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Phaseolus bean improvement in Tanzania, 1959–2005

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Summary

Common bean is an important source of dietry protein and starch in Africa and a primary staple in parts of the Great Lakes Region. Tanzania remains one of the worlds' major bean producing countries although according to official statistics, production per capita has almost halved in the last 20 years. The main international bean improvement programmes are run by the Centro Internacional de Agricultura Tropical [CIAT] from Colombia and by the Collaborative Research Support Programme [CRSP] co-ordinated by the Land Grant Universities in the USA. CIAT also maintains the world's largest collection of *Phaseolus* germplasm. The National Bean Programme in Tanzania is supported by both CIAT and CRSP. Collaboration between these international programmes and the National Programme has resulted in the release of more than 20 improved bean varieties. The paper reviews the development of bean improvement programmes in Tanzania since 1959, the contribution made by the international programmes and the strategies used to develop high-yielding bean varieties with resistance to pests and diseases and tolerance to some edaphic stress factors.

Introduction

The common bean (*Phaseolus vulgaris* L.) is one of the principle food and cash crop legumes grown in the tropical world and most of the production takes place in developing countries (Pachico, 1989). Beans are a major staple in eastern and southern Africa, where they are the second most important source of dietry protein after maize and the third most important source of calories after maize and cassava. Although beans are grown largely for subsistence and mainly by women farmers, about 40% of the total production from Africa is marketed, at an average annual value of USD 452 million (Wortmann et al., 1998). In some parts of Africa, annual per capita consumption is higher than the average for Latin America (Kirkby, 1987). The high protein content of common bean supplements diets based on cereals, root and tuber crops and banana. Beans contain 20–25% protein, mainly in the form of phaseolin. Phaseolin is deficient in methionine but most cereals have adequate levels of sulphur amino acids (although deficient in lysine), and a balanced diet can be obtained if cereals and legumes are consumed in the ratio 2:1 (Broughton et al., 2003). The leaves can be consumed as a green vegetable and in some areas including southern Tanzania, this is an important consideration in the varieties grown.

Beans are the main grain legume crop grown in Tanzania, where they are often intercropped with maize. Cultivation of beans can be seen in most areas of Tanzania, but the crop does not tolerate prolonged periods without rainfall, and to obtain a reliable yield in the drier areas supplementary irrigation is required. The main areas of production are therefore the mid to high altitude areas of the country, which experience more reliable rainfall and cooler temperatures. The most suitable areas for bean cultivation in Tanzania are in the northern zone particularly Arusha Region, the Great

Table 1. Top 10 producers of dry bean in SSA in 2004 (FAO)

Country	Production [Mt]
Kenya	535,000
Tanzania	270,000
Uganda	255,000
Burundi	220,218
Rwanda	198,224
Cameroon	170,000
Ethiopia	116,000
Congo DR	109,340
Benin	105,000
Malawi	79,000
SSA total	2,447,325
World	18,724,766

Lakes region in the west and in the Southern Highlands. Most of the bean production in Tanzania is carried out by smallholders for their own consumption, with around 20% surplus being marketed. In Kilimanjaro and Arusha Regions, where there is a suitable climate for commercial bean cultivation [and access to an international airport], beans are grown for export, either as seed for northern producers, haricot beans for the canning industry, or as fresh green beans. Tanzania is among the top twenty largest producers of dry beans in the world and the second largest producer in sub-Saharan Africa, after Kenya (Table 1). In 2004 the country produced 270,000 Mt. There was a large increase in bean production between 1960 when 80,000 Mt were produced, and 1980 when production reached 282,000 tonnes (FAO, 2005). In the same period, the Tanzanian population grew from 11 million to around 20 million and by 2005, the population had reached 38 million. Between 1960 and 1980 therefore, increases in bean production more than kept pace with population increase, but since 1980, total bean production has remained static while the Tanzanian population has almost doubled. These figures are however, disputed by some experts in Tanzania who believe that in some areas such as the Southern highlands there is more local and cross-border trade in beans than there was 20 years ago (C. S. Madata, unpublished). It has also been suggested that since the removal of fertiliser subsidies in the 1990s, there has been a trend for maize to be replaced by beans and cash from the sale of surplus beans to be used to purchase maize required for household food security.

Table 2. Pest, disease and edaphic constraints to bean production in East Africa ranked in order of estimated yield loss (Source: modified from CIET Atlas of Bean Production)

Constraint	Causal organism
Angular leaf spot	*Phaeoisariopsis griseloa*
N deficiency	–
Anthracnose	*Colletotrichum lindemuthianum*
P deficiency	–
Stem maggot	*Ophiomyia* spp.
Root rot	*Pythium* spp. and *Fusarium* spp.
Bruchid	*A. obtecrus* and *Z. subfasciatus*
Exchangeable bases	–
Common bacterial blight	*Xanthomonas axonopodis* pv. *phaseoli*
Bean common mosaic	BCMV
Aphids	*Aphis* spp.
Ascochyta blight	*Phoma* spp.
Halo blight	*Pseudomonas savastanoi* pv. *phaseolicola*
Water deficit [mid season]	–
Rust	*Uromyces appendiculatus*
Water deficit [late season]	–
Al/Mn toxicity	–
Pod borer	*Helicoverpa armigera*
Floury leaf spot	*Mycovellosiella phaseoli*
Leaf beetles	*Ootheca* spp.
Pod borer	*Maruca testualis*
Water deficit [early season]	–
Brown bug	*Clavigralla* spp.
Fusarium wilt	*Fusarium oxysporum* f. sp. *phaseoli*
Thrips	*Megalurothrips sjostedii*
White mould	*Sclerotinia sclerotiorum*
Charcoal rot	*Macrophomina phaseolina*
Scab	*Elsinoe phaseoli*
Web blight	*Thanatephorus cucumeris*

Average bean yields in Tanzania are around 500 kg/ha although the potential yield under reliable rainfed conditions is 1500–3000 kg/ha, using improved varieties and proper crop and land husbandry. The main reasons for the low yield obtained by most smallholders are; poor seed quality, poor performance of the local landraces, mainly due to their susceptibility to pests and diseases, low soil fertility, drought and poor crop management, such as late weeding.

The bean crop may be attacked by a wide range of insect pests, diseases and nematodes. Many of these are a major cause of yield loss in East Africa (Table 2). Insect pests attack all parts of the bean plant from the roots and lower stem, through to the pods and seeds. One of the major bean insect pests in East Africa is the beanfly or bean stem maggot, *Ophiomyia phaseoli* and *O. spencerella*. During the seedling stage the chrysomelid beetle, *Ootheca bennigseni* and *O. mutabilis* may seriously damage the leaves and the larvae damage the roots. Aphids (*Aphis fabae, A. craccivora*) are sometimes a problem on beans during dry spells, especially in the early stages of crop growth. The most serious of the pod borers in Tanzania are *Maruca vitrata* and *Helicoverpa armigera*. The most important insect pests in stored beans are the bean bruchids (*Acanthoscelides obtectus* and *Zabrotes subfaciatus*) (Schwartz and Pastor-Corrales, 1989; Allen et al., 1996).

Of the large number of diseases that can affect beans in the tropics, the most important in Tanzania are angular leaf spot (ALS) (*Phaeoisariopsis griseola*) halo blight (HB) (*Pseudomonas phaseolicola*), rust (*Uromyces phaseoli*), and *Bean common mosaic virus*(BCMV) (see Allen, 1983, 1995; Allen and Lenne, 1998). In warmer areas, damage due to common bacterial blight (CBB) (*Xanthomonas campestris* pv. *phaseoli*) may be substantial. On sandy soils the root-knot nematodes *Meloidogyne incognita* and *M. javanica* can be a problem (Ijani et al., 2000). Depleted soil fertility is associated with an increase in root rot diseases caused by *Pythium* spp. and *Fusarium* spp.

Besides crop losses to biotic constraints, further loss of yield may be attributed to edaphic constraints, even in developed countries (Boyer, 1982). In Tanzania much of the agriculture is rainfed and low-input, resulting in low yields. Drought remains the single most important factor affecting food security in sub-Saharan Africa. In the past few years the northern mid-altitude highlands of Tanzania and other major bean production areas have experienced a series of droughts, which have resulted in reduced bean production. Higher temperatures associated with global climate change are likely to exacerbate these more frequent droughts (IPCC, 2001).

Some of the major bean production areas such as the Usambara and Uluguru Hills have acid soils with pH <5.5, which limit crop productivity (Wortmann et al., 1998). Under increasing population pressure, acid soils are now rapidly being brought into cultivation in many parts of Africa, including Tanzania. Most published research however, focuses on individual abiotic stress factors, but multiple edaphic stresses often occur simultaneously in farmers' fields. For example, drought is often accompanied by high temperature and high photosynthetically active radiation, and can be exacerbated by subsoil Al toxicity, which reduces root elongation, limits water and nutrient use by crops, and magnifies the effects of moisture deficit (Rao and Cramer, 2003). If due to climate change these problems intensify as is predicted, the interaction of drought and Al toxicity will become more acute.

