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Targeting Actions to Improve the Quality of Farmer Planting Material in Bananas and Plantains – Building a National Priority-setting Framework

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ABSTRACT

In recent decades the productivity of banana and plantain, traditionally important small farmer crops, has come under increasing threat from the spread of viruses and other phytosanitary problems transmitted in vegetative planting material. In addition, while for many other crops small farmers have improved access to new cultivars with increased yield potential and pest and disease resistance, for banana and plantain such access is as yet incipient. To harness the potential of banana and plantain as a small farmer crop, we propose that systems for cultivar deployment and the propagation of clean planting material need to be developed for the specific conditions of each country or region. A clonal crop "seed" system consists of all individuals, organizations and institutions which are linked to the genetic make-up, the quality and the supply of planting material. To develop guidelines for the identification of priorities for system strengthening, a survey was carried out in Asia, Africa and Latin America. National seed systems were profiled using a questionnaire designed to capture simple information about the quality and quantity of planting material and the extent of the formal mechanisms for deploying cultivars and multiplying planting material. Information from more than 30 countries was analyzed and scientific advances in pest and disease management and genetic improvement reviewed to generate a four-level decision tree (*Musa* diversity, importance of AAB types, presence of diseases such as banana bunchy top virus and the current formal seed system capacity). Based on an exercise to prioritize distinct and specific actions, 12 different groups of countries were identified with similar limiting factors, obstacles and opportunities for strengthening their system for cultivar deployment and planting material propagation.

Keywords: clonal crops, formal seed system, informal seed system, *Musa*

CONTENTS

IMPROVING FARMER SEED QUALITY – CLONAL VERSUS TRUE SEED CROPS

The improvement of seed has been a key component of increasing agricultural productivity. Seed quality for production has several components: 1) physiological - germination rate and initial vigor; 2) genetic - heritable traits and purity, 3) sanitary - presence of pests and diseases (Almekinders and Louwaars 1999). Improved yields can come from more uniform and vigorous crop stands, clean planting material free of pests and diseases and cultivars with greater yield potential or resistance to key pests and diseases.

The importance of improved quality seed for higher and more secure yield has been well demonstrated whether through purchased seed or through better seed selection by farmers. Over 90% of maize farmers in North America use purchased hybrid seed, although more than 70% of wheat farmers use saved seed from improved varieties (Tripp 2003). In Sub-Saharan Africa only 5-25% of farmers, depending on the country, use hybrid maize seed (Tripp 2003). For self-pollinated crops such as *Phaseolus* beans, African farmers use saved seed, but often their cultivars have originated genetically from public sector breeding programs. For clonal and tree crops in the tropics, farmers depend almost exclusively on their own fields or of their neighbors. In countries of Europe and North America commercial growers of potatoes, sweet potatoes and fruit crops use primarily planting material of improved cultivars from commercial sources. However, in East Africa farmers can learn to rogue potato and sweet potato with virus symptoms, thereby reducing virus levels in the next crop (Gildemacher *et al.* 2007). The development of virus-resistant cassava cultivars has offset losses from the *Cassava mosaic virus* (Legg and Thresh 2000). The use of molecular markers to accelerate conventional breeding and genetic modification is expected to accelerate the improvement in seed quality of many types of crops (Ortiz and Smale 2007).

To harness the potential in seed quality for improving agricultural productivity through the efficient investment in key infrastructure and human resources by the public and

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Table 1 Clonal crops characteristics of planting material and cultivar improvement.

Crop	Planting material	Planting density (plants/ha)	Planting material (kg/ha)	Yield (t/ha)	Seed-borne pests/diseases	Breeding improved cultivars
Potato	Edible tuber, true potato seed	25000-50000	1500-3000	10-40	*PLRV*, *PVY*, *Ralstonia solanacearum*, *Pthorimaea operculella*	Hand pollination; Viable seed
Sweet potato	Vegetative shoot	15000-40000	100-200	8-30	*SPCSV*, *SPFMV*, *SPMMV*, *SPCFV*, *SPLCV*, *Cylas* spp., *Alternaria* spp.	Trellis for flowering; Hand pollination; Viable seed
Cassava	Woody stem section with 5-7 nodes	8000-16000	500-1000	10-30	*Colletotrichum gloeosporioides*, *Xanthomonas manihotis*, *EACMV*, *ACMV*, *EuCMV*, *CBSV*, Frog-Skin disease	Hand pollination; viable seed
Yam	Edible tuber piece, aerial tube	8000-12000	2000-3000	10-30	*DAV*, *CMV*, *DbBV*, *DaBV*, *YMV*, *Colletotrichum gloeosporioides*, *Erwinia amylovora*	Non-synchronous flowering; Ploidy incompatibility; Pollen storage; Viable seed
Cocoyam	Edible central corm, cormel	8000-12000	1000-2000	5-25	*DsMV*, *RRD*, nematodes, *Pseudomonas solanacearum*, *Erwinia carotovora pv. atroseptica*	Artificial flower stimulation; Hand pollination; Viable seed; Ploidy incompatibility
Taro	Corm, sucker, cormel, edible head set	10000-30000	400-2000	8-25	*DsMV*, *CBDV*, *TaBV*, *Papuana* spp.	Artificial flower stimulation; Hand pollination; Viable seed
Banana and plantain	Non-edible corm	1000-2000	500-1600	10-70	*Cosmopolitus sordidus*, nematodes, *Fusarium oxysporum* pv. *cubense*, *Xanthomonas campestris* pv. *campestris*, *BBTV*, *BSV*, *BBrMV*, *CMV*	Flowering limited; Hand pollination, but limited crossing; Embryo rescue

