those particular pulses (Babu *et al*., 2003). In addition, at the time of egg laying, *Callosobruchus* females secrete oviposition markers (Oshima *et al*., 1973; Credland and Wright, 1990) that deter other females from laying eggs on the same pulses.

Table 2: Pheromones used in the reproductive behaviour of the Bruchidae

Species	Female released pheromone
Callosbruchus maculatus (Cork *et al.*, 1991; Phillips *et al.*, 1996)	3-Methyleneheptenoic acid (Z)-3-Methyl-3-heptenoic acid (E)-3-Methyl-3-heptenoic acid (Z)-3-Methyl-2-heptenoic acid (E)-3-Methyl-2-heptenoic acid
Callosobruchus subinnotatus (Shu *et al.*, 1999)	(E)-3-Methyl-2-heptanoic acid (Z)-3-Methyl-2-heptanoic acid
Callosobruchus chinensis (Shimomura *et al.*, 2008)	(2Z,6E)-7-Ethyl-3,11-dimethyl-2,6,10-dodecatrienal (2E,6E)-7-Ethyl-3,11-dimethyl-2,6,10-dodecatrienal
Callosobruchus analis (Cork *et al.*, 1991)	(Z)-3-Methyl-2-heptenoic acid
	Male released pheromone
Acanthoscelides obtectus (Horler, 1970)	(R) (E2)-Methyl-2,4,5-tetradecatrienoate
	Contact sex pheromone
Callosbruchus maculatus (Nojima *et al.* 2007)	2,6-Dimethyloctane-1,8-dioic acid Nonanedioic acid Mixture of C(27)-C(35) straight chain and methyl branched hydrocarbons

There is an interchange of bruchids between crops in the field and in granary over the storage season (Fig. 6). Eggs of the first generation laid on the new harvest may be laid on seed pods, subsequently infested seeds are carried into store where further generations develop and may become the source of infestation for the next new harvest.

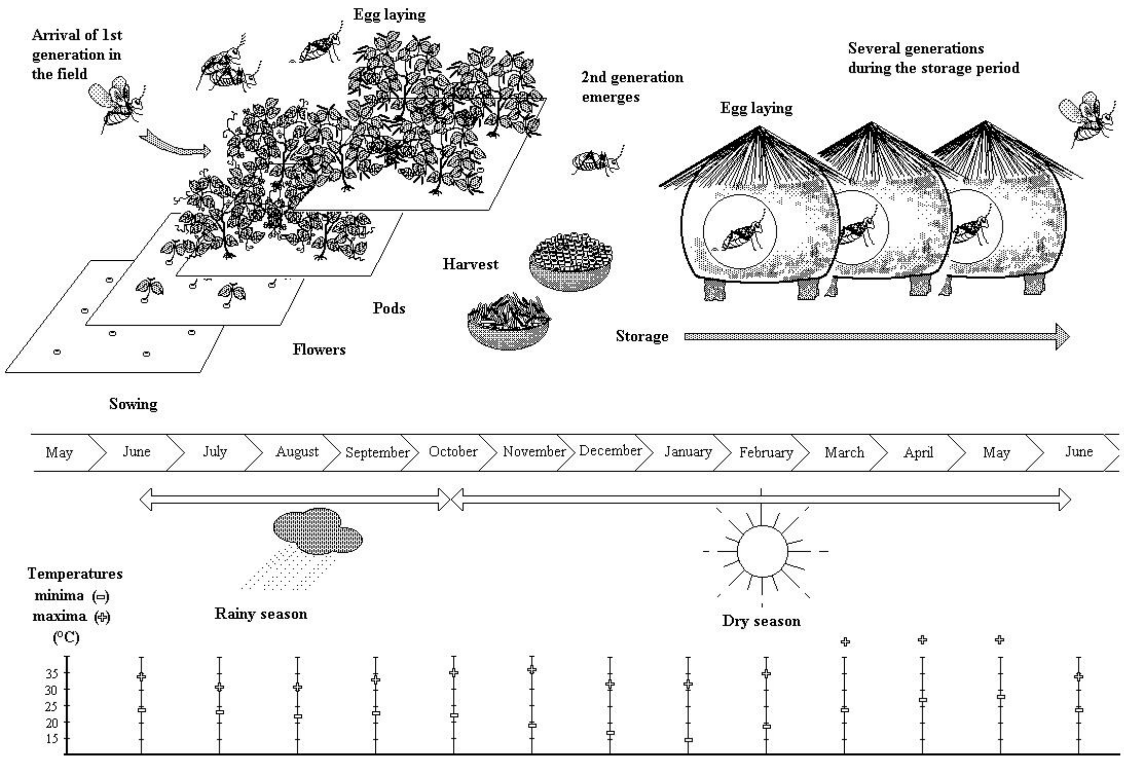


Figure 6: Interchange between field and granary of *Callosobruchus maculatus* infesting cowpea in northern Ghana (source - NRI)

Apart from bruchid beetles, the other postharvest insects pests attacking pulses generally do so in large-scale commercial storage, they are generalist feeders, unlike the specialist pulse feeding bruchids, and migrate from other products (such as maize, sorghum, dried cassava). Generally they are not the cause of serious infestations but on shelled groundnuts the moths *Plodia interpunctella* and *Ephestia (Cadra) cautella* are troublesome and the beetle *Trogoderma granarium* can be the cause of very serious losses, as it was in the Nigerian groundnut industry of the 1950/60s.

Extent of losses due to postharvest insect pests

Most previous research suggests that storage losses in pulses are substantial (Table3) although figures presented in the literature are often unsubstantiated. However, a detailed study of weight loss during on-farm storage of cowpea and bambara in northern Ghana recorded lower losses than might be expected from previous reports (Golob *et al*., 1998. The method of assessment they used took into account the consumption pattern of the farmer so that a cumulative loss was calculated based on the amounts of grain present in the store after each month of storage; this had been done in few, if any, previous studies. The effect of this correction was illustrated with an example of a farmer who stored 80 bowls of cowpeas. During the storage period the maximum number of damaged cowpea was 42.5% and this corresponded to a weight loss of 7.2%. But on a cumulative basis there was only a 3.1% weight loss. Overall, the weight losses suffered by the 35 farmers of that study appeared to be negligible. However, insect infestation led to significant income losses because damaged cowpea commanded a much reduced market price. This observation is echoed for common beans infested by *A. obtectus* and *Z subfasciatus* in Uganda where after 3-4 months storage, weight loss may be low but multiple holes in the seeds reduce the value of the pulse to the extent that the farmers considered it a total loss (Giga *et al.*, 1992).

Effective loss assessment methodology is required to enable the scale of postharvest pest problems to be documented and for the cost/benefit analysis of interventions designed to reduce losses. Rapid loss assessment techniques, relying on the conversion of the numbers of holes in pulses into an estimate of the % weight loss, have been explored for both for cowpea (Wright and Golob, undated) and beans (Muwalo, undated). Both studies suggest that the approach is feasible but neither progressed to implementation or a peer reviewed publication.

Table 3: Storage losses from bambara, common beans and cowpea (from Wright M.A.P. and Golob P. unpublished, undated report)

Crop/ Country	% damage	%weight loss	Storage period	Source
Bambara				
Ghana		3.7%	5 months	Amuti and Larbi (1981)
Nigeria		Wide range		Mbata (1993)
Ghana	14-100%		6-8 months	Golob *et al.* (1996)
Common beans				
Ghana	?	19.5% (unshelled) 45.1% shelled	5 months	Adams (1977)
Colombia	20%	7.4%	45 days	Schoonoven and Cardona (1986)
E. Africa		Total because of quality decline	4-5 months	Giga *et al.* (1992)
Colombia	c.60%		9 months	Baier and Webster (1992)
Uganda		3% 8%	3 months 6 months	Silim Nahdy (1994)
Uganda	25% 65%		6 months 9 months	Quoted in Gudrups *et al.* (1996)
Cowpea				
Nigeria	14-37%			Caswell (1968)
Nigeria	9-30%			Caswell (1984)
Nigeria	Up to 70%	Up to 30%		Singh and Jackai (1985)
Ghana	15-94%		7-9 months	Golob *et al.* (1996)
Uganda		5.9%	6 months	Quoted in Gudrups *et al.* (1996)

Approaches to insect pest management

A wide variety of pest management options have been tested for the postharvest protection of pulses and there are many opportunities to combine these methods to improve the efficiency of control, this is dealt with in the next section. All the methods described below have their own merits, the important issue is not whether they will work but whether they will be acceptable to farmers and if they are acceptable then how can farmers be helped to adopt them.

1. Resistant cultivars

A cowpea cultivar with moderate resistance to bruchid attack (TVu 2027) has been bred by the International Institute of Tropical Agriculture (IITA) although its other agronomic characteristics and disease susceptibility are relatively poor so that it is generally not suitable in most cowpea growing areas. Furthermore, when *C. maculatus* is reared on this cultivar over several generations, resistance can be overcome (Dick and Credland, 1986) hence this source of resistance must be carefully deployed if it is to be retained.

One approach to preserving this resistance has been to cross TVu 2027 with cultivars showing good pod resistance. The resultant line (BR1) has both good pod and seed resistance and has been recommended in northern Cameroon where typically farmers store their cowpea in the pod on platforms (*dankis*) in direct sunlight for extended periods after harvest. BR1 has tough pods that are resistant to breakage and remain intact (non-dehiscent) during harvest and storage, so that the seeds are protected from bruchid attack. Nearly 80% of bruchid larvae chewing through the pods of BR1 will die. Combined pod and seed resistance was found to result in less than 10% of bruchid eggs laid on the pods of BR1 surviving to become adults (Endondo *et al*., undated).

More recently the potential benefits of transgenic lines of cowpea with bruchid resistance genes have been investigated in an artificial seed system prepared with several transgenic insecticidal compounds. Very high levels of mortality were achieved 98-99% (Tarver *et al.*, 2007). Furthermore, in India, bean α-amylase inhibitor 1 has been successfully transferred to cowpea. For *C. maculatus* and *C. chinensis* this resulted in a 60-70% decline in survival and those that did survive were significantly reduced in weight and longevity (Solleti *et al*., 2008).

In the case of common beans, the lectin areclin has been associated with strong suppression of *Z. subfasciatus* but with only sub-lethal effects on *A. obtectus* (Cardona *et al*., 1990). Nevertheless, there is sufficient effect of arcelin on *A. obtectus* life history traits for it to be a component for a combined control strategy with parasitoids (Velten *et al*., 2007). Genetic resistance has been incorporated into commercial bean lines but the cultivars produced have not reached farmers in Latin America because they lack resistance to preharvest fungi and viruses (Cardona and Kornegay, 1999).