Phaseolus gene pools

There are about 50–60 wild *Phaseolus* species found in the South American Centre of diversity. Five of these have been domesticated; common (*P. vulgaris*), yearlong (*P. polyanthus*), scarlet runner (*P. coccinueus*), tepary (*P. acutifolius*) and lima (*P. lunatus*). Each domesticated species constitutes a primary gene pool with its wild ancestral form. Wild beans dispersed northwards and southwards to form two geographically distinct gene pools in Mesoamerica and the southern Andes (Broughton et al., 2003). Domestication gave rise to several domesticated races in each of the two gene pools; races Mesoamerica, Durango, Guatemala and Jalisco in the Mesoamerica genepool and races Nueva Granada, Peru and Chile within the Andean gene pool (Sing et al., 1991; Chacon et al., 2005). The two distinct gene pools may be regarded as sub-species on the basis of their partial reproductive isolation resulting from F_1 lethality. As a consequence, it has proved difficult to transfer traits between gene pools. Where success has been achieved in transferring qualitative traits such as pest and disease resistance from wild species, this has been done by inter-generic and interspecific crosses within the same gene pool (Kelly, 2004). However, the use of inbred backcross breeding and molecular markers is making it possible to exploit the variability in wild species by identifying quantitative traits that contribute to yield enhancement and which were previously masked by undesirable morphological characteristics. CIAT maintains a collection of over 13,000 wild *Phaseolus* accessions and there are over 11,000 in the USDA Plant Germplasm System. A full evaluation of these collections for economically useful traits is only just beginning, but it is already known that the wild accessions are a source of resistance to several pests and diseases. Resistance to bruchid was found in wild accessions of *P. vulgaris*, while tepary bean (*P. coccineus*) is a source of resistance to anthracnose, white mould and root rots, common bacterial blight and bruchids (Kelly, 2004).

Biotechnology for bean improvement

Marker-assisted selection

Genetic linkages between desirable traits and markers that can be detected using PCR-based techniques such as random amplified polymorphic DNA [RAPD], are now being exploited in bean breeding programmes (Kelly et al., 2003). To improve reproducibility of RAPD markers, sequence characterised amplified region (SCAR) markers, derived from corresponding RAPD markers, have become the basis for the indirect selection of economically viable traits in bean breeding (Kelly, 2004). For instance, markers linked to race specific disease resistance genes form the basis for indirect selection for major gene resistance. Marker-assisted selection (MAS) offers a way to overcome problems of masking of hypostatic genes and inadequate inoculation techniques, resulting in disease escape in conventional screening. It has also been possible to identify linkages between markers and quantitative trait loci controlling complex traits such as stress tolerance (Schneider et al., 1997).

Two RAPD markers linked to major rust resistance genes have been identified in contrasting DNA bulks (Johnson et al., 1995). Common bacterial blight resistance loci have been mapped using RAPD markers (Jung et al., 1995). RAPD markers flanking the 'ARE' anthracnose resistance gene have been identified in both Andean and Mesoamerican bean populations (Young and Kelly, 1996). A number of other RAPD markers linked to major gene resistance have been identified in common bean (Kelly and Miklas, 1998; Kelly et al., 2003) (Table 3).

Table 3. RAPD markers linked to major gene resistance in common bean (Kelly and Miklas, 1998)

Resistance gene	Source	Gene pool	Pathogen
Co-1	Michigan DRK	AND	Anthracnose
Co-2	Cornell 49-242	MA	Anthracnose
Co-4	SEL1308 G2333	MA	Anthracnose
Co-5	TU, G2333 SEL1308	MA	Anthracnose
Co-6	AB136 Catrachita	MA	Anthracnose
I	Seafarer Montcalm	MA AND	BCMBV
bc-3	B85009 MCM3031 MCR2205	MA MA AND	BCMV
bgm-1	Garrapato A429	MA	BGMV
Mp-1	BAT477	MA	*Macrophomina*
Mp-2	BAT477	MA	
Ur-3	NEP II	MA	*Uromyces*
Ur-3	PI 181996	MA	*Uromyces*
Ur-4	Early Gallatin	AND	*Uromyces*
Ur-5	Mexico 309	MA	*Uromyces*
Ur-9	Pompadour Checa	AND	*Uromyces*

Genetic transformation

Transformation of large-seeded leguminous species is often difficult (Broughton et al., 2003). Aragao et al. (1996) obtained transgenic bean plants using particle bombardment and the transformed plants were reported to be stable and some of the traits to be heritable. Aragao et al. (2002) used the same method to obtain herbicide-tolerant plants although only 0.5% of the regenerated plants carried the trait. The same laboratory claims to have genes for resistance to abiotic stress (Svetleva et al., 2003). A number of laboratories have reported successfully carrying out genetic transformation of *P. vulgaris* using *Agrobacterium*-mediated methods for whole plants, or using protoplasts (e.g. Svetleva *et al*., 2003). A protocol for developing transgenic bean plants expressing the *Cry2* gene from *Bacillus thuringiensis* [Bt], using *A. tumefaciens* was described by Suresh et al. (2000), but the production of stable transformed plants by this method has proved difficult. Transformation is easier with tepary bean than with common bean (De Clerq et al., 2002) and it should be possible to introduce genes from *P. vulgaris* into *P. acutifolius* by this method and then backcross into *P. vulgaris* (Broughton et al., 2003).

Important selection criteria in bean breeding programmes

Breeding primarily for enhanced yield is a strategy that works better for advanced agriculture than for low-input smallholder agriculture. Yields obtained by the average smallholder in Tanzania are well below the genetic potential of improved varieties currently available. Therefore, it follows that new varieties are unlikely to be adopted if they offer only the expectation of higher yields under optimum conditions. Although it has been recognised for many years by scientists that damage caused by pests and diseases contributes greatly to poor smallholder bean yields, disease resistance alone is not attractive to smallholders who may have a poor understanding of aetiology. Communities in the main bean-growing areas in Tanzania commonly grow a mixture of local 'land races' and may add improved varieties to the mixture. Although many of the local land races are inherently low-yielding, each component of the mixture will have an attribute that prevents the whole crop from being lost to particular biotic and edaphic constraints (Bisanda, 2000). A combination of multiple attributes such as, yield enhancement and disease and pest resistance or tolerance to drought and low soil fertility, are required to develop bean varieties that are adapted to a wide range of bean production agro-ecologies. Such biological attributes however, must be combined further with other traits that make a bean variety attractive to smallholders; desired seed colour and size, suitable taste and good cooking qualities such as forming a thick broth, and short cooking time. The absence of a combination of a few of these attributes is considered to be a major factor in low adoption rates of improved varieties (Sanchez, 2002). This has resulted in a change in emphasis in bean breeding programmes for smallholders in Africa, shifting towards selection for improved performance under adverse conditions, using more participatory approaches to variety selection, ensuring that new varieties meet the culinary and organoleptic requirements of the end-users. The ideal smallholder bean variety must meet these socio-economic criteria as well as being able to produce higher yields than the local varieties under conditions of low soil fertility, periodic drought and attack by an array of pests and diseases.

Disease resistance

Breeding beans for disease resistance up to 1990 is well reviewed by Beebe and Pastor-Corrales (1991) and is updated by Allen et al., (1998) and by Kelly (2004). It is summarised briefly below. More recent information and that particular to Tanzania can be found below in the section on bean improvement programmes.

Anthracnose. There is strong evidence for co-evolution of many of the bean pathogens with their host within the two centres pf origin on *P. vulgaris*. Varieties that are resistant to races of the anthracnose pathogen from Central America are susceptible to those from the Andean Region (Beebe and Pastor-Corrales, 1991). Until it proved susceptible to races of the pathogen from Europe and Latin America, Cornell line 49–242 was the main source of resistance. The ARE resistance genes from 49–242 are still used in combination with other resistance genes for more stable resistance (Graham and Ranalli, 1997). When 20,144 bean accessions were evaluated by CIAT in Colombia, 350 of them were found to be resistant to Andean and Mesoamerican isolates of the pathogen e.g. Mex 222, Ecuador 299, PI207262, G2333, G811 and G2641 (Pastor–Corrales et al., 1994). G2333 of Mexican origin has for many years continued to exhibit resistance to anthracnose and is a valuable source of resistance (Allen et al., 1998). Cultivar G2333 has resistance to 380 isolates of *C. lindemuthianum* conferred by three independent dominant genes. Due to the variability of the pathogen, durable resistance to anthracnose requires a combination of genes. Such gene pyramiding is difficult to achieve with conventional breeding due to the need to inoculate with a wide range of races. In the absence of effective selection due to lack of differentiating races, epistatic interactions between resistance genes prevent the identification of masked alleles which may be lost from breeding populations (Kelly and Miklas, 1998). Marker-assisted selection enables hypostatic genes to be retained in the breeding population. Chinook, a light red kidney cultivar and Red Hawk, a dark red kidney cultivar, carry both the *Co-1* and *Co-2* anthracnose resistance genes (Beaver et al., 2003). The gene *Co-4*^{2} confers resistance to 97% of American races of the pathogen (Balardin and Kelly, 2001). Ten major genes conditioning resistance to anthracnose have been characterised and markers linked to six independent dominant genes have been identified (Vallejo and Kelly, 2001).

Angular leaf spot. There is considerable pathogenic variability in *P. griseola* and a set of six differential cultivars have been identified (Allen et al., 1998). Fifty-six resistant genotypes were selected from a collection of 13,000 accessions screened at CIAT (Schwartz et al., 1982). These formed the basis of an international nursery containing several sources of broad-based resistance to the disease. CAL 143 was one of the first Andean beans to be identified with resistance to ALS and has proved to be resistant in Malawi, South Africa and Tanzania (Aggrawal et al., 2004).

Halo blight. There are at least 9 races of the halo blight bacterium recognised, infecting a range of legume species (Taylor et al., 1996a,b). Races 1,2 and 6 are found worldwide, while races 3,4, 5 and 8 were confined to eastern and southern Africa. Races 1(45%), 2 (52%) and 3 (3%) were reported from common bean in southern Tanzania (Mabagala and Saettler, 1992). Genes used in breeding for halo blight resistance are derived from two main sources: cv. Red Mexican (resistant to race 1) and PI 150414 (resistant to races 1 and 2).

Rust. U. appendiculatus is a macrocyclic rust pathogen with numerous races and changes in virulence are frequent (Alexander et al., 1985). Race non-specific resistance has been reported in bean populations (Mmbaga and Steadman, 1992) and would offer a more durable approach than race-specfic resistance. A wide range of rust-resistant germplasm has been produced and tested since 1984, but none has remained resistant across all sites and seasons. Some of the more resistant cvs are Mexico 309, Ecuador 299, Relands Greenleaf, Turrialba 1 and 4 and Puerto Rico 5 (Allen et al., 1998). Efforts are currently being made to identify the rust races in East Africa. The Andean *Ur-4* gene for rust resistance is ineffective against African races, *Ur-3* confers resistance to most African races and to all known African rust races when combined with *Ur-5* (Beaver et al., 2003).

Root rots. May be caused by one or a combination of *Fusarium solani* f.sp. *phaseoli*, *Rhizoctonia solani* and *Pythium* spp. (Abawi et al., 1990) Root-knot nematodes may also play a role in predisposing plants to infection. Root rot may become a serious problem on impoverished soils and the use of less susceptible varieties needs to be integrated with measures to improve soil fertility and organic matter content (Mutitu et al., 1989). A Kenyan bean germplasm collection of 374 accessions was screened without finding any resistant varieties. However, ten resistant varieties were identified among 26 introductions from Rwanda, of which farmers' preferred MLB-49-89a because of its early maturity, SCAM 80-CM/5 and RWR 532 for their high yield and RWR 719, as it was similar to a previously popular variety in western Kenya which was susceptible to root rots (Otsyula et al, 1998).

Common bacterial blight. X. campestris pv. *phaseoli* has a wide host range among legume species. Although isolates vary in pathogenicity, physiologic specialisation on *P. vulgaris* is unknown. It has not proved possible to find high levels of resistance to bacterial blight in *P. vulgaris* and out of 12,000 accessions screened at CIAT, only 39, mainly from the Andean gene pool, were found with moderate resistance (Allen et al., 1998). Resistant lines such as Great Northern Nebraska 1 and PI207262, bred in temperate programmes are useful as sources of resistance but are poorly adapted agronomically and unsuitable for use in the tropics. The tepary bean, *P. acutifolius*, has proved to be a good source of resistance to CBB. Lines XAN 159, 160 and 161 are highly resistant to CBB and were selected during the early 1980s, from populations derived from crosses with tepary bean PI319433 (Thomas and Waines, 1984). Lines such as XAN 112 suffer little crop loss from CCB in Africa and resistance is quantitative and is expected to be durable (Opio et al., 1992, 1996). There is great potential for the use of markers to assist breeders to distinguish between resistance loci. The pyramiding of qualitative genes from common and tepary bean will contribute to more effective durable resistance to CBB in the future (Kelly et al., 2003).

BCMV. Bean common mosaic virus is aphid-transmitted and can be seed-borne, facilitating spread over long distances. There are two serotypes of the bean mosaic virus that are now recognised as separate viruses. Strains in Serotype A types do not cause symptoms of root necrosis, known as 'black root' and are classified as BCMV. Strains in Serotype B cause black root in bean cultivars carrying the 'I' gene for resistance, and are classified as *Bean common mosaic necrotic virus* (BCMNV). BCMNV is predominant in eastern and southern Africa (Spence and Walkey, 1991, 1995) and therefore cultivars carrying the 'I' gene are prone to black root. This problem can be overcome by combining I-gene resistance with recessive resistance genes that prevents the systemic necrosis reaction (Mukoko et al., 1994). Markers linked to the I gene have been used to develop enhanced germplasm with the I + *bc-3* gene combination (Kelly, 2004).

Multiple disease resistance. In most bean growing areas of Tanzania, bean yield is affected by at least three diseases and if improved varieties are to be successful, multiple disease resistance is required. Four genotypes were identified in the 2004 CIAT bean project with resistance to ALS, anthracnose and ashy stem blight (*Macrophomina phaseolina*) and several HGA lines were identified with combined resistance to rust, CBB, anthracnose and ALS (CIAT, 2005b).

Insect resistance

Bruchids. The bruchids *A. obtectus* and Z. *subfasciatus* are widespread in Africa. In Tanzania. *A. obtectus* is the more prevalent bruchid in the south and west but in warmer, lower altitude areas, *Z. subfasciatus* is the more prevalent. The importance of *A. obtectus* has been underestimated in the past due to seasonal variations in the relative occurrence of the two bruchids (Nchimbi-Msolla and Misangu, 2001; Myers et al., 2001). Bruchid resistance has been identified in wild *P. vulgaris* from Mexico (Schoonhoven et al., 1983). Resistance to *Z. subfasciatus* has been associated with the presence of a seed protein, arcelin (Osborne et al., 1986, 1988). Since 2004, lines containing arcelin alleles have been evaluated for bruchid resistance in several African countries, including Tanzania. The arcelin alleles Arc 2 and Arc 4 have been transferred into locally adapted, high yielding varieties, conferring resistance to both types of bean bruchids. A polysaccharide in the wild accession G12953 is suggested as another factor responsible for resistance to *A. obtectus*. A CIAT accession of P acutifolius, G40199, was reported to show a high degree of resistance to *A. obtectus* at SUA (Nchimbi-Msolla and Misangu, 2001). Resistance to bean bruchid has also been identified by CIAT in Colombia, in progeny from interspecific crosses between *P. vulgaris* and *P. acutifolius* (CIAT, 2005b).

Beanfly. Bean varieties with tolerance to beanfly have been reported (Kornegay and Cardona, 1998) and this is often related to their ability to recover from attack by producing adventitious roots. High levels of resistance to *O. phaseoli* have been found in *P. coccineus* germplasm and progeny from interspecific crosses with *P. vulgaris* have proved to be resistant (Kornegay and Cardona, 1998).

One of the major challenges in bean breeding for resistance to bean fly is to develop a systematic screening procedure that provides a consistent bean fly population exerting pressure uniformly on each genotype. A mass rearing technique has been developed by scientists in South Africa that provides for a steady population of bean flies that can be used under controlled conditions in screening for resistance. Its practical application is however, yet to be documented. Using natural bean stem maggot population, CIAT-Tanzania identified a few lines (Mlama 49, Mlama 127, G222501) that showed some resistance to bean fly. Some of them are currently used a sources of resistance in both ECABREN and SABRN regional bean breeding programmes (Chirwa et al., 2003).

Drought tolerance

It has been estimated that about 40% of bean production in Africa takes place in environments subject to moderate to severe mean water deficit (Broughton et al., 2003). Attempts to breed beans for drought tolerance have been hampered by the lack of clearly defined selection criteria, as the trait is likely to be based on a number of different mechanisms. Drought tolerance must be distinguished from drought escape due to early or late maturity. Nevertheless, some success has been achieved by CIAT breeders simply by selecting for yield under dry conditions (White and Singh, 1991). Drought tolerant lines SEA 5 and SEA 13 were developed at CIAT using this approach (Sing et al., 2001). CIAT cultivars BAT477 and RAB96 have performed well under drought conditions and were recommended in Brazil for breeding programmes (Guimaraes et al., 1996). In the CIAT bean project in 2004, RAB 650 and SEA 23 were two lines from the breeding programme with outstanding adaptation to water stress (CIAT (2005). Genetic variability for drought tolerance is low in *P. vulgaris* but the tepary bean, *P. acutifolius* has superior tolerance. Crosses with tepary bean have been recovered at CIAT using 'embryo rescue' techniques (White et al., 1998).

Bean improvement programmes in Tanzania

Early history 1959–1980

The first bean improvement programme in Tanzania was initiated at Tengeru Agricultural Research Institute (TARI), near Arusha, in 1959 to produce white haricot beans for the canning industry. The production of navy beans for export in northern Tanzania had started around 1937 and by 1952, 2500 Mt were being exported. As more, and inexperienced producers became involved, declining quality began to threaten the viability of the trade. In response, the cv. Michigan Pea was introduced from the USA, but proved to be highly susceptible to rust, unlike the cv. it replaced, Comptesse de Chambord (Allen et al., 1989). More care was then taken to ensure that introduced material was screened for local adaptability. Mexico 142 proved to have good rust resistance and became one of the most widely grown navy bean varieties in E.

Africa. Eighty-two accessions were introduced into the breeding programme at TARI from around the world in 1960/61 (McCartney, 1966). The first varieties to be released from that programme were Tengeru 8 and 16 (T8, T16), both of which were resistant to bean rust. Unfortunately, T8 proved to be highly susceptible to anthracnose (Shao and Teri, 1985).