2. Cultural methods

Timely harvesting has a role in limiting infestation. Harvesting the crop as soon as it is physiologically mature and ensuring that it is not left in the field to the point that pods split open will help to limit infestation (Prevett, 1961). This is because bruchids appear to prefer to lay eggs on the seed coat than on pods and this is certainly the case with cowpea (Caswell, 1984).

Besides timely harvesting, leaving the pulses in their pods for as long as possible, especially break resistant and non-dehiscent varieties, can reduce bruchid development by 95% (Kitch *et al.*, 1991; Kitch & Shade, 1993). Even in the absence of such varieties some farmers might gain an advantage by storing pulses unthreshed. Most subsistence farmers thresh pulses prior to storage but not all, for example, not the farmers in the Babati area in Uganda where *Z. subfasciatus* is a significant problem on common beans. They store the beans unthreshed for up to three months as *Z. subfasciatus* is unwilling to lay eggs on the seed pod (Giga *et al.*, 1992).

3. Postharvest sorting and store hygiene

The incoming crop should be carefully inspected and any damaged pulses or those with signs of insect infestation should be removed. Inspection should continue at frequent intervals throughout the period of storage to check for signs of infestation. The appearance of eggs glued to the pulses, pre-emergence 'windows' or of adults are all clear indicators of problems. In the case of *A. obtectus* where eggs are not easily visible and where there may be a substantial developing population hidden within the grain, farmers are able to recognize the decline in quality due to the specific odour associated with this pest (Giga *et al.,* 1992).

The spread of infestation in storage can be limited by good store hygiene. Before the new crop is placed in store the storage container and the surroundings should be thoroughly cleaned to remove all insect infested residues, it is important not to place the new harvest on top of what remains of the previous harvest. If not given to animals to eat then these should be burnt or buried.

4. Sunning, solarisation and steam

Exposing pulses to heat treatments can have very beneficial effects. Traditionally, farmers have exposed their pulses to sunshine at various intervals after storage and this has helped reduce losses from mould and insects by lowering moisture content and by driving off some adult insects and perhaps even killing some of the developmental stages. The practice of sunning common beans is often practiced in several parts of Uganda and Tanzania with a frequency of every 1 to 4 weeks although it is usually combined with other types of treatment such as admixture of botanicals, ash or even soil (Giga *et al.*, 1992). However, the benefits of the practice are reduced if eggs are not removed from the bags/containers in which the beans are stored.

Although sunning is advantageous, it does not normally result in a high enough temperature for long enough to kill all the insects. If cowpea are held at 65°C for about five minutes then all life stages of *C. maculatus* can be killed or at 57°C all stages can be killed in about 1 hour (Murdock and Shade, 1991). Studies on the heat sensitivity of both *C. maculatus* and *C. subinnotatus* infesting bambara groundnuts show that the immature stages of *C. subinnotatus* are more sensitive to heat than *C. maculatus* and adults about the same (Lale and Ajayi, 2001; Lale and Vidal, 2000 and 2001). To achieve lethal temperatures pulses need to be solarised in a solar heater. In its most simple form, the solar heater consists of an insulting layer on which cowpea are laid to a depth of about 2-3 cm, they are then covered with a sheet of translucent plastic and the edges of the sheet are weighed down with stones or other heavy items. In a more costly version there is a black plastic sheet laid over the insulating layer. The edges of the black plastic and translucent plastic are rolled together to give a sealed envelope. The solar heater is retained in the sun for at least 5 hours. Such solar heaters are suitable for treating small quantities of cowpea (25-50 kg) but as the system is enclosed it does not reduce the moisture content of the pulses but if applied correctly then the cowpea will be heated to a high enough temperature for long enough to kill all insects. However, if the cowpea are to be used as seed for planting this may not be an appropriate procedure as there is some evidence that it can reduce germination rates by up to 20% (Tran B.R.D. unpublished results) but this may vary according to variety since other researchers have found that cowpea can be heated to 80ºC for six hours without any significant effect on germination (Murdock *et al.*, 2003). An alternative to plastic sheeting is to use a solar heater constructed from corrugated galvanised iron, this can be used for larger quantities and is more durable than plastic sheeting so may be a more cost effective option in larger scale operations. The plastic sheeting solar heaters have been successfully extended in Cameroon (IRA Cameroon/Purdue CRSP project), Uganda and northern Ghana (Crop Postharvest Programme, UK Department for International development Project) and several well illustrated extension guides have been prepared (see Annex 2)

Heat treatments need not necessarily be delivered by sun light. In parts of the Cameroon cowpea may be heated on metal plates over the fire but such treatment can result in scorching which may be an unacceptable reduction in quality. A possibly more acceptable method would be to treat cowpea with steam. Farmers in The Gambia may treat their cowpea with steam and experimental treatments of this involving steaming three different varieties for 25 minutes then sun drying before storage appeared to result in disinfestation but not permanent protection in the case of two varieties but rather more permanent protection in the case of a third variety for at least 12 weeks. In contrast, preliminary studies in Ghana have shown that steaming of small lots of cowpea at 98°C for 5 to 15 minutes make the cowpea more or less resistant to *C. maculatus (*Sefa-Dedeh *et al.*, 1998). It seems that the process hardens the seed coat and reduces water absorption properties but does not modify the cooking or processing characteristics. The contrast between The Gambian and Ghanaian result may well reflect varietal differences.

5. Sealed containers

Protection of pulses, and also cereal grains, from insect attack by placing them in containers that are either insect-proof or even airtight has been known and practiced for a long time (Hall and Hyde, 1954); and especially for gain being kept for seed. Truly airtight (hermetic) containers have the added advantage that with time oxygen levels decrease and carbon dioxide levels rise with the result that insect populations may decline or die out. In the case of hermetic storage the storage container needs to be as full as possible; large empty spaces filled with air can be a buffer against significant changes in gas composition. Consequently, pulses need to be stored threshed in hermetic storage since stored pulses in pods would be similar in effect to half filling the container with threshed grain.

A series of experiments was undertaken with sealed stores in Northern Nigeria, involving storage in small traditional granaries, the same granaries with polythene liners and underground pits (O'Dowd, 1971). The most promising treatment was to place up to 150kg of cowpea in a polythene sack which had a cotton inner liner to protect it from insect penetration. The cotton liner is necessary because if a cowpea with a pupa developing in it is pressing against the plastic sheet then when the adult emerges it will continue to cut its way out of the plastic leaving a neat round hole of 1-2 mm diameter. The polythene bags and cotton liners were firmly shut with string and placed in the mud granaries. Within 1 to 6 days of loading the oxygen levels fell to just above 2%; the lethal concentration is about 2% by volume (Oxley and Wickenden, 1963). Peak carbon dioxide concentrations were 7-9% and these were reached in about one day; such concentrations are not lethal to *C. maculatus (Storey 1978)*. Nevertheless in five months storage damage rates did not increase much above those at the start of storage, except in one case where the plastic was damaged by a lizard. It was recommended that opaque black plastic liners should be preferred over translucent ones as these are less likely to suffer lizard damage.

Subsequently, other methods of sealed storage for pulses have been developed, as follows:-

Metal drums of 200 litre capacity, well cleaned with detergent after initial use for transport of oil, have been used in several African countries, including Senegal (Seck and Gaspar, 1992) for cowpea storage. The drum is filled with about 150kg of sun dried cowpea and fitted with its cap. This should be greased before tightening to ensure that it is airtight. Similar sized plastic drums with tight fitting lids would be equally effective.

Large plastic drums, originally intended as 3 or 4 thousand litre capacity water tanks, have been adapted for cowpea storage by small traders or farmer groups (Tran *et al*., 2001). An outlet was added at the base of the tank for offloading, the tanks were placed on platforms and provided with shade from the sun. The cowpeas loaded into the tanks were fumigated with phosphine and good storage achieve, further testing was recommended to determine whether reliance could be placed on the hermetic properties of the tank to kill insect without the need for fumigation.

Triple plastic bagging developed as an effective hermetic storage method in the Cameroon and is subsequently being extended elsewhere (Kitch and Ntourkam (1991). Low cost plastic bags holding about 50kg of cowpea are used. Well dried cowpea fill the first bag which is tied shut securely using string. The first bag is placed within a second bag and this is securely closed. A third bag is used to enclose the first two. Clear plastic bags are recommended so that the cowpea can be inspected easily for any signs of bruchid attack. It is also recommended that the bags should remain sealed for at least two months after they are opened and then they should be resealed quickly to prevent entry of bruchids. The bags must be kept safe from rodents that might make holes in them and so break the seal. Details of the extension advice given for triple bagging are shown in Annex 1.

All the sealed storage options offer best cost efficiency when the storage period is at least 2-3 months (Gomez, undated) since the containers are relatively expensive and opening the container, even very briefly, will allow the entry of oxygen and may result in the resumption of insect activity.

6. *Admixture with ash, soil, inert dusts, plant materials and oils*

In a study of parts of Uganda and Tanzania, 39% ad 28% of farmers respectively, were admixing fine sand, clay dust or wood ashes with their common beans (Giga *et al.*,1992). This did not prevent bruchid damage but hindered the activities of newly hatched adults. For ash to be effective requires an admixture rate of 3-4% and possibly more for sand or clay as it is important to ensure that all the intergranular spaces are filled. In the Cameroon, the use of ash has been extended to farmers and it is recommended that cowpea are mixed with an equivalent volume of ash, from which large particles have been sifted (Wolfson *et al.*, 1991; Kitch and Giga, 2000). Once the storage vessel has been filled with ash then a further 3 cm layer of ash is added to the top to provide a barrier to pest entry (see Annex 3). In the case of ash there may be a problem with tainting and discolouration and all these types of admixture are inconvenient in that they requiring cleaning of the beans before cooking. The method is probably most appropriate for the storage of pulses for planting and for cultural reasons may be unacceptable to certain groups (Murdock *et al.*, 2003). Pulses may also be protected by admixture with diatomaceous earth (DE). DEs are available commercially although not necessarily registered for use in many African countries, even though countries such as Tanzania and Zimbabwe are known to have their own deposits of DEs. In laboratory test using the DEs Dryacide (1.25 g/kg) or Gasil (0.5 g/kg) against Ugandan strains of *C. maculatus* infesting cowpea and *A. obtectus* infesting common beans, good levels of control were achieved with either formulation (Golob, 1995). Field tests in Zimbabwe have shown that the DE 'Protect-it' at a rate of 0.1% (w/w) is as effective and persistent as conventional synthetic pesticides for protecting cowpea against *C. rhodesianus* during a 40 week storage period (Mvumi *et al*., 2001; Stathers *et al*., 2002).