In the Southern Highlands and Great Lakes regions of Tanzania, landraces of mixed seed types are grown. These are bush types and mainly consumed by the producing households as 'dry beans'. Although the yield potential of most of these land races is low, they provide the farmer with a reliable yield under low input adverse conditions. In 1971 the first National Bean Improvement Programme in Tanzania, began breeding to improve the quality and yield of dry beans (Karel et al., 1981). When the Tengeru bean programme ended in 1965, it was several years before the new bean improvement programme was initiated at the Uyole Agricultural Centre (UAC), Mbeya. The main objectives of this programme were to determine the reasons for poor bean yields among smallholders in the Southern Highlands and to select high-yielding cultivars. Disease was identified as the major yield-limiting factor and disease resistance became the main thrust of the programme. By 1975 a total of 1046 germplasm lines had been collected at three centres; UAC in the south, Ilonga Agricultural Research Institute in the Centre and Lyamungu Agricultural Research Institute (LARI) in the north (Karel et al., 1981).

The bean improvement programme was extended in 1975 under the National Grain Legume Research Project, now with Ilonga as the main centre and LARI and UAC as sub-stations. The first improved bean varieties for smallholders, T3 and Kabanima, were released from this programme in 1979/80. Both were resistant to rust and ALS. The national programme was further strengthened when in 1979, the Ministry of Agriculture inaugurated a new phase of bean improvement, based at LARI, with UAC and Ilonga as sub-stations.

From the 1046 accessions that were introduced during the early 1970s, preliminary screening reduced the number to 56 lines that were disease resistant with suitable agronomic and yield characteristics. These were further evaluated at Ilonga and LARI during 1977 and the best 20 lines were evaluated in multi-locational trials in 1978 and 1979. Canadian Wonder (CW) was included as a check and the only variety to significantly out-yield CW was P311-A.L. P113 was fast-growing and disease resistant, but it had a black seed coat colour which was not popular with farmers or local consumers, so it was retained as a breeding line. Lines that performed well during the late 1970s and 80s and have similar seed colour and maturity to CW, were T23, YC-2 and P692-A.

Regional networks

The national bean research programmes in eastern and southern Africa are now linked through the Pan-African Bean Research Alliance (PABRA) consisting of two networks; the Eastern and Central African Bean Research Network [ECABREN] and the Southern Africa Bean Research Network (SABRN). The networks receive funding from several government and donor organisations, including the Canadian International Development Agency (CIDA), the Department for International Development (DFID), UK, the Swiss Government, the United States Agency for International Development (USAID) and the Rockefeller Foundation. These networks are members of two regional organisations; the Association for Strengthening Agricultural Research in Africa (ASARECA) and the Southern Africa Development Council (SADC).

International programmes

In 1980, The Canadian International development Agency (CIDA) established the Selian Agricultural Research Institute (SARI) Centre near Arusha, as part of the Tanzania-Canada Wheat Project. Since 1989 SARI has been designated as the Zonal Headquarters for Agriculture and Livestock Research and Training for the Northern Zone of Tanzania. The National Bean Programme was then moved from LARI to SARI, but UAC continued to be an important sub-station for bean research.

Sokoine University of Agriculture (SUA) was from 1969 the Faculty of Agriculture of the University of Dar es Salaam. It became a fully fledged university in 1984. SUA has become another centre for research on *Phaseolus* bean and is the Regional Centre for the Bean/Cowpea Collaborative Research Support Programme (Bean/Cowpea CRSP)–East Africa. SUA is also the national centre for improvement of beans suited to low altitude growing areas of Tanzania.

CIAT regional bean programme

The Centro Internacional de Agricultura Tropical (CIAT) was inaugurated in 1967 and the legume crops component of the Agronomic Systems Programme began work in 1969. CIAT has the global mandate within the CGIAR system for *Phaseolus* improvement. A bean research team has worked at CIAT since 1973, but it was not until 1977 that the Bean Programme was formally initiated. From 1997 bean research has been based on two projects; Project IP-1, Bean Improvement for Sustainable Productivity, Input Use Efficiency & Poverty Alleviation and Project IP-2, Meeting Demand for Beans in sub-Saharan Africa in Sustainable Ways. The first Regional Programme for beans in Africa was in the Great Lakes Region. It was based in Rwanda and launched in 1984 with support from CIDA and USAID. Later, another program for East Africa was initiated, and this was based in Uganda, covering several countries in East Africa. The third program started in 1987, and was based in Arusha, northern Tanzania, which covered countries in the Southern Africa Development Community (SADC). In the mid-90s, the Great Lakes and the East Africa regional programmes merged, to form one network called East and Central Africa Bean Research Network (ECABREN) operating from Arusha, Tanzania, under the umbrella of the Association for Agricultural Research in East and Central Africa (ASARECA). Simultaneously, the SADC-CIAT program changed to the Southern Africa Bean Research Network (SABRN), which moved it's Headquarters from Arusha in Tanzania to Chitedze Research Station in Malawi, operating under the umbrella of Food Agriculture and Natural Resources (FANR), within the SADC secretariat based in Botswana. The two networks are linked through the Pan-Africa Bean Research Alliance (PABRA) where CIAT is a coordinating partner, and they implement the same PABRA log frame across the member countries. Tanzania, is a large country that cuts across the two agro-climatic environments; bimodal rainfall in the central and northern parts which fall under ECABREN, and uni-modal rainfall in the south which falls under SABRN.

Since 1984 CIAT have introduced improved bean seeds from tropical America into breeding programmes for the mid-altitude and highland areas of central, eastern and southern Africa. The first varieties introduced were climbing types of Mexican origin and have been widely adopted in Rwanda. Climbing beans are being slowly adopted across the region where they are well adapted to maize/bean intercropping.

Nineteen bean varieties have been released in Tanzania since 1980 and several of these have been CIAT lines or were selections made in Tanzania from CIAT crosses (Table 4.) (CIAT, 2005).The earlier improvement programmes selected mainly for disease resistance but more recently, there has been an emphasis on tolerance to drought, low fertility and micronutrient deficiency. In Africa, beans are often produced on soils that are acid, low in available phosphorus [P] and high in aluminium. Symbiotic nitrogen fixation is adversely affected by low P availability. In some areas beans are grown on alkaline soils where iron availability is low and local inhabitants often suffer from iron deficiency (Broughton et al., 2003).

One of CIAT's priorities has been to develop PCR-based markers, mainly sequence characterised amplified regions (SCAR) and simple sequence repeats (SSRs). These markers have been used to tag genes of agronomic importance and selection in marker-assisted breeding programmes. All new markers are mapped onto CIATs principle mapping population which now contains 500 markers. Several mapping populations have been developed at CIAT to tag quantitative trait loci, including tolerance to abiotic stress, micronutrient content and pests and disease resistance. For example, quantitative trait loci (QTLs) have been mapped for low phosphorus tolerance, agronomic performance and disease resistance in a population derived from the cross G19833 × DOR364. The Andean variety G19833 is tolerant to low P and has resistance to anthracnose, ALS and Ascochyta blight. DOR364 is a high yielding variety from Central America (Broughton et al., 2003).

MAS has been implemented in East Africa to improve resistance to BCMV and anthracnose in climbing beans. Five SCAR markers have been evaluated for selection of two resistance genes for BCMV; ROC11 for the *bc-3* gene and SW13 for the dominant *I* gene; and three resistance genes for anthracnose; SAS13 and SBB14 for the *Co-4* gene and SAB3 for the *Co-5* gene (Blair et al., 2005).

Conventional breeding methods were used by CIAT in East Africa to develop a population from multi-parent crosses among 51 genetically diverse lines from Andean and Mesoamerican gene pools. Several new lines were selected with combined resistance to ALS, root rot, low soil N, low soil P and low soil pH. These lines are being evaluated in seven countries in the region, including Tanzania (Kimani et al., 2005).

ALS is the disease that most affects yield in Tanzania. The CIAT variety CAL 143 (red mottled) has proved to be resistant to ALS when grown in Tanzania, although it is susceptible to one of the races of the pathogen present in Uganda (Aggarawal et al., 2004). Some of the lines recently screened in the breeding nursery at Chitedze in Malawi, have out-yielded CAL 143 by up to 18% and perform well in soils with low fertility. CIAT has identified various sources for resistance to ALS (Mexico 54, AND 277, AND 279), which are used in generating crosses within the regional bean breeding programs in Africa, including those by the network partners in Tanzania.

In 2000, CIAT together with the two regional networks in Africa, ECABREN and SABRN, and the collaborating national programs, including Tanzania, developed a bean breeding strategy that focuses on market-led approaches. The types of markets vary from local to regional. Preferences for bean types differ with markets and countries, reflected in the diversity of varieties in the region. The size of markets differs for different bean types. For example, markets for red mottled and reds account for about 50% of the total production in Africa. However, some grain market types (cream mottled, red mottled, dark red kidney, cream, small red and small white), although representing smaller proportions of the total bean market, are popular across several countries and there are great opportunity for their regional marketing. The regional breeding programmes have taken the responsibility to coordinate and technically support breeding activities in these major market classes. Some of the NARS breeding programmes have also been assigned responsibilities for specific market classes, where they have comparative advantage. Within the SABRN, the assignments are as follows:

Program 1. Red Mottled:
Lead countries: Malawi
Support country: Republic of South Africa–can supply some lines
Important constraints: ALS, low P, BSM (MW)
Anthracnose (Southern Highlands of Tanzania)
Collaborating NARS: Mozambique, Angola and Zambia
Program 2a. Dark Red Kidney :
Lead countries: Zimbabwe
Important constraints: ALS, low P, BSM (Malawi)
Collaborating NARS: Zambia, Mozambique
Program 2b. Small Red beans:
Lead country: Southern Highlands of Tanzania
Important constraints: ALS, Anthracnose, low P and CBB
Collaborating NARS: Zambia, Democratic Republic of Congo (DRC)
Program 3. Browns: Yellow, Brown and Tan:
Lead country: Zambia and Southern Highlands of Tanzania
Important constraints:–ALS, CBB, low P;
Collaborating NARS Angola, DRC and Lesotho
Program 4. Cream–Sugar:
Lead countries: South Africa
Important constraints: ALS, CBB, Rust, low P, BSM
Malawi to support in low P and BSM screening
Collaborating NARS: Zambia, Mozambique, Swaziland, Lesotho and Angola
Program 5a. White: Navy (small-white)
Lead country: RSA
Important constraint: Rust, ALS, CBB, BSM (Malawi)
Collaborating NARS: Southern Highlands of Tanzania, DRC
Program 5b. White Large:
Lead country: South Africa (Where and when available)
Important constraint: Rust, ALS, CBB, BSM (Malawi)
Collaborating NARS Zimbabwe, Southern Highlands of Tanzania, Zambia, DRC
Program 6 Purples:
Lead country: Southern Highlands of Tanzania:
Important constraints: Low P, ALS, CBB
Support country: Zambia

Currently, the CIAT/NARS strategy is to develop improved bean varieties for major market classes, using participatory approaches. The major stakeholders are involved at all stages from problem identification and the development desired solutions, through product identification, promotion and dissemination. The resulting improved bean varieties combine various attributes, ranging from resistance to biotic constraints (diseases and pests) and edaphic constraints (drought and low soil fertility) to culinary and organoleptic characteristics (reduced cooking time, improved nutritive value and market preferences, taste, shelf life after cooking). The strategy recognizes the challenges of incorporating multiple traits in a single cultivar, but it is hoped that as molecular biology tools become more readily available, some biotic and edaphic traits will easily be combined in a single variety, by use of marker assisted selection.

The main priorities for the bean breeding program are:

- Focus on specific market classes (red mottled, cream mottled, dark red kidney, reds (small and large), small whites (small and large), yellows
- Yield improvement
- Identification, characterization of useful sources of resistance to major biotic constraints (angular leaf

spot, common bacterial blight, bean common mosaic virus, rust, anthracnose)
- Identification, characterization of useful abiotic constraints in the pilot site (drought, low P, low N and low pH)
- Identify useful germplasm for productivity in maize-bean intercrop, and for dual purpose legumes (grain and soil fertility improvement)
- Develop germplasm for fast cooking
- Develop germplasm with increased nutritive content (protein, Fe and Zn)
- Develop germplasm for early maturity and better appeal in competitive markets
- Use of organic manures and farmyard manure to improve soil fertility, for improved bean production
- Use more innovative means (e.g. PPB) by involving various partners in variety development and selection processes. Intensification and diversification of cropping systems

CIAT and SABRN are working with NARS partners in Tanzania in developing these new bean varieties, by providing training to develop capacity for generating and handling diverse germplasm. Other partners from the extension services, NGOs and farmer groups are involved in participatory plant breeding (PPB), or participatory variety selection (PVS), including organoleptic tests. Partnerships with the private sector, traders, processors and farmers in product processing or marketing are equally important and these partnerships are proving critical in ensuring seed supply, input and output markets and dissemination of germplasm.

The Bean/Cowpea CRSP

In 1975 the Collaborative Research Support Programme (CRSP) was created by the US AID to focus the capabilities of U.S. Land Grant Universities to carry out the international food and agriculture research mandate of the U.S. Government. The CRSPs are expected to interact with and complement the activities of the National and International Agricultural Research Institutes. The Bean/Cowpea CRSP began in the late 1970s with a research agenda that was to meet the needs of smallholders in countries of East and West Africa, the Caribbean and Latin America. The first grant ran from 1980 to 1986 and the second from 1986 to 2002. The current phase of the Bean CRSP based at SUA in collaboration with Oregon State University and Washington State University, is scheduled to cover the period from 2002 to 2007. The programme also operates from Malawi for southern Africa from a base at Bunda College of Agriculture, near Lilongwe.

CRSP-supported work in East Africa led to the discovery of BCMNV as a separate virus from BCMV (Beaver et al., 2003). Two improved bean varieties were released in Tanzania from the earlier grant periods of CRSP. SUA 90 has a khaki seed colour and was released in 1990. 'Rojo' is a red kidney type released in 1997. Rojo contains the *I* gene for BCMV resistance in combination with recessive genes creating a more durable form of resistance without showing 'black root rot'. Both of the varieties developed in collaboration with the CRSP programme at SUA, are adapted to low and mid-altitude (300–1500 m) bean agro-ecologies, are high yielding under smallholder conditions (up to 2000 kg/ha) and are resistant to rust, ALS, BCMV and BCMNV. Both varieties show some tolerance to drought, and beanfly [observations in farmers' fields in northern Tanzania], are early-maturing (65–74 days) and cook more quickly than most local varieties (CRSP, 2005).

Since the release of cv. Rojo, the CRSP at SUA has undertaken further crosses with the following objectives:

- Backcrossing to transfer arcelin genes to SUA lines to incorporate resistance to bruchid.
- Crosses and backcrossing to improve the popular 'Kablanketi' bean types.
- Crosses to incorporate root-knot nematode resistance for beans grown on sandy soils.
- Crosses to decrease the cooking time of some of the best SUA lines.
- Crosses to incorporate disease resistance: ALS, CBB, BCMV and BCMNV

The new Bean/Cowpea CRSP Programme running from 2002/03–2005/06 is entitled; Regional Bean/Cowpea Consumption and Production in Africa and Latin America. The programme places a stronger emphasis than previously on improving quality and developing markets for beans and value-added products. In the Programme for Eastern and Southern Africa, three projects are concerned specifically with breeding for bean improvement:

1. Edaphic constraints to bean production in Eastern Africa: The selection of bean cultivars and *Rhizobium* having tolerance to low N and P and ability to grow at acid pH.

2. Developing bean cultivars for eastern and southern Africa with enhanced resistance to diseases and insects.
3. Using marker-assisted selection to improve selection efficiency in East and Southern Africa and US programmes.

Project No 2 above has the following objectives:

- Evaluate promising bean lines with resistance to ALS and BCMV in on-farm field trials and multiply seed: 15 most promising lines selected from three populations developed by the National Bean Breeding Programme at Uyole.
- Evaluate germplasm and preliminary and advanced lines for resistance to diseases and abiotic stress: Advanced lines were obtained from crosses between the local variety 'Kablanketi' and SUA 90 or 'Rojo', that were backcrossed to Kablanketi. These were evaluated at SUA and Selian Centre. Ten drought resistant lines were identified at SUA and have been evaluated in on-farm trials.
- Incorporate and evaluate arcelin alleles to protect against bruchids and to release arcelin-protected materials: SUA to evaluate Rojo with *Arc2* and *Arc 4* alleles for resistance to bruchid.
- Obtain germplasm and make crosses to elite materials to incorporate disease resistances: Crosses made between wide range of disease resistant germplasm and the improved varieties SUA 90, Rojo, Kablanketi breeding lines and selected yellow varieties. Marker-assisted selection will be used.

DFID, UK-crop protection programme

During the period 1997–2003 the Crop Protection Programme of the UK's Department for International Development (DFID) supported two collaborative projects involving the Natural Resources Institute (NRI) and Horticulture Research International (HRI) in the UK and UAC, to develop and promote, improved bean varieties. Disease resistant lines from two crosses were screened at HRI and at UAC.

The original crosses were; 'Kabanima' selection (5060/6) × Canadian Wonder and 'Small Masasu' (5082/2) × Canadian Wonder. 5060/6 is a bean mixture component selected from one of several bean mixtures collected from the Southern Highlands by NRI and UAC scientists in 1991. It was identified as having very rare resistance to angular leaf spot. Canadian Wonder was selected as a parent because of its good size and deep red colour. It is however, susceptible to several diseases. The progeny of this cross (F6) were selected to combine the phenotypic characteristics of Canadian Wonder, which is a type that is popular with farmers and consumers in Tanzania, with the disease resistance characteristics of 5060/6. Small Masasu (5084/2) was a selection from a mixture component collected from Mrs Fides Benson of Tukuyu village in 1991. It was found to have almost unique resistance not only to all known races of halo-blight (race non-specific resistance), but also showed resistance to the four races of anthracnose against which it was tested (D. Teverson and C. S. Madata, unpublished).

Thirty-two lines from these crosses were screened down to 8 which were evaluated in participatory selection plots on-farm in 2002. The most promising line was 7068/2, derived from the Kabanima cross and was released in 2003 as the variety 'Urafiki'.