A wide range of plant materials as well as oils derived from plants have been used with some success in bruchid control. The efficacy of plant materials is highly variable even within plant species depending on variety, season, soil types and the way that the plant material is used (whole dried products, powders, extracts etc.). The products may act as natural insecticides or as repellents. In most case their safety for the consumer has not been established, even though some are known to be toxic and in many case they will taint the pulses so limiting their commercial value. A particular case in point is the use of neem oil extended for the treatment of cowpea in Benin. The bitter taste of the oil discouraged farmers from applying it even though the taste could be completely removed when soaked for a long time in water (Gomez, undated). An extensive listing of botanical materials that have been used for the suppression of insect pests of stored crops, including bruchids on pulses, is given by Dales (1996).

The non-volatile cooking oils (e.g. maize, sunflower, cotton seed, groundnut etc) and essential oils (West African black pepper, ginger etc) can be used to coat pulses. All oils may create a surface on pulses that deters egg laying and oil itself may coat eggs and kill them by preventing respiration. The essential oils may also be repellent or even kill bruchids in confined spaces with a 'fumigant' effect. However, the efficacy of oil treatment is lost after a few months, with the more viscous oils having greater persistence. In a study of common bean protecting using non-volatile soya bean oil in Colombia, at a rate of 5ml/kg, damage levels were kept at below economic threshold (4% damaged seeds) for 8 months after harvest (Baier & Webster, 1992). Many other studies document a good degree of control using cooking or essential oils. Treatment with essential oils would clearly lead to some degree of taint but at least where the oils are obtained from commonly used culinary spices the application may not provoke a negative response from consumers (Ajayi & Lale, 2001). In the case of cooking oils, in the short term they do not affect the viability, palatability, cooking quality or physical appearance of pulses however after lengthy storage periods all oils that are persistent are likely to become rancid. Although cooking oils are relatively expensive usually the cost for treating small quantities of pulses is well justified (Kitch & Giga, 2000).

Sacks impregnated with plant extracts have also been shown to offer some protection (Koona *et al*., 2007). In a test with miniature jute sacks (26 x 15 cm), soaked in aqueous plant extracts of *Chenopodium ambrosioides* (Chenopodiaceae) or *Lantana camara* (Verbenaceae), both cowpeas and common beans were protected against *C. maculatus* and *A. obtectus* respectively. The protection was less effective than when the extract was applied directly to the pulses but was about 80% lower than untreated pulses and offers an indirect method of treatment so avoiding taint and potential toxic hazard.

7. Admixture of synthetic insecticide

Synthetic insecticides especially organophosphorus compounds such as pyrimiphos methyl, fenitrothion and malathion are used for the protection for stored pulses, usually by admixture of a dilute dust formulation. However, access to these is usually restricted due either to limited availability or the inability or reluctance of farmers to pay for them. Their use on common beans has been documented in Uganda, Tanzania and Zimbabwe (Giga *et al.*, 1992) where Actellic Super, a mixture of two active ingredients pyrimiphos methyl and the synthetic pyrethroid permethrin, was available at that time as a result of an extension progamme against a pest of stored maize and dried cassava, the Larger Grain Borer *Prostephanus truncatus*. The same treatment was used as a comparator for trials of indigenous methods in eastern Kenya at an application rate to beans of 9 ppm pirimiphos methyl and 1.7 ppm permethrin and less than 1% of beans were damaged after 4 months storage compared with about 11% in the untreated control. When primiphos methyl alone (0.01g a.i./kg) was applied to three different cowpea varieties in the Gambia then good control was evident for the first 12 weeks of storage where damage from *C. maculatus* was held below 1% compared with 70-80% in the control while after 18 weeks damage rates had risen to 33% in the most susceptible cowpea variety (Cockfield, 1992).

8. Disturbance/sieving methods

In the case of *A. obtectus*, females lay their eggs loosely on the beans, larvae emerge after about 7 days and then larval entry into a bean can take at least 24h. In this period the larva is very susceptible to disturbance. If the beans are shaken then the larva may be crushed or if repeatedly forced to initiate new holes may die of exhaustion (Quentin *et al.,* 1991). To test the method for the protection of beans against *A. obtectus,* jars, buckets or jute sacks were half filled and then tumbled briefly once a day. The *A. obtectus* populations that developed were only 3% of those in stationary controls. This lead to a recommendation that beans could be protected by farmers by storing them in cylindrical containers. The containers would be less than 75% full, structured to so that beans tumble thoroughly when containers are rolled e.g. by adding baffles, and would be rolled every morning and evening by one circumference.

An alternative method was suggested in which eggs and emergent adults could be removed by sieving every five days for 70 days using the typical coffee sieves available to farmers in some parts of Uganda (Silim Nahdy, 1994). At the start, test beans were either lightly infested or heavily infested and stored in 16kg tightly-woven cloth bags. Even after 150 days, sieved beans showed only a negligible increase in damage while unsieved beans were heavily damaged – 60% increase in damaged for beans that were initially lightly-infested and 80% increase for beans initially heavily infested.

9. Biological control

The eggs and larvae of the bruchids that attack stored pulses are hosts to many species of hymenopteran parasitoid (Huis van, 1991; Huis van *et al.* 1991) and are susceptible to predation by the hemipteran *Xylocoris falvipes* (Sing and Arbogast, 2008).

At least in theory, the use of biological control, perhaps combined with other compatible methods, can offer a means of suppressing infestation. Parasitoids may be cultured artificially and then introduced into granaries to ensure that there are enough present early in the infestation cycle so that a significant reduction in bruchid population can be achieved (Huis van, 1991). There has been some success with this approach in Africa for both larval parasitoids such as *Dinarmus basalis* (Amevoin *et al.*, 2007) and egg parasitoids such as *Uscana lariophaga* (Huis van et al., 1998). However, a study combining both parasitoids (Huis van *et al.* 2002) showed that if stores were inoculated with only one of the two species then both *D. basalis* and *U. lariophaga* significantly suppressed *C. maculatus* populations. However, *D. basalis* did so more effectively than the latter. A combination of *D. basalis* and *U. lariophaga* resulted in the same suppression of bruchid populations as when *D. basalis* was the only parasitoid. Fifteen weeks after storage, the parasitoids reduced the number of grains damaged by 38-56%. *Dinarmus basalis* is also known to be an effective parasitoid of *A. obtectus* (Schmale *et al.* 2003). To date there appears to have been little or no investigation of how storage facilities might be made more accessible to parasitoids to gain greater benefit from natural biocontrol.

Suppression by the predator *Xylcoris flavipes* has been demonstrated in laboratory conditions for *A. obtectus*, *Z. subfasciatus* and three *Callosbruchus* spp and was successful when the predator was introduced up to three days after the initiation of infestation by *A. obtectus* (close to 100% reduction) but less effective for the other species (50% reduction at best) (Sing and Arbogast, 2008)

The use of other biological control agents against bruchids has received limited study. For example it is known from laboratory studies that *C. serratus* is susceptible to strains of the entomopathogenic fungus *Metarhizium anisopliae* but this has not advanced to any field testing (Eksi *et al*., 2001).

Control methods in combination

Farmers typically use their own combinations of control methods for the protection of pulses. They might implement all or some of the following,

- timely harvesting,
- selecting out damaged or infested pulses at the time of storage,
- sunning the pulses at regular intervals,
- admixing ash, botanicals or soil, and
- keeping the pulses in a well closed or sealed storage container.

If all such measures were implemented with diligence then in most cases losses would be reduced acceptable levels. Researchers have also investigated the opportunities for the combination of control methods to yield better best management.

1. Sunning with sieving

In a study of indigenous methods, farmers in eastern Kenya found a combination of sunning common beans for 7h followed by sieving at a frequency of once a week for four months to be as effective as insecticide treatment and both practical and affordable (Songa and Rono, 1998); however the high frequency of sunning was a disincentive. In a subsequent extension programme for sunning and sieving, it was recommended that the beans be spread on a mat, sunned for about 6h followed by sieving. During the first 3 months after harvest this process should be done very 2 weeks and thereafter every 3 weeks (Annex 4).

2. Disturbance with neem admixture

A combination of tumbling small, half-filled sacks of common beans and admixture of a variety of neem products (dried leaves, powder or oil) was tested for the control of *A. obtectus* (Facknath, 2006). Tumbling alone every two weeks reduced emergences by 52% or if tumbling was done daily then by 71%. Tumbling beans to which neem powder or oil had been admixed showed a similar increase in control so that with tumbling very two weeks damage was reduced by about 88% and for daily tumbling reduced by 98%. With neem leaves the reduction was 82% and 88% respectively.

3. Varietal resistance with groundnut oil

A combination of groundnut oil (5cm^3/kg) with three varieties of cowpea of different resistance to *C. maculatus*, offered good protection in the first 6 weeks of storage as damage rates were very similar to the same varieties treated with insecticide (pirimyphos methyl) but for the most susceptible variety, protection was observed to have declined by the 12th week but for the other two varieties was as effective as insecticide for at least 18 weeks.

4. Varietal resistance with steaming

A combination of steaming with three varieties, with contrasting resistance to *C. maculatus*, demonstrated little or no advantage for the two susceptible varieties whereas for the more resistant variety the steamed cowpea was much less damaged than the untreated control for first 12 weeks of storage and was no different from cowpea treated with insecticide. It may therefore be concluded that at least for certain varieties streaming could be of particular value.

5. Varietal resistance with biological control

Varietal resistance in common beans, based on arcelin, is effective in suppressing *Z. subfasciatus* but has only sublethal effects on *A. obtectus*. A laboratory trial (Schmale *et al.*, 2003) has demonstrated that arcelin-containing beans will prolong the development of *A. obtectus* by 15% as compared to the control, allowing the parasitoid *D. basalis* to have access to suitable host stages for longer. Over a 20-week storage period, the combined use of a semi-resistant host and *D. basalis* kept bruchid damage below 1%, as compared to 4.7% with arcelin-free beans, and *A. obtectus* were eradicated in 80% of the replicates. Further recent studies have confirmed that arcelin is a promising component for integrated storage systems and showing that is is not associated with any detectable changes in bean cooking quality (Velten *et al.*, 2008).

6. Solarization with ash or shea butter admixture

In field studies with 95 farmers in Ghana and 150 farmer in Uganda, the following three treatment combinations were tested, monthly solarization, solarization at harvest followed by the admixture of ash or admixture of shea butter. These were compared with a non-treatment control. The treatments were applied to 20kg lots of cowpea which were then stored according to the normal methods. The farmers considered monthly solarization as the best option, while a single solarization with shea butter admixture as best for storage of pulses for seed because of the unfavourable smell/taste. In Uganda rains and cloudy skies were a constraint to the use of solarization. The researchers concluded that it would be best if solarization was combined with storage of the pulses in containers that are insect-proof to avoid subsequent infestation and so reduce the monthly labour costs of solarization (Tran, 2006)

Cost-effectiveness and adoption of control methods

Whilst most researchers deal with the efficacy of control procedures, the cost effectiveness and related barriers to adoption are also a key areas of concern. An example of the financial feasibility of adoption is quoted in FAO's Cowpea Postharvest operations manual (Gomez, undated). This deals with a comparison between three options, solarization by two different methods, plastic sheet or permanent placement, and insecticide treatment. Neglecting any labour costs and assuming a 3-month storage period in open weave bags, the financial implications of the options were similar, provided the solarizers were used to treat high volumes of cowpea. If there was a 6-month storage period, which would require a repeat solarization or insecticide treatment, then the solarizing options were around 30% cheaper.

An important constraint to the adoption of potential pest control procedures is whether or not the cost benefit and opportunity costs is perceived by farmers to be favourable. Financial expenditure on pest management might appear to make good sense when it will ensure sufficient food for the household or yield a higher income in the future. However, competing demands for very limited cash resources may present very high opportunity costs (estimated at 50% in the example above) and this coupled with the risks inherent in agricultural activities may present significant barriers to the adoption of new approaches.

Adoption of solarization using plastic sheets has been reported in Ghana and Uganda. In northern Ghana subsistence farmers in both the validation and at least 10 neighbouring villages of the Gushegu/Karaga district, amounting to 5 to 6 thousand farmers, were solarizing monthly to treat small quantities of cowpea (100 -200 kg) being stored for home consumption or later sale. In 2006, the costs of providing sufficient sheeting to treat batches of 25kg of cowpea was US$1.8. In the Kumi, Amuria and Katakwi districts of Uganda, farmers were solarizing monthly and for seed grain are admixing ash or shea butter or in some cases had substituted moringa leaf powder, neem leaves, red pepper or tobacco. Small scale traders, storing up to 2000 kg were also adopting the method. Cost effectiveness calculations were made allowing for cost of materials and benefits of arbitrage and these showed that for households with sufficient cowpea surpluses and resources (cash and labour), monthly solarization would be quite profitable. However, experience at village level suggested that at the time of harvest many households had debts to repay or new expenses to meet so that lack of availability of polythene sheeting and/or access to credit prevented these households from investing in storage treatment (Tran, 2006).

On-going postharvest research/extension efforts

In East and Southern Africa, there would appear to be few current research/extension projects dealing with the postharvest protection of pulses. The only research study that has come to light is on the breeding of common beans. In a PhD programme supported by the Program for Africa's Seed System (PASS), Geoffrey Kananji in Malawi generated over 900 bean lines and tested them in the laboratory for resistance to storage pests. Two common bean landraces KK25 and KK35 were not damaged by either *Z. subfasciatus* or *A. obtectus*. KK35 had the lowest susceptibility index and no F1 adults emerged. Verification experiments to confirm the observed resistance did not show any damage symptoms for KK35. The other landrace, KK25, however, which initially showed some level of resistance, did eventually succumb to attack by *A. obtectus*. These results will be used to strengthen the bean improvement programme through multiplication and delivery of KK35 landrace seeds to farmers. Farm awareness events will also be organized to educate farmers on the planting of resistant and other improved bean varieties.

The triple bagging technique to control bruchid infestation of cowpea is being promoted in 10 countries of west and central Africa with funding from the Bill and Melinda Gates Foundation. The objective is to reach 3 million households so that within 5 years, 50% of cowpea stored in the target areas will be in triple layer plastic bags. The 'one-time' cost for triple bagging is around US$3 while the average increase in household income is estimated to be US$150 (http://www.entm.purdue.edu/news/murdock_gates.html).

Research gaps and opportunities for Malawi, Mozambique and Tanzania

1. Gathering data on postharvest losses

Action to prevent postharvest loss needs to be based on a reliable understanding of the extent of losses. Yet cumulative postharvest losses from production are rarely determined but when they have been they have been lower than expected (Golob *et al*., 1998). As a basis to investment in research to limit losses in pulses, rapid loss assessment surveys, using visual scales to convert damaged grain into weight loss, would be of value but these would need to be combined with investigations linking insect damage to loss of market value as small weight losses may be associated with significant quality decline and financial loss. Although losses may be small this could result in forced sales of pulses due to farmers' fear of infestation. Such forced sales may also represent a loss of opportunity. These studies can be used to prioritise geographical areas and farming situations for adaptive trials with loss reducing technologies.

2. Adaptive research on loss reducing technologies

Technologies for farmers to reduce postharvest losses in pulses caused by storage pests are well known and some successes have already been achieved with the extension of solarization, triple bagging and an improved method of ash admixture for cowpea. For common beans, sunning and sieving in Kenya may have had some impact. Reports on trying these methods with farmers in Malawi, Mozambique and Tanzania, or for other pulses such as groundnuts or pigeon peas, appear to be lacking and so this may present an opportunity for adaptive research as a forerunner to large-scale promotion. In addition, in countries where storage containers are available that are sealable and affordable by subsistence farmers then their use as hermetic stores, alone or in combination with other techniques, should be investigated. Any attempt to introduce these technologies would require a careful needs assessment, an analysis of postharvest practice and constraints to adoption followed by carefully planned adaptive trials undertaken with farmers. Such trials should be at least of medium scale, 100-200 households, and include households from a wide range of wealth rankings. Data should also be gathered on potential benefits of introducing the technologies perhaps by detailed case studies with particular households. The research should be planned so that its outputs are a basis and justification for efficient large-scale promotion of the technologies.

3. Resistant varieties

Varietal resistance to postharvest pests is another area offering opportunities. In Malawi the recent discovery of one particular bean land race (KK35) with apparently complete resistance to both *A. obtectus* and *Z. subfasciatus* offers the opportunity to attempt to reduce losses at localities where this variety has appropriate agronomic characteristics. For the future there is potential for further screening for resistance and for crossing resistance into other lines to produce pulses with other agronomic potential. Such lines may offer a means to reduce losses by themselves or could be usefully combined with other control methods. In the past varietial resistance in cowpea has been problematic despite some success with combined pod and seed resistance. Now the success in transferring genes for bean α-amylase inhibitor 1 to cowpea will offer transgenic varieties that could be of real value to farmers. However, the use of transgenic varieties will need to satisfy local regulations and will require very careful consideration for use in small-scale/subsistence farming, for example where it might lead to dependency on the external supply of seed.

4. Novel pest management options

Two technologies have given promising results but appear to need further investigation – steam treatment and the use of DEs. Steam treatment of cowpea conferred resistance to bruchid attack without altering cooking or processing characteristics. This could be investigated further and perhaps extended to common beans and pigeon pea. Such studies would necessarily include investigation of the practicalities of on-farm steaming, especially as the cost or availability of firewood may be a major constraint in many situations. DEs have been shown to be effective alternatives to synthetic insecticides for the protection of common beans in the laboratory and cowpea on farm in Zimbabwe, this could be investigated further in different situations and perhaps coupled with efforts to exploit locally occurring deposits of these materials.

5. Methods for monitoring bruchids

The pheromones of several species of bruchid, especially their sex attractants, are now known and can be synthesised in the laboratory. To date these appear not to have been tested outside the laboratory and they may be useful in investigations of the biology and incidence of these pests. Results of such studies can lead to a better understanding of local problems with bruchids, especially the relationship between field and store populations, giving insights into better approaches to pest management and more appropriate extension advice.

A SOCIO-ECONOMIC PERSPECTIVE

1. INTRODUCTION

Any socio-economic review must be set within the wider context of IPM for African smallholders. From a social science perspective, its record is mixed. There have been spectacular successes, reflected in widespread farmer adoption of IPM strategies. But there have also been expensive failures, where farmers have not adopted IPM technology. Moreover, success on a local scale has not always been easy to replicate on a regional or national level. Where IPM strategies are knowledge-intensive, scaling-up may require large investments in training for farmers and extension agents. Spillover benefits may be limited. All this has led to debate about the role of IPM in Africa, its cost-effectiveness, and potential impact (Morse and Buhler, 1997; Orr, 2003).

IPM for legumes targets a wide range of pests and diseases, and uses a variety of strategies (Table 1). However, the number of farmers using specific strategies varies widely by country and by region, even for the same crop. In Kenya, 46 % of pigeonpea growers use insecticides, whereas no farmers use pesticides for pigeonpea in Malawi, Tanzania, and Uganda (Minja et al 1999). These differences reflect variation in the severity of pest damage, which is location-specific. But they also reflect socio-economic factors, which are the subject of this report.

Table 1. Pests and diseases, and IPM strategies for major legumes

	Crop	Pests/diseases	Typical IPM Strategies
1	Groundnuts	Rosette disease Leaf spots	Host plant resistance (HPR) Pesticide sprays Close spacing Row planting Early planting
2	Cowpea	Insect pest complex	HPR Pesticide sprays
3	Pigeonpea	Insects pest complex *Fusarium* wilt	HPR
4	Beans	Pest complex	HPR Mulching Varietal mixtures Early planting Plant spacing

2. OBJECTIVES

From a socio-economic perspective, the design of an effective IPM strategy for legumes depends on four key questions. These are:

1. *Supply and demand*: is IPM for legumes being driven by supply from researchers or by demand from farmers?

2. *Strategies*: what IPM strategies for legumes are available and are they appropriate for African smallholders?

3. *Systems*: how do these strategies complement the needs of the farming system and the farmer's objectives?

4. *Services*: how are these IPM strategies delivered or implemented at a regional or national level, and how cost-effective is this?

Data

The discussion draws primarily on personal experience of IPM projects as well as published socio-economic literature on IPM in Africa and on FFS in Asia.

3. SUPPLY AND DEMAND

Generally, farmers will not invest much in crop protection for crops that have low yields or have limited market value. Consequently, where IPM strategies that require additional resources (labour, expenditure), farmers are more likely to invest in crop protection for a high-yielding food crop, or a cash crop that brings income. IPM for low-yield, low-value crops is likely to be supply- rather than demand-driven.

A key question, therefore, is whether the yields of legumes, and their market value, justify the costs of protecting these crops? The answer may vary according to the crop, the region, and the farmer's objective.

For example, cowpea growers in Uganda may grow the crop for sale, for home consumption or for both uses. But farmers growing cowpeas purely for sale will grow a variety with a higher market value, invest in pesticides and spray more frequently than others. Farmers growing purely for home consumption grow another variety less susceptible to pests, and do not use pesticides (Isubikalu et al 2000).

Where legumes are a major part of the diet – such as climbing beans in the Central African Highlands, which has the highest consumption of beans in the world – farmers *do* practise a range of low-cost, non-chemical, strategies to protect their crops (Trutmann et al 1993). These include sowing density, staking, defoliation, weeding, timing, rotation, and sanitation of stored seed. Mixing varieties of beans is a key strategy to reduce crop loss from diseases, and because they cannot identify specific diseases, farmers may continue to use this strategy even when new disease-resistant bean varieties become available.