The DFID, UK-crop Protection Programme has also supported an on-going regional project through CIAT in eastern (Kenya and Tanzania) and southern (Malawi) Africa, on the promotion of integrated pest management for major insect pests on beans for the past four years. Host-plant resistance is a key component of the IPM strategy. The project adopted a participatory farmer group approach in which target communities and active partners (district extension personnel, NGOs, policy makers, private sector) have been involved. Both indigenous and improved pest management technologies were selected by farmers and partners, tested and promoted by participating farmer groups in northern and the southern highlands of Tanzania. Service providers (researchers, extension personnel, local community leaders, NGOs and the private sector) have supported the efforts of the farmer groups.

Among the improved technologies being promoted are the use of improved bean varieties including 'Urafiki' in the southern highlands, high yielding beanfly-tolerant beans (such as SUA 90, G22501, G1106 -climber, Sinon and Wanja), other bean varieties demanded by farmers in the north and southern zones, in combination with the application of Minjingu rock phosphate fertilizer and animal manure in the northern zone, row planting, multiple crop intercropping, pest scouting, timely weeding and pest control, timely harvesting and clean storage. Farmers have selected indigenous pest control and soil fertility management strategies including the use of selected botanical crude leaf and tuber extracts (*Vernonia* spp., *Tephrosia* sp., *Neuratanenia* sp.), animal products such as cow urine and cow shed slurry, mixed crop and livestock farming and use of wood ash in the field and in grain storage.

Integration of these strategies in different combinations has helped farmers increase bean yields for food security and household income. Farmer training sessions, demonstrations, field days and farmer exchange visits enabled farmers and partners to learn from each other. Farmers have adopted different component strategies depending on the suitability to their local area conditions.

The present Tanzanian national programme

The National Bean Programme has been fragmented somewhat by the decentralisation of agricultural research, whereby agricultural research institutes in each of the seven agroecological zones have considerable autonomy. National co-ordination is often difficult, partly due to shortage of funding and the long distances between the research centres. This has become less significant as Zonal Agricultural Centres install effective e mail communications. Co-ordination of bean research in the region and within Tanzania is facilitated to some extent by the regional networks, CIAT centres at SARI in Tanzania and at Chitedze in Malawi, and also by the Bean-CRSP programme at SUA. Within the National Agricultural Research System, the National Bean Research Programme is co-ordinated from SARI with SUA and UAC as sub-centres and these three centres are responsible respectively, for developing varieties adapted to medium, low and high altitude ecologies. Beans are grown in most of the Zones but mainly in the Northern, Western and Southern Highlands Zones, although each zone contains areas that are at high, medium and low elevation.

Bean improvement programme for the mid altitude areas

In the mid-altitude bean growing areas of Tanzania, mainly in Arusha and Kilimanjaro Regions, in addition to navy bean production for export and canning, bush types are grown by smallholders for their own consumption and for market. Since the mid 1980s the objective has been to produce improved bean varieties for smallholder farming systems that meet consumer demand. Six varieties have been released since 1985 (Table 4) beginning with Lyamungu 85, followed by Lyamungu 90. Lyamungu 90 had a yield potential more than double that of the popular local variety at the time, Masai red (Limbu, 1999). Selian 94 and Selian 97 were released in the mid 1990s when the programme shifted from Lyamungu and the most recent release for the mid-altitude areas is 'Jesca'. All of these varieties except Selian 94, were derived from CIAT accessions.

Table 4. Bean varieties released in Tanzania since 1980

Year	New name	Original ID code	Type of* germplasm
2004	Uyole 04	7068/2	7
2004	BILFA-Uyole	CIAT	3
2003	Uyole 03	DRK124	2
2003	Urafiki	Kabanima × Can Won	5
2003	Wanja	A197	2
1999	Uyole 98	Bred at Uyole	6
1998	Selian 97	TMO110 × PVA782	3
1997	Rojo	EP2-2	4
1996	Uyole 96	CIAT	6
1996	Jesca	G13369	1
1996	G13374	G13374	1
1994	Uyole 94	DRK 6	2
1990	Lyamungu 90	G5621	1
1990	SUA 90	G5476	1
1990	Uyole 90	CIAT	6
1990	Ilomba	Local line	6
1985	Lyamungu 85	G5621	1
1984	Uyole 84	CIAT	6
1980	Kabanima	Ugandan accession	5

(Source: modified from information on the CIAT website)
**Type of germplasm:*
1 = CIAT accession.
2 = CIAT line.
3 = CIAT cross selected locally [BILFA = Bean lines for low fertility in Africa].
4 = NARS cross with CIAT parent.
5 = Var or advanced line from NARS distributed through CIAT network.
6 = Selection of local variety or land race.
7 = Can Wonder × local landrace.
CIAT accession codes:
A = Advanced line for America.
DRK = Dark red kidney.
PVA = Pre-VF, Andean beans.

Bean improvement programme for the high altitude areas

UAC is located at Mbeya in the Southern Highlands and is the centre for the National Bean Programme for high altitude areas. UAC is also the Zonal Agricultural Centre for the Southern Highlands Zone with very diverse agro-ecologies from below 1000 m to above 2500 m in elevation. The bean programme at UAC therefore has to evaluate beans for all three agroecologies and this is reflected in the range of varieties released from Uyole since 1980: Uyole 84, Uyole 94, Uyole 96,

Table 5. Characteristics of improved bean varieties in Tanzania

	Seed								
Varieties	size	Colour	Habit	Maturity	Cooking	Palatability	Leaves [eating]	Yield [max]	Year released
Kabanima	Med/Large	Calima	Bush	3.50	Slow	Fair	Fair	2.5	1979
Uyole 84	Small	Cream	Climber	3.75	Slow	Fair	Excellent	4.0	1984
Uyole94	Large	Red striped	Semi-climber	3.25	Fast	V. good	Excellent	2.5	1994
Uyole 96	Large	DRK	Semi-climber	3.25	Fast	Good	Excellent	2.5	1996
Uyole 98	Medium	Orange	Semi-climber	3.25	V. fast	Excellent	Fair	3.0	1998
Wanja	Large	Khaki	Bush	2.75	Fast	V. good	Good	2.0	2002
Urafiki	Medium	DRK	Bush	3.25	Fast	V. good	Good	3.0	2003
Uyole 03	Large	Sugar	Bush	3.25	Fast	V. good	Good	3.0	2003
Uyole 04	Medium	Cream	Semi bush	3.25	V. fast	Excellent	Good	3.0	2004
BILFA-Uyole	Medium	Calima	Semi bush	3.25	V. fast	V. good	Good	2.5	2004
Kablanketi	Medium	Purple	Semi-climber	3.00	Fast	V. good	Poor	1.5	Local
Masasu	Large	Brown	Semi-climber	3.5	Fast	Good	Good	2.0	Local

Table 6. Reaction to diseases and pests of improved bean varieties released from Uyole

	Diseases									Pests		
Variety	ANC	ALS	HB	CBB	ASC	RUST	BCMV	BCNMV	Drought tolerance	Beanfly	Pod borers	Bruchid
Uyole 04	1	2	2	2	4	1	6	9	4	S	SS	S
BILFA Uyole	1	3	2	?	1	4	?	1	?	S	S	S
Uyole 03	1	2	3	?	1	8[V]	4	1	4	S	S	S
Urafiki*	4	4	4	4	2	5	6	?	2	S	S	S
Wanja**	7	7	3	?	1	4	1	1	2[escape]	S	S	S
Uyole 98	1	3	3	?	2	1	7	?	5	S	SS	S
Uyole 96	7	7	7	?	2	7	6	1	5	S	S	S
Uyole 94	5	5	9	?	1	4	8	1	4	S	S	SS
Uyole 84	1	5	2	?	7	5	8	1	2	T	S	T
Kabanima	1	4	4	?	2	1	5	?	6	SS	S	S

Disease scale: 1–9 where 1–3 is considered resistant and 7–9 as susceptible.
? = unknown at present, V = variable response.
Pests: S = Susceptible, SS = highly susceptible, T = has some tolerance.
*Urafiki may show a high incidence of diseases in wet weather, but recovers quickly in drier conditions so that yield may not be much affected.
**Wanja is very early maturing and can escape the effects of drought by being harvested before the end of the rains.

Table 7. Main advantages of some recent improved bean varieties in Tanzania

Variety	Main advantages
Uyole 04:	High yields tolerant to diseases, very fast to cook extremely palatable attractive seeds attractive colour, liked for consumption and for market
BilfaUyole:	High yields, Fair tolerance to disease, tolerant poor soil, fast to cook, palatable, attractive seeds, liked for consumption and market
Uyole 03	High yields, tolerant to diseases, fast to cook, very palatable attractive colour, liked for consumption and market.
Urafiki:	High yields, tolerant to drought, fair tolerance to diseases, fast to cook, palatable, liked for consumption, good colour
Wanja:	Fair yields very early maturity, good performance under poor conditions, fast to cook, palatable, liked for food and market
Uyole 98:	High yields, tolerant to diseases, very fast to cook, very palatable liked for food and market.
Uyole 96:	High yields, tolerant to diseases, fast to cook, very palatable attractive colour, liked for consumption and market.
Uyole 94:	High yields, tolerant to diseases, fast to cook, very palatable attractive colour, liked for consumption and market.