Demand for crop protection differs between field and storage pests. Generally, farmers *will* take steps to control storage pests, even for low value crops. This may reflect Africa's history of land-surplus, which made it more rational for farmers to protect the quantity stored rather than the area planted. Farmers may also perceive a higher risk of *total* crop loss from storage pests. Finally, storage pests like bruchids are a relatively constant threat, which gives an incentive for protection.

Demand-shifters

Three variables can change the demand for crop protection by smallholders:

1. *Market price*. Rapidly urbanising countries like Nigeria have seen growing markets for low-value staples, including legumes, and this has increased the incentives for smallholders to invest in crop protection. Proximity to urban markets is therefore likely to be a key determinant of the demand for IPM for legumes. Farmers without ready access to urban or export markets will have limited incentives to invest in crop protection.

2. *Technical change*. If research increases yields and cuts unit costs of production, this will increase farmers' incentives to protect their crops. The main route to cut costs has been to raise yields through varietal improvement. The main constraint on yield of legumes is crop losses from pests and diseases. Varietal improvement has therefore focused on breeding for Host Plant Resistance (HPR).

3. *Farmer perceptions*. If farmers already use pesticides or non-chemical controls for legumes (as some do) then the amount invested will depend on their perceptions of the effectiveness of the control method in preventing crop losses. These perceptions may be wrong, and there may be scope to cut the cost of crop protection by improving the flow of information to farmers (eg reducing the frequency of pesticide sprays, how to recognise specific pests and diseases). Better information would change the demand for specific types of crop protection as farmers moved to more effective controls.

But where these demand-shifters are absent, farmers may have limited incentives to invest in crop protection for legumes. In such situations farmers rank pests and diseases as a major – even *the* major – constraint on crop production; they may have a wealth of knowledge about insect pests; they may know several traditional control strategies. But they do nothing. For example, a study of cowpea in northern Nigeria reported that, “Despite the high level of pest awareness most farmers did not report any type of control, chemical or traditional” (Bottenberg, 1995).[1] Inaction is often attributed to the *supply* of knowledge or of insecticides. But also the demand for crop protection may be very limited: otherwise why would farmers not use lower-cost, traditional methods, if in their interest to do so? The likely answer is that that costs exceed benefits.

IPM adoption studies study “demand for innovation” by identifying demand-shifters at the household level (eg. age, education, income, knowledge, extension contact). When researchers find significant differences in these variables between IPM adopters and non-adopters, they make recommendations to increase the supply of these variables (eg “more extension”).

However, some studies include only “supply-side” variables that constrain adoption, and omit to include variables that capture market “demand” for the new technology and its profitability (eg. Mugisha *et. al.,* 2004). Studies that include “demand shifters” such as *access* to the technology and farmer perceptions of *profitability* show that these are the major determinants of farmer demand for IPM (eg. Shiferaw et al 2005).

4. STRATEGIES

IPM for legumes typically involves a ‘package’ of different pest management strategies (PMS). It is important to unpack this concept, because different strategies have different implications for design and adoption (Orr *et al.,* 2001).

Strategy as a plan

Some IPM strategies are implemented regardless of pest incidence in a given season. Where these strategies have a cost (eg in labour time) farmers will only use them where they suffer severe and *regular* crop losses from pests. They may be reluctant to adopt a planned strategy where pest damage is low and infrequent.

[1] This is also true for other crops. A study of maize in western Kenya by Chitere and Omolo (1993) noted that “Stem borers, the most frequently mentioned pests, were not controlled by the majority of farmers”.

Strategy as a performance

Some strategies are not part of a pre-determined plan, but react to pest attacks as they unfold during the season. The classic IPM strategy of basing pesticide sprays on pest thresholds falls into this category. Only if pests reach a certain threshold is the strategy implemented.

Strategy as an accident

Some IPM strategies may be accidental in the sense that they are the by-products of other decisions unrelated to pest control. This is often the case where farmers find it hard to identify what is causing crop damage, as with many plant diseases and with nematodes. Where the pests themselves are invisible, and known only through their symptoms, it is hard for farmers to develop effective strategies.

Legume strategies

IPM for legumes uses a mix of these different strategies (Table 1). The difference in the costs and benefits of these strategies helps explain why farmers adopt some and not others.

Planned strategies are like insurance. You pay but you may never collect. They are a cost regardless of whether or not the crop falls prey to pests in that season. For this reason, they are usually only justified and effective where farmers experience fairly high levels of crop loss. Even here, farmers may be selective. Close spacing and row planting are labour intensive. Farmers may not adopt them because the extra labour required at planting (a seasonal peak) may not justify the benefits in yield saved. This seems to be the case with IPM for groundnut in eastern Uganda (Mugisha *et al.,* 2004). Extra labour for IPM strategies may add to the workload for women if they are responsible for managing legumes. Since women already work longer hours than men, this is a major disincentive to adoption. Households may prefer strategies (like seed dressing) that cost a little more but which require less labour.

Reactive strategies have the advantage that they are activated only when a critical threshold is reached where benefits exceed costs. One disadvantage of this type of strategy is that it may require timely inputs or services from dealers or contractors. If farmers cannot find pesticides, or sprayers, they cannot respond. Reactive IPM strategies that use chemical control therefore rely on effective supply and distribution networks. Farmers often cite availability, rather than cost, as the main reason for not using pesticides (Minja et al 1999).

Effective strategies

Historically, the most successful IPM strategies have been host plant resistance (HPR) and classical biological control (CBC). The main reason for their success is that neither strategy requires any additional investment from the farmer. The cost is borne by the research system. Also, adoption of these strategies does not require expensive investments in farmer training. This reduces the cost of scaling-up and allows quicker impact.

HPR is not a panacea, however. Most breeding has been for resistance to one or a few races of a pest (vertical resistance) rather than for resistance to all races (horizontal resistance). This can result in rapid breakdown, as with resistance to different strains of the geminivirus that causes cassava mosaic disease. HPR is also problematic when yield losses are due to a complex of pests, as with pigeonpea (Hillocks *et al*., 2000) and cowpea (Jackai & Adalla, 1997).

Even where new varieties with HPR are available, their cost may prevent adoption by poorer smallholders. One simulation study estimated that, with “very good” access to new wilt-resistant varieties and no economic constraints, almost 100 % of farmers adopted. Once economic constraints were factored in, adoption dropped to 68 % (Shiferaw *et al*., 2005).

A second effective strategy has been CBC, or the introduction of exotic natural enemies against pests. The major success story of IPM in Africa (with the cassava mealybug) has been with this IPM strategy (Zeddies *et al*., 2001). Scope for CBC for pests of legumes is more limited, however, since these pests are endemic to Africa and not recent introductions. Likewise, very low levels of natural enemies are found in pigeonpea, even in the absence of insecticides (NRI, 1991).

5. FARMING SYSTEMS

Crop protection is just one component of the farming system. The interactions between IPM and the farming system have to be considered in the design of IPM strategies. Some strategies may not be adopted if they conflict with other components of the system. For example, experience in Malawi showed that Kalima beans were less susceptible to pests and gave higher yields than other varieties but many farmers did not adopt them because (1) they were unsuitable for intercropping with maize, the staple food crop (2) their leaves were less tasty (Masangano, 2002). These were critical disadvantages for smallholders with limited land who relied on bean leaves for relish. Farmers may have many good reasons for continuing to grow “susceptible” varieties of legumes. Kiros-Meles and Abang (2008) provide useful insights into this type of thinking for farmers in Ethiopia.

Crop protection is rarely the farmers' top priority, and IPM is more likely to succeed where it contributes to meeting wider objectives, such as improving household food security or addressing the problem of declining soil fertility. For example, early maturity in beans is recognized as an effective strategy to avoid or reduce crop losses as pests build up. But early maturity is also important for food security, since beans provide food earlier in the hungry season. Early maturing varieties of beans often have names that reflect their importance to household food security (Orr *et al*., 2001).

Similarly, a systems approach focuses on ways to increase the plant's ability to *compensate* for pest damage, rather than focusing exclusively on improving farmers' pest management. If the main constraint facing African smallholders is declining soil fertility, then IPM should be viewed as part of a crop management program to arrest this decline and improve sustainability. Examples of successful ''IPM'' projects turn out on closer inspection to include new varieties and agronomic practices that raised crop yields (Bruin and Meerman, 2001). In Africa, therefore, ''most projects aimed at subsistence farmers are not IPM projects *per se*, but general agricultural development projects which come to have an IPM component'' (Kiss and Meerman, 1991).

IPM therefore needs to think carefully about the role that legumes play in the farming system. Why do farmers grow them, what are farmers' priorities for their legume crops, and how can IPM *complement* research for development that aims to improve not just specific components, but the system as a whole?

6. SERVICES

Farmer Field Schools

Scaling-up has proved a key challenge for IPM. In Asia, the classic extension route was through Farmer Field Schools (FFS). It was expected that FFS graduates would train others and IPM would diffuse farmer-to-farmer. Two recent studies have cast doubt on the effectiveness of this diffusion model in Indonesia and Sri Lanka (Tripp *et al*., 2005).[2] They found little if any evidence

[2] Another drawback of FFS particularly relevant in the African context is the time farmers must give to participate in FFS meetings (in Asia, up to 15 half-day meetings in a single season). In many African farming systems characterised by a hoe-agriculture and a single wet season, time is at a premium. Well before the end of the season, poorer smallholders are busy with wage-work to buy food.

of farmer-to-farmer transmission of IPM. Critics have challenged the narrow definition of costs and benefits used in these studies (van den Berg and Jiggins, 2007; Feder *et al*., 2008; van den Berg and Jiggins, 2008). But the evidence on limited impact of farmer-to-farmer diffusion of IPM seems sound. However one measures the costs and benefits, FFS has had very limited success in spreading IPM.

By contrast, in Vietnam radio campaigns based on simple rules of thumb have had very wide impact on pesticide use (Heong et al 1998). The reason is that farmers' decision-making for pest management is based on social norms of "appropriate" behaviour against pests. Thus, if farmers believe that insects can only be controlled with insecticides, they will use them. Change farmers' norms and you change their behaviour. Clearly, the FFS is not the best instrument for achieving quick and wide application of standardized recommendations.

This is clearly relevant in the African context where most farmers do not yet use pesticides. This lack of knowledge makes them vulnerable to biased information from pesticide companies that seek to promote pesticides as the "norm" for crop protection. This "norm" has been effectively challenged by media campaigns (Heong *et al*., 2002).