Table 8. Some bean lines that have been tested and introduced on-farm in the SH but not released as official varieties

Line	Seed type	Main qualities	Reason for non-release
MG-38	Large Calima cream mottled	Yields, market	Planned for release
Sugar 131	Large, Sugar	Yields, market, food	To be added in mixtures
Sinon	Med, Cream	Tolerate BSM, food	“
Uyole sugar	Large Sugar	Yields, market	“
EAT 2525	(Kablanketi)/Sinon	Yields, Market, food	“
Tm-27 J1/J2	Med Red	Yields market, food	Planned for release
Kablanketi-2	Purple	Food, Market	Planned for release
Uyole 84 × Kablanketi	Purple	Market, food	Planned for research
Uyole 84 × Kablanketi)/Sinon	Cream	Market, food	To be added in mixtures

Uyole 98, Urafiki, Uyole 03, BILFA-Uyole and Uyole 04 (Table 4). The main objectives of the high altitude breeding programme are to produce beans adapted to agro-ecologies at altitudes above 1500 m that have acceptable cooking and eating qualities and for which there will be market demand. New varieties require resistance to the main diseases, angular leaf spot and anthracnose. Some local communities prefer particular seed types but most grow beans as mixtures with a range of seed colours. The programme aims to develop improved varieties of each of the main seed types.

Bean improvement programme for the low altitude areas

SUA has the mandate for bean breeding for low altitude areas and this part of the National Programme is supported largely by the CRSP. Low altitudes environments are usually hotter and drier than those at higher altitudes and therefore less suitable for bean cultivation. It is challenging to develop bean varieties that outperform locally adapted ones in harsh environments. Only two improved varieties have been released in the last 15 years and have been widely adopted. SUA 90 was derived from a CIAT accession and ‘Rojo’ which is a cross between CIAT germplasm and an accession from the Prosser Irrigated Research Station in the USA.

Seed distribution systems

It is not possible in this paper to say much about seed supply, but David et al. (2002) have pointed out that poor seed availability has often been ignored in studies of variety adoption and that seed dissemination strategies aimed at smallholders should re-supply seed over several seasons until new varieties become established in the informal sector. The formal seed sector has been unable to meet the needs of smallholders for high quality seed of self-pollinated legumes and this is an issue which needs to be addressed if more farming households are to benefit from legume breeding programmes.

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References

Abawi, G.S. & M.A. Pastor-Corrales, 1990. Root rots of bean in Latin America and Africa: Diagnosis, research, methodologies and management strategies. CIAT, Cali, Colombia, 114 pp.

Aggrawal, V.D., M.A. Pastor-Corrales, R.M. Chirwa & R.A. Buruchara, 2004. Andean beans with resistance to the angular leaf spot pathogen (*Phaeoisariopsis griseola*) in southern and eastern Africa. Euphytica 136: 201–210.

Allen, D.J., 1983. The pathology of Tropical food Legumes: Disease Resistance in Crop Improvement. John Wiley & Sons, Chichester, UK, 413 p.

Allen, D.J., 1995. An annotated list of diseases, pathogens and associated fungi of the common bean (*Phaseolus vulgaris*) in eastern and southern Africa. Phytopathological Papers No 34, CAB International, Wallingford, UK, 23 pp.

Allen, D.J., R.A. Buruchara & J.,B. Smithson, 1998. Diseases of common bean. In: D.J. Allen & J.M. Lenne (Eds.), The Pathology of Food and Pasture Legumes. CAB International, Wallingford, UK, pp. 179–265.

Allen, D.J., M. Dessert, P. Trutman & J. Voss, 1989. Common beans in Africa and their constraints. In: H.F. Schwartz & M.A. Pastor-Corrales (Eds.) Bean Production Problems in the Tropics. CIAT, Cali, Colombia, pp. 9–31.

Allen, D.J. & J.M. Lenne, (Eds.), 1998. The Pathology of Food and Pasture Legumes. CAB International, Wallingford, UK, 750 pp.
Allen, D.J., J.K.O. Ampofo & C.S. Wortmann, 1998. Pests Diseases and Nutritional Disorders of the Common Bean in Africa. CIAT, Colombia, 131 pp.
Alexander, H.M., J.V. Groth & A.P. Roelfs, 1985. Virulence changes in *Uromyces appendiculatus* after five sexual generations on a partially resistant cultivar of *Phaseolus vulgaris*. Phytopathology 75: 449–453.
Aragao, F.J.L., L.M.G. Barros, A.C.M. Brasileiro, S.G. Ribeira, F.D. Smith, J.C. Sanford, J.C. Faria & E.L. Rech, 1996. Inheritance of resistance of foreign genes in transgenic bean co transformed via particle bombardment. Theor Appl Genet 93: 142–150.
Aragao, F.J.L., G.R. Vianna, M.M.C. Albino & E.L. Rech, 2002. Transgenic dry bean tolerant to the herbicide glufosinate ammonium. Crop Sci 42: 1298–1302.
Balardin, R.S. & J.D. Kelly, 1998. Interaction between *Colletotrichum lindemuthianum* races and gene pool diversity in *Phaseolus vulgaris*. J of the Am Hortic Soc 123: 1038–1047.
Beaver, J.S., J.C. Rosas, J. Myers, J. Acosta, J.D. Kelly, S. Nchimbi-Msolla, R. Misangu, J. Bokosi, S. Temple, E. Arnaud-Santana & D.P. Coyne, 2003. Contributions of the bean/cowpea CRSP to cultivar and germplasm development in common bean. Field Crops Res 82: 87–102.
Beebe, S.E. & M.P. Pastor-Corrales, 1991. Breeding for disease resistance. In: A. Schoonhoven, O. van and Voyest (Eds.) Common Beans–Research for Crop Improvement. CIAT, Cali, Colombia, pp. 561–617.
Bisanda, S., 2000. *In situ* conservation and the role of the farmer and natural selection in changing the components of bean landrace mixtures. PhD Thesis, University of Greenwich, Chatham, UK. 300 pp.
Blair, M.W., P.M. Kimani, H.F. Buenida, L.N. Garzon, R. Chirwa & J. Tohme, 2005. (Abstr.). Novel climbing bean genotypes developed through conventional breeding and marker-assisted selection. Paper presented at the 2nd General Meeting on Biotechnology, Breeding and Seed Systems, Nairobi, Kenya, 24–27 January 2005.
Boyer, J.S., 1982. Plant productivity and environment. Science 218: 443–448.
Broughton, W.J., G. Hernandez, M. Blair, S. Beebe, P. Gepts & J. Vanderleyden, 2003. Beans (*Phaseolus* spp.)–model food legumes. Plant and Soil 252: 55–128.
Chacon, S.M., B. Pickersgill & D.G. Debouck, 2005. Domestication patterns in common bean (*Phaseolus vulgaris* L.) and the origin of the Mesoamerican and Andean cultivated races. Theor Appl Genet 110: 432–444.
Chirwa, R., P. Kimani, R. Buruchara & M. Pyndji, 2003. Bean Breeding in Africa–Where are we? A paper presented at the Bean Biofortification Workshop, held at Great Rift Valley Lodge, Naivasha, Kenya.
CIAT, 2005a. CIAT in Africa. Available from: http://www.ciat.cgiar.org/africa.
CIAT, 2005b. Annual Report 2004. Available from: http://www.ciat.cgiar.org/beans/pdfs.
CRSP, 2005. Bean/Cowpea Collaborative Research Support Programme. Available from: http://www.isp.msu.edu/CRSP/home.htm.
David, S., L. Mukandala & J. Mafuru, 2002. Seed availability, an ignored factor in crop varietal studies: A case study of beans in Tanzania. J of Sust Agric 21: 5–20.
De Clerq, J., M. Zambre, M. Van Montagu, W. Dillen & G. Angenon, 2002. An optimised Agrobacterium-mediated transformation procesdure for *Phaseolus acutifolius*. Pl Cell Reps 21: 333–340.
FAO, 2005. FAOSTAT available from http://faostat.fao.org/faostat/collections?subset=agriculture.
Gatehouse, A.M.R., P. Dobie, R.J. Hodge, J. Meik, A. Pustzai & D. Boulter, 1987. Role of carbohydrates in insect resistance in *Phaseolous vulgaris*. *J of Insect Physiol* 33: 943–950.
Graham, P.H. & P. Ranalli, 1997. Common bean (*Phaseolus vulgaris* L.). Field Crops Res 53: 131–146.
Guimaraes, C.M., L.F. Stone & O. Brunini, 1996. Adaptation of dry bean (*Phaseoluis vulgaris*) to drought: II Yield and agronomic components. *Pesquisa Agropecuaria Brasileira* 31: 481–488.
Ijani, A.S.M., R.B. Mabagala & S. Nchimba-Msolla, 2000. Root-knot nematode species associated with beans and weeds in the Morogoro region, Tanzania. *Af Pl Protect* 6: 37–41.
IPCC, 2001. Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC). J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden & D. Xiaosu (Eds.), Cambridge University Press, Cambridge, UK.
Johnson, E., P.N. Miklas, J.R. Stavely & J.C. Martinezcruzado, 1995. Coupling phase and repulsion phase RAPDs for marker assisted selection Theor Appl Genet 100: 659–664.
Jung, G., D.P. Coyne, P.W. Skroch, J. Neinhuis, E. Arnaid-Santana, J. Bokosi, H.M. Ariyarathne, J. Steadman & J.S. Beaver, 1995. Construction of a genetic linkage map and locations of common blight, rust and web blight resistance loci in *Phaseolus vulgaris* using random amplified polymorphic DNA (RAPD) markers. Hortic Sci 30: 820.
Karel, A.K., B.J. Ndunguru, M. Price, S.H. Semuguruka & B.B. Singh, 1981. Bean production in Tanzania. In: *Potential for Field Beans in Eastern Africa, Proceedings of a Regional Workshop*, Lilongwe, Malawi, March 1980. CIAT, Cali Colombia, pp. 124–154.
Kelly, J.D., 2004. Advances in common bean improvement: Some case histories with broader applications. Acta Hortic 637: 99–121.
Kelly, J.D., P. Gepts, P.N. Miklas & D.P. Coyne, 2003. Tagging and mapping of genes and QTL and molecular marker-assisted selection for traits of economic importance in bean and cowpea. Field Crops Res 82: 135–154.
Kelly, J.D. & P. Miklas, 1998. The role of RAPD markers in breeding for disease resistance in common bean. Molec Breed 4: 1–11.
Kimani, P.M., R. Burachara, J. Muthamia, N. Mbikayi, A. Namayanja, R. Otsyula & M. Blair, 2005. [Abstr.]. Selection of marketable bean lines with improved resistance to angular leaf spot, root rot and yield potential for smallholder farmers in eastern and central Africa. Paper presented at the 2nd General Meeting on Biotechnology, Breeding and Seed Systems, Nairobi, Kenya, 24–27 January 2005.
Kornegay, J. & C. Cardona, 1991. Breeding for insect resistance in beans. Breeding for disease resistance. In: A. Schoonhoven & O. van and Voyest (Eds.), Common Beans – Research for Crop Improvement. CIAT, Cali, Colombia, pp. 619–648.
Limbu, F., 1999. Agricultural technology, economic viability and poverty alleviation in Tanzania. *Proceedings of the Structural Transformation Policy Workshop*, Nairobi, Kenya, 27–30 June 1999. Michigan State University Press, 160 p.
Mabagala, R.B. & A.W. Saettler, 1992. Races and survival of *Pseudomonas syringae* pv. *phaseicola* in northern Tanzania. Pl Disease 76: 678–682.