Seed delivery systems

IPM based on HPR requires an effective system for multiplying and timely delivery of seed. Yet the private sector has no incentive to produce seeds of self-pollinating crops like legumes. Consequently, IPM strategies based on HPR usually require publicly-financed seed systems.

Diffusion of new seeds with HPR cannot be left to farmer-to-farmer diffusion or to informal networks. Experience with beans in Africa has generated useful lessons on how to diffuse new seeds (David and Sperling, 1999):

1. Since farmers are willing to buy seed, the free distribution of bean seed should be avoided except in emergency relief situations.
2. Farmers are likely to assume the risk of trying out new crop varieties distributed by NARS, NGOs, and other development agencies.
3. Since farmers are only willing to pay a small premium for seed of new varieties, seed prices will usually not cover the actual cost of production and delivery.
4. Efforts may be needed to hasten diffusion of new crop varieties, since farmer seed networks may not function efficiently.

Experience with groundnuts in Malawi also suggests that farmer-to-farmer diffusion of new sees can be slow, and confined to close social networks (Freeman *et al.*, 2002). Hence, rapid dissemination of HPR seeds for legumes is difficult unless seed is injected on a very large scale.

Market-led approaches

IPM adoption is likely to be market-driven because, increasingly, it is the market that gives farmers the economic incentive to reduce crop losses from pests. For example, cowpea in eastern and northern Uganda was originally grown for its leaves that provided food in the hungry season. But the decline of cotton and the opening up of external markets has transformed cowpea into a valuable cash crop (Isubikalu *et al*., 2000). To protect cowpea from pests, commercial growers rely heavily in chemical control, and there is evidence that excessive spraying has reduced natural enemies and increased resistance among pests. This has presented IPM with a clear opportunity to rationalize pesticide use.

Increasingly, therefore, IPM is seen as part of a wider strategy to *create* new market opportunities for legumes. This has involved assessment of markets, development of value-added products, and breeding for quality traits as well as for HPR. Once again, the rationale is that where farmers have a strong economic incentive to grow legumes, they will also have an incentive to invest in crop protection.

For example, in 1987 ICRISAT pigeonpea breeders developed the variety ICP 9145, which was resistant to *fusarium* wilt, which is the main constraint on yields in countries like Tanzania. Experience in Malawi shows that ICP 9145 has never been popular because its tight seed-coat reduces its recovery rate from milling and because of its long cooking time. Newer varieties, like ICEAP 00040, released in 2002, have since been developed that are more market-friendly (Makoka, 2009).

Involving smallholders in markets may have high transaction costs, particularly where infrastructure is poor and farmers are far from markets. One way of reducing these costs is through producer marketing groups are. Producer marketing groups for legumes have the potential to simplify and shorten the marketing chain by directly connecting small producers to secondary and tertiary markets; better coordinate production and marketing activities and facilitate farmer access to production inputs at fair prices (Shiferaw *et al*., 2006). Thus, market-led IPM strategies have potential, but the big challenge is developing the institutions that link smallholders with markets.

Where IPM is market led, there may also be an economic incentive for the private sector to deliver services to smallholders. This was the case with supply of *fusarium*-resistant pigeonpea varieties in Tanzania. It required a partnership between ICRISAT (new seeds), TechnoServe (market information) and local buyers (seed supply and purchase) (Shiferaw *et al*., 2005). This example of successful partnership is from the main centre for commercial production of pigeonpea in Tanzania. It may be difficult to replicate in areas with less favourable market conditions. But similar opportunities for other legume crops may exist in specific regions with good market access.

Market-led IPM has implications for gender equity (Malena, 1994). In smallholder farming systems, women play a major role in management of legumes. In Eastern and southern Africa, for example, women receive the income from legume intercrops. Commercialisation of legumes may change the gender division of labour and allocation of income, however, as men now have a greater incentive to participate in the production and marketing of these crops. A gender perspective is important to ensure that the commercialisation of legumes also benefits women. IPM strategies to raise yields and income from legume crops should be targeted at women as well as men, and the design of these strategies needs to take careful account of women's priorities (which may differ from men's, since cooking time is a priority for them), women's resources (such as labour time) and women's ability to keep or at least share in the extra income created by more effective crop protection.

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Annex 1 Potential roles for selected African vegetables

	Overall	Nutrition	Food Security	Rural Development	Sustainable Landcare	PRIMARY OCCURRENCE			
						West Africa	Central Africa	East Africa	Southern Africa
Amaranth	**	***	**	***	*	√	√	√	√
Bambara	***	***	***	***	**	√	√	√	√
Baobab	**	**	***	***	**	√	√	√	√
Celosia	**	*		*	*	√			
Cowpea	**	***	***	**	**	√	√	√	√
Dika	**	**	*	***	***	√	√		
Eggplant	**	*	**	**	**	√	√	√	√
Egusi	***	***	**	***	**	√	√		√
Enset	*	*	***	*	**			√	
Lablab bean	***	**	**	***	***	√	√	√	√
Locust bean	**	**	***	**	***	√			
Long bean	***	**	*	***	**	√	√	√	√
Marama	*	*	*	*	*				√
Moringa	***	***	**	***	**	√	√	√	
Potatoes	*	**	**	**	*	√	√	√	√
Okra	**	**	**	***	**	√	√	√	√
Shea	***	*	**	***	***	√			
Yam bean	**	***	**	*	***	√	√	√	√

***** = Outstanding; ** = Notable; * = Average**

NB: The underlying justifications for these broad rankings are discussed in the following sections on Nutrition, Food Security, Rural Development, and Sustainable Landcare; greater detail is provided in the separate chapters on individual crops.

Anonymous (2006)

Annex 2: Increasing cowpea productivity and utilization – constraints

CONSTRAINT	PROBLEM
1) Seed constraint (productivity)	1.1 Seed production and availability 1.2 Seed 1.3 Access/distribution/marketing 1.4 Quality
2) Field constraints (productivity)	2.1 Access to inputs (not prioritized) 2.2 Heat stress 2.3 Striga 2.4 Drought 2.5 Insect pests 2.6 Photoperiod 2.7 Viruses 2.8 Pathogens-Bacterial fungal and viruses 2.9 Soil fertility (nitrogen fixation)
3) Post-harvest constraints (utilization)	3.1 Limited availability of diversified value added products 3.2 Processing equipment 3.3 Nutritional quality 3.4 Storage pests/bruchids) 3.5 Insufficient research and promotion of VAP 3.6 Reliable access to inputs 3.7 Reliable access to output markets 3.8 Lack of market information systems
4) Marketing constraint (utilization)	4.1 Reliable access to inputs 4.2 Reliable access to output markets 4.3 Lack of market information systems

Taken from Terry *et al.*, 2003

Annex 3: Increasing cowpea productivity and utilization in time horizons

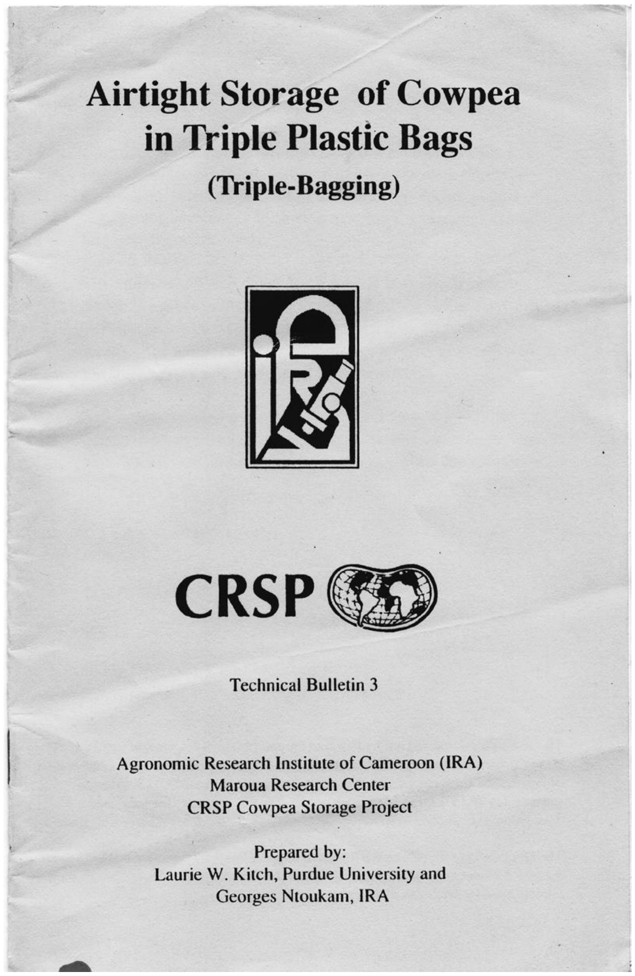
Horizon 1 (1-3 years), Horizon 2 (4=7 years), Horizon 3 (7+ years)

Constraints	**Problems**	**Interventions Marketing systems**	**Horizon (years)**		
			1-3	**4-7**	**7+**
1) Seed constraint (productivity)	1.1 Quality seed production	IPM, storage quality control			
	1.2 Seed access and distribution of improved varieties	- Seed and technology fair - Marketing			
2) Field constraints (productivity)	2.1 Access to inputs Marketing				
	2.2 Heat stress	Varieties (CB)			
	2.3 Striga	Varieties (MAS)			
	2.4 Drought	Varieties (MAS)			
	2.5 Insect pests - Maruca) - Pod Sucking Bugs) - Thrips) - Aphids)	- Varieties (*Bt*. GM) - Varieties (MAS) - Varieties (MAS) IPM			
	2.6 Viruses - CYMV - CABMV - SBMV	Varieties (CB)			
	2.7 Pathogens-Bacterial fungal and viruses	Varieties (CB)			
	2.8 Soil fertility (nitrogen fixation)	Varieties (MAS)			
	3.1 Limited availability of diversified value added products	- High protein Cowpea flakes - Flour - Pre-cooked peas (canned) - Weaning food - Canned stews Dried spinach and green pods			
	3.2 Processing equipment	Design			
	3.3 Nutritional quality - Biofortification (Zn, Fe)	- Flatulence (RFOs) (RNAi)			

	Selection and/or supplementation				
	3.4 Storage pests (bruchids)	-Amylase inhibitor (GMO) IPM			
3) Post-harvest constraints (utilization)	Insufficient research and promotion of VAP	Marketing			
4) Marketing constraint (utilization)	4.1 Insufficient research and promotion of VAP	Information dissemination			
	4. 2 Reliable access to inputs	Market information systems			
	4.3 Reliable access to output markets	(MIS)			

Annex 4

1. Extension leaflet on triple bagging



Airtight Storage of Cowpea in Triple Plastic Bags

(Triple-Bagging)

CRSP

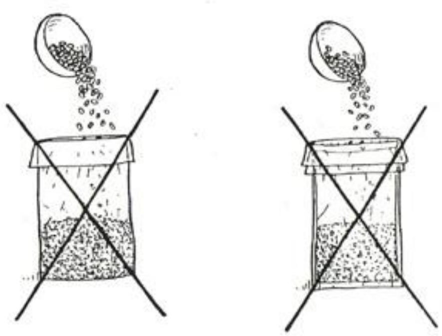
Technical Bulletin 3

Agronomic Research Institute of Cameroon (IRA)
Maroua Research Center
CRSP Cowpea Storage Project

Prepared by:
Laurie W. Kitch, Purdue University and
Georges Ntoukam, IRA

IRA/CRSP researchers have shown that by using **three** of these 50 kg capacity plastic bags, placed one inside the other, effective airtight conditions can be achieved.

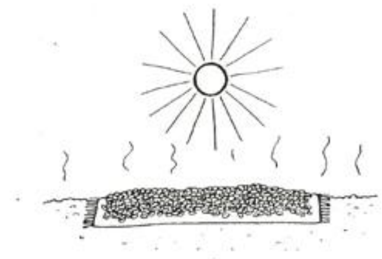
One or two bags are **not** sufficient to ensure reliable airtight storage.



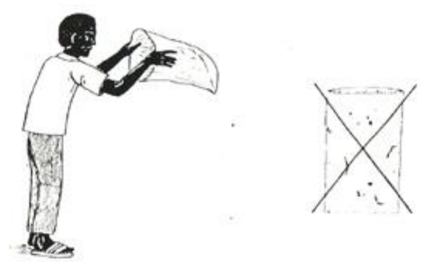
Procedure

The following procedure, utilizing the 50 kg clear plastic bags available in Maroua, is referred to as "triple bagging" and is recommended by the IRA/CRSP cowpea storage project.

Thoroughly dry the cowpeas to be stored.

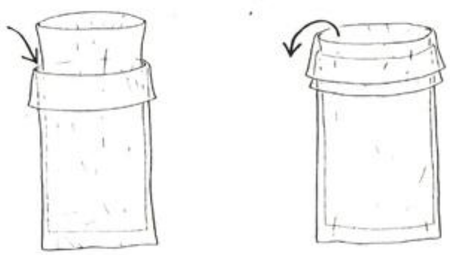


Carefully inspect the plastic bags for any holes. Even extremely small holes will reduce effectiveness. **Do not use** any bags with holes or tears.

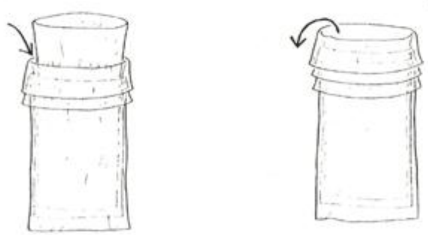


Fold back the top of the first bag.

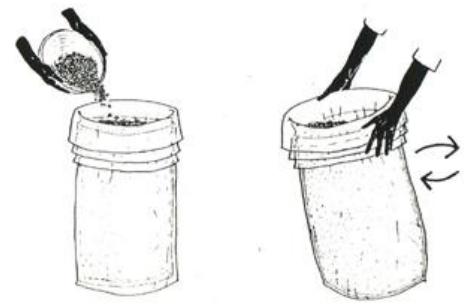
Place the second bag inside the first bag — then fold the top of the second bag over the first.



Place the third bag inside the second bag and fold the top down over the first two bags so that cowpeas can be easily poured into the third, inner-most bag.

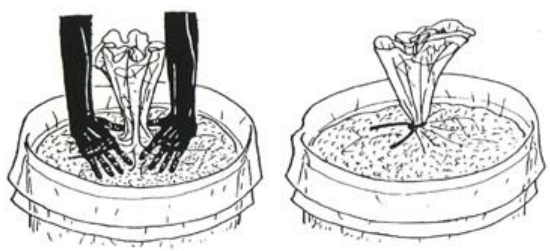


Slowly fill the inner-most bag with cowpeas, being careful to shift or rock the bags frequently to eliminate air spaces. Fill the inner-most bag nearly to capacity, leaving only enough room for the plastic bags to be tightly drawn together, folded back on themselves, and tied.



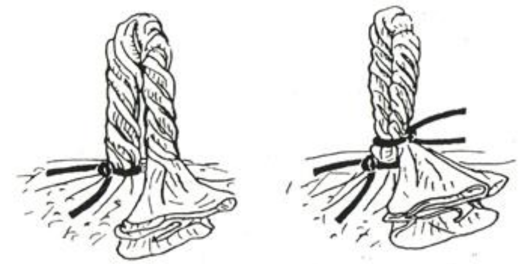
Firmly draw together the top plastic of the inner-most bag, squeezing tightly to press air out. Gently rock the bagful of cowpeas back and forth to help eliminate any air spaces.

After the cowpeas are well settled in place, squeeze the top plastic of the inner-most bag to force out any air and tie the bag closed with string or cord.



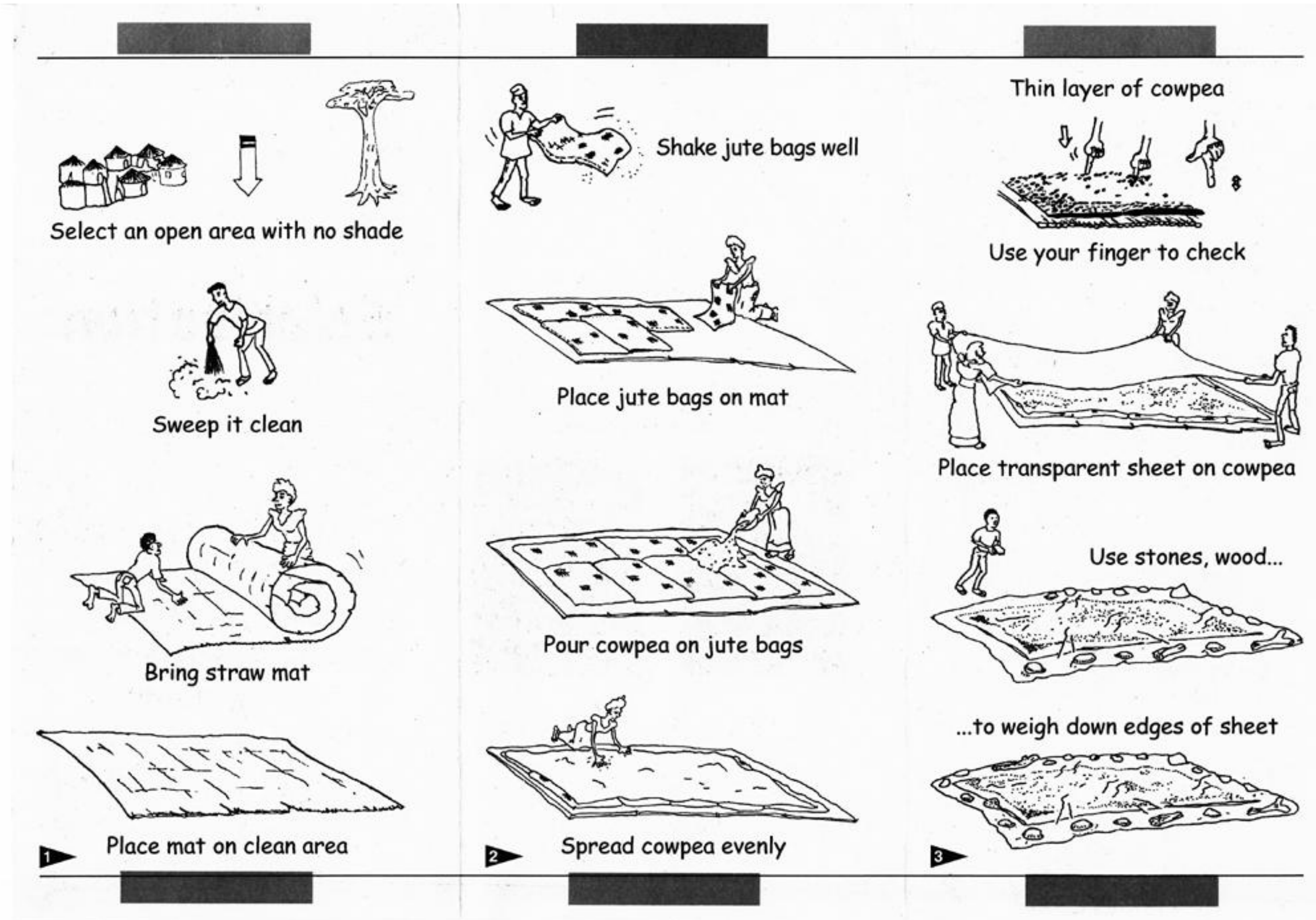
Twist up the remaining plastic above the tie and fold this back on itself.