McCartney, J.C., 1966. The selection of haricot bean varieties suitable for canning. E African Agric Forest J 32: 214–118.

Mmbaga, M.T. & J.R. Steadman, 1992. Nonspecific resistance to rust in pubescent and glabrous common bean genotypes. Phytopath 82: 1283–1287.

Mukoko, O.Z., M.W. Galwey & D.J. Allen, 1994. Developing cultivars of the common bean (*Phaseoluis vulgaris)* for southern Africa: Bean common mosaic virus resistance, consumer preferences and agronomic requirements. Field Crops Res 40: 165–177.

Mutitu, E.W., D.M. Mukunya & S.O. Keya, 1989. Effect of organic amendments on Fusarium yellow disease on the bean host. Discovery Innovation 1: 67–70.

Myers, J.R., J. Davis & D. Kean, 2001. Backcross breeding to introduce arcelin alleles into improved African bean cultivars. *Proceedings of the Bean Seed Workshop, Arusha*, Tanzania, 12–14 January, 2001. Bean/Cowpea Collaborative Research Support Program–East Africa, 8 p.

Nchimbi-Msolla, S. & R.N. Misangu, 2001. Seasonal distribution of common bean bruchid species in selected areas in Tanzania. *Proceedings of the Bean Seed Workshop*, Arusha, Tanzania, 12–14 January, 2001. Bean/Cowpea Collaborative Research Support Program–East Africa, 5 pp.

Opio, A.F., D.J. Allen & J.M. Teri, 1992. Assessment of yield losses caused by common bacterial blight of beans. Ann Rept Bean Improv Coop 35: 113–114.

Opio, A.F., D.J. Allen & J.M. Teri, 1996. Pathogenic variation in *Xanthomonas campestris* pv. *phaseoli*, the causal agent of common bacterial blight. Pl Pathol 45: 1126–1133.

Osborn, T.C., T. Blake, P. Gepts & F.A. Bliss, 1986. Bean arcelin2: Genetic variation, inheritance and linkage relationships of a novel seed protein of *Phaseolus vulgaris* L. Theor Appl Genet 71: 847–855.

Osborn, T.C., D.C. Alexander, S.S.M. Sun, C. Cardona & F.A. Bliss, 1988. Insecticidal activity and lectin homology of arcelin seed protein. Science 240: 207–210.

Otsyula, R.M., S.I. Ajanga, R.A. Burachara & C.S. Wortmann, 1998. Development of an integrated bean root rot control strategy for western Kenya. African Crop Sci J 6: 61–67.

Pachico, D. 1989. Trends in world common bean production. In: H. F.Schwartz & M. A. Pastor-Corrales (Eds.), Bean Production Problems in the Tropics. CIAT, Cali, Colombia, pp. 1–8.

Pastor-Corrales, M.A., O.A. Erazo, E.I. Estrada & S. Singh, 1994. Inheritance of anthracnose resistance in common bean accession G2333. Pl Dis 78: 959–962.

Rao, I. & G. Cramer, 2003. Plant nutrition and crop improvement in adverse soil conditions. In: M. Chrispeels & D. Sadava (Eds.), *Plants, Genes, and Crop Biotechnology*. Published in partnership with the American Society of Plant Biologists and ASPB Education Foundation. Jones and Bartlett Publishers, Sudbury, Massachusetts, USA, p. 270–303.

Sanchez, P.A., 2002. Soil fertility and hunger in Africa. Science 295: 2019–2020.

Schneider, K.A., M.E. Brothers & J.D. Kelly, 1997. Marker-assisted selection to improve drought resistance in common bean. Crop Sci 37: 51–60.

Schoonhoven, A., van, C. Cardona & J. Valor, 1983. Resistance to the bean weevil (Coleoptera: Bruchidae) in non-cultivated common bean accessions. J Econ Entomol 76: 1255–1259.

Schwartz, H.F. & M.A. Pastor-Corrales (Eds.), 1989. Bean Production Problems in the Tropics. CIAT, Colombia, 654 pp.

Schwartz, H.F., M.A. Pastor-Corrales & S.P. Singh, 1982. New sources of resistance to anthracnose and angular leaf spot of beans. Euphytica 31: 741–754.

Shao, F.M. & J.M. Teri, 1985. Yield losses in *Phaseolus* beans induced by anthracnose in Tanzania. Trop Pest Manage 31: 60–62.

Singh, S.P., P. Gepts & D.G. Debouck, 1991. Races of common bean *Phaseolus vulgaris* L., Fabaceae. Econ Bot 45: 379–396.

Singh, S.P., H. Teran & J.A. Gutierrez, 2001: Registration of SEA 5 & SEA 13 drought tolerant dry bean germplasm. Crop Sci 41: 276–277.

Spence, N.J. & D.G.A. Walkey, 1991. Identification of strains of bean common mosaic virus occurring in different regions of Africa. Ann Rept Bean Improv Coop 34: 5–6.

Spence, N.J. & D.G.A. Walkey, 1995. Variation for pathogenicity among isolates of bean common mosaic virus in Africa & reinterpretation of the genetic relationship between cultivars of *Phaseolus vulgaris* & pathoypes of BCMV. Pl Pathol 44: 527–546.

Suresh, K.Y., T.E. Weerawadena & J.M.R.S. Bandara, 2000. Agrobacterium-mediated transformation of common bean (*Phaseolus vulgaris*) var. topcrop. Trop Agric Res 12: 64–74.

Svetleva, D., M. Velcheva & G. Bhowmik, 2003. Biotechnology as auseful tool in common bean (*Phaseolus vulgaris*) improvement. Euphytica 131: 189–200.

Taylor, J.D., D.M. Teverson, D.J. Allen & M.A. Pastor-Corrales, 1996a. Identification & origin of races of *Pseudomonas syringae* pv. *phaseicola* from Africa & other bean growing areas. Pl Pathol 45: 469–478.

Taylor, J.D., D.M. Teverson & J.H.C. Davis, 1996b. Sources of resistance to *Pseudomonas syringae* pv. *phaseicola* races in *Phaseolus vulgaris*. Pl Pathol 45: 479–485.

Thomas, C.V. & J.G. Waines, 1984. Fertile backcross & allotetraploid plants from crosses between tepary bean & common bean. J Hered 75: 93–98.

Vallejo, V. & J.D. Kelly, 2001. Development of a SCAR marker linked to the CO-5 locus in common bean. Ann Rept Bean Improv Coop 44: 212–122.

White, J.W. & S.P. Singh, 1991. Breeding for adaptation to drought. In: Schoonhoven A van & Voyest O. [eds] Common Beans–Research for Crop Improvement. CIAT, Cali, Colombia, pp. 501–560.

Wortmann, C.S., R.A. Kirkby, C.A. Eledu & D. J. Allen, 1998. Atlas of Common Bean in Africa. CIAT, Cali, Colombia.

Young, R.A. & J.D. Kelly, 1996. RAPD markers flanking the ARE gene for anthracnose resistance in common bean. J Am Soc Horti Sci 121: 37–41.