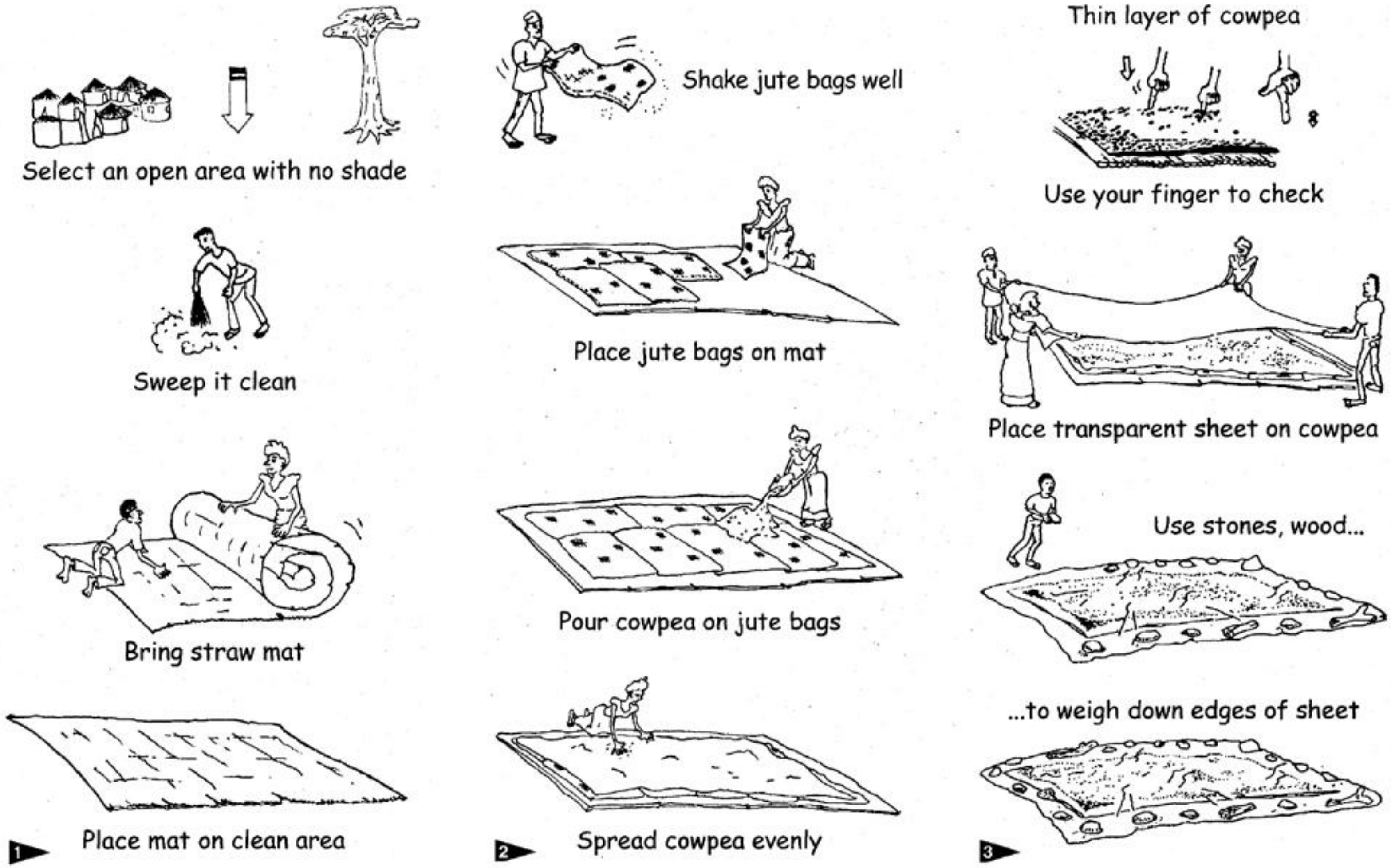
Firmly tie the double-folded plastic together.



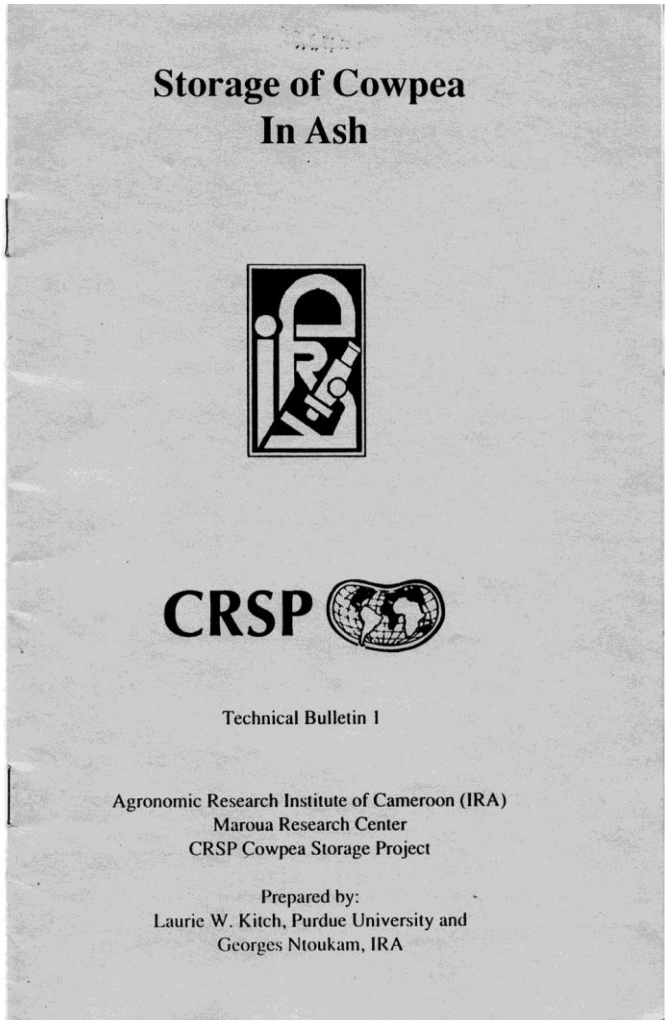
Repeat this tying procedure individually for each of the 3 plastic bags.

Annex 5. Extension leaflet on solarisation




Select an open area with no shade
Sweep it clean
Bring straw mat
Place mat on clean area
1
Shake jute bags well
Place jute bags on mat
Pour cowpea on jute bags
Spread cowpea evenly
2
Thin layer of cowpea
Use your finger to check
Place transparent sheet on cowpea
Use stones, wood...
...to weigh down edges of sheet
3

Annex 6.Extension leaflet on ash



Storage of Cowpea
In Ash

CRSP

Technical Bulletin 1

Agronomic Research Institute of Cameroon (IRA)
Maroua Research Center
CRSP Cowpea Storage Project

Prepared by:
Laurie W. Kitch, Purdue University and
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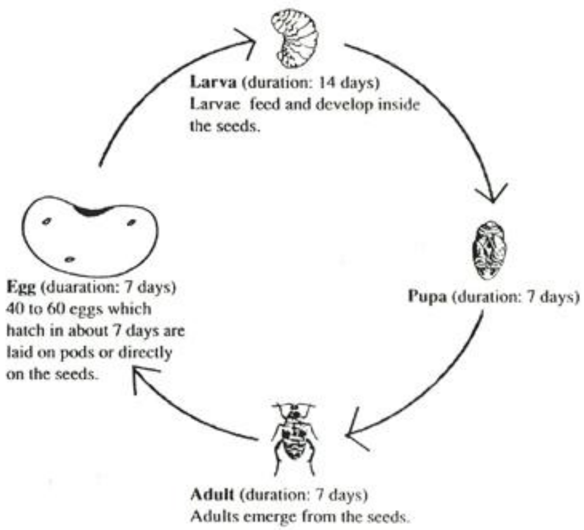
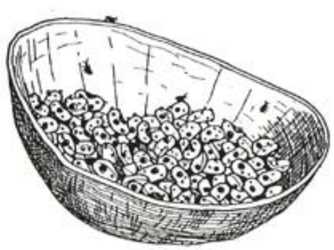
Life Cycle of the Cowpea Bruchid

Callosobruchus maculatus

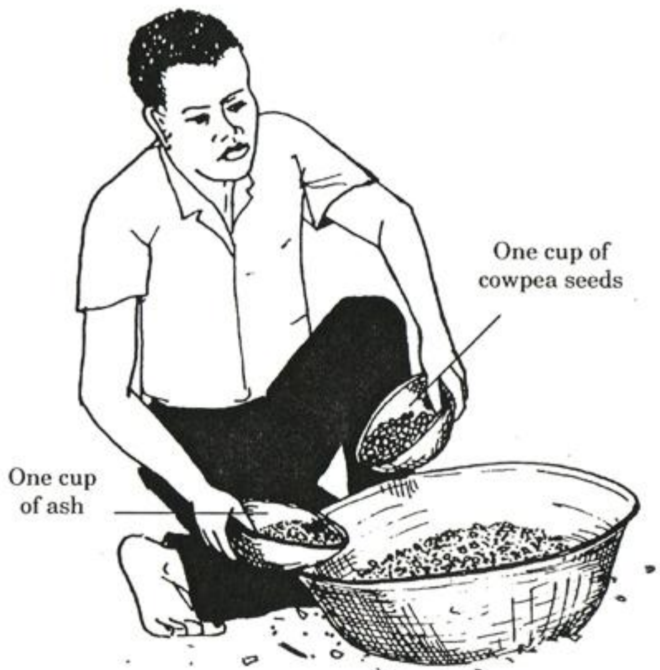
The life cycle of the bruchid is composed of four stages: egg, larva, pupa, and adult. The life cycle is completed in about 5 weeks.





Storage of cowpeas in ash is a traditional practice in certain regions of northern Cameroon.

IRA/CRSP researchers have shown that bruchids cannot reproduce if cowpeas and ash are mixed together in equal amounts.



One cup of wood ash is thoroughly mixed with one cup of cowpeas in a large mixing bowl.

6

This process is continued until the bowl is full and the cowpeas and ash are well mixed.

7

The ash storage method recommended by the IRA/CRSP storage project uses a large canary (guirawal in Fulfulde) commonly used for water.

When mixed with an equivalent volume of ash, this canary can hold 35 to 40 kgs of cowpea seeds.

Smaller canaries can also be used for smaller quantities of cowpeas.

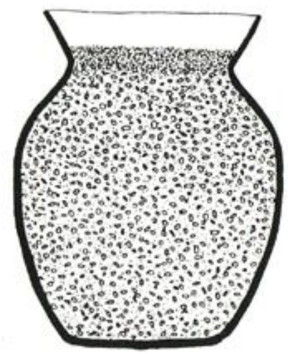
Ash to be used should be sifted to eliminate large particles of charcoal.

Research has shown that any wood ash is effective.

The mixture of ash and cowpea is then emptied into the canary. After each addition of ash and cowpeas, the mixture should be compacted with open hands to remove all open spaces.

This procedure is repeated until the canary is filled.

When the canary is full, a 3 cm layer of ash should be used to cover the stored cowpeas.



Each time that cowpeas are removed from the canary the ash cover should be restored.

Annex 7 Extension leaflet on sunning and sieving

One of the major causes of bean loss in storage is damage by bruchids (grain weevils). Bruchids feed within the bean, leaving beans with many holes and low weight.

BRUCHIDS CAN BE CONTROLLED BY:

1. Mixing 2 match boxes full of Actellic Super with a 90 kg bag of bean grain.
2. Mixing the dry bean grain with wood ash at 5 kg of ash per 90 kg bag of beans.
3. Mixing a teaspoon of corn oil like Elianto per 1 kg kimbo tin of grain.
4. **Sunning and sieving:**
   If you have 1 or 2 bags of beans and you live in a sunny area, sunning and sieving kills the eggs and larvae and makes the adults fly away. To use this method do the following:

- Spread out the beans on a mat under the sun for about 6 hours.
- After sunning the beans sieve them using an ordinary kitchen wire sieve or use a flat tinsheet with holes punched in it. This cuts down on costs.
- During the first 3 months after harvest, sieve the beans once every 2 weeks. After 3 months, sieve the beans once every 3 weeks.

Farmers in Machakos found sunning and sieving to be the best control method because:

- Storage loss is reduced by using Actellic Super.
- It allows you to save money.
- The beans are not harmed or damaged and they germinate well.
- The vigour of the small bean plant is not affected.
- The beans stay clean and taste nice.
- There is no risk of poisoning from insecticide.

Sieving beans

Sunning beans

Two people helping each other to sieve beans