ACMV, African cassava mosaic virus; *BBrMV*, banana bract mosaic virus; *BBTV*, banana bunchy top virus; *BSV*, banana streak virus; *CBDV*, Colocasia bobone disease virus; *CBSV*, cassava brown streak virus; *CMV*, cucumber mosaic virus; *DaBV*, Dioscorea alata badnavirus; *DAV*, Dioscorea alata virus; *DbBV*, Dioscorea bulbifera badnavirus; *DsMV*, dasheen mosaic virus; *EACMV*, East African cassava mosaic virus; *EuCMV*, Euphorbia crinkle mosaic virus; *PLRV*, potato leaf roll virus; *PVY*, potato virus Y; *RRD*, root rot disease complex; *SPCFV*, sweet potato chlorotic fleck virus; *SPCSV*, sweet potato chlorotic stunt virus; *SPFMV*, sweet potato feathery mottle virus; *SPLCV*, sweet potato leaf curl virus; *SPMMV*, sweet potato mild mottle virus; *TaBV*, taro bacilliform virus; *YMV*, yam mosaic virus

private sectors, we need to understand under what conditions improvements in seed quality can improve agricultural productivity. The challenge for breeders, agronomists and rural development planners is not to convert all farmers to commercial seed use, especially under conditions where very few farmers use commercial seed, but to target actions and zones where improved seed quality can have the highest impact. In some zones this may mean improving the quality of farmer-saved seed, while in other zones a shift to commercial seed as an annual input may be necessary or at least profitable and possible.

The breeding system has been identified as an important variable in the success of new cultivar dissemination. Crops planted with true seed can be separated into cross-pollinated, mostly self-pollinated with some cross pollination and primarily self-pollinated (Parlevliet 2007). Improved seed has been very important for cross pollinated crops which are attractive for private industry and with vegetables which have a high value for a low quantity of seed which cannot be easily produced by growers themselves. On the other hand, improved cultivars for self pollinated crops have been less commercially viable for private seed producers, since growers save their own seed. In addition, yield per seed planted may be low and the yield differences between improved and farmer cultivars may not be large enough to justify the annual cost of purchased seed. For crops such as beans and rice, public sector breeders have produced improved cultivars. However, an important segment of growers acquire the new variety and then save seed from year to year, reducing the financial returns to seed companies.

In general, commercial companies are not interested in crops demanding a high volume of planting material, crops grown on marginal lands, minor crops and crops grown primarily in remote areas (Minot and Smale 2007). Emerging market opportunities for tree products may offer opportunities to small scale businesses to provide high quality seed, although they may not invest in conservation and breeding (Graudal and Lillesø 2006). On the other hand, farmers may not be interested in improved cultivars which do not have the same taste, cooking quality or yield stability under marginal conditions of their traditional cultivars (Almekinders *et al.* 1994). Traders play an important role when local cultivars meet specific agroecological conditions (Sperling and McGuire 2009).

Clonal crops have some of the characteristics which can slow the commercialization of planting material. They generally have low multiplication rates. The return per unit of seed planted is low (**Table 1**) and large volumes of seed are needed to plant a field. Additional processing may be needed to prepare planting material (sweet potato). In some cases, the edible material is also planting material (potato, yams, cocoyams and taro). However, in other cases, other plant parts are used for planting (banana and plantain, cassava). For these crops farmers cannot use village or town markets as a source of planning material. Riesco (2003) calculated that in terms of transportation and management, cassava planting material was 27 times more expensive than seed for maize or beans.

On the other hand, clonal crops have opportunities for increased productivity through the improvement of the quality of planting material (physiological, genetic, sanitary), in spite of other characteristics favoring a local system of plant material. Pests and diseases are frequently transmitted from one field to another through infected planting material (Markham *et al.* 2007) (**Table 1**). These problems may be accentuated by land use intensification and new pests and diseases may be introduced through the informal introduction of planting material across national borders. Local cultivars maintained by farmers may also be quite variable genetically. The actions to improve the quality of planting material may be feasible within the local seed system or may require new seed system capacity.

In this paper we review the case of banana and plantain where generally the vast majority of farmers use local planting material, to address the challenge of how to target actions and zones for the most favorable return and for the most useful multiplier effect in strengthening a national system for improving the quality of farmer planting material of clonal crops. We take the country perspective as starting point. An early overview study of seed systems financed by the World Bank (Venkatesan 1994) concluded that since different countries face different situations in terms of pests and diseases, preferred cultivars, marketing channels and existing public and private infrastructure, each country must develop its own strategy targeted to specific regions. More recently Louwaars (2007) proposed that seed systems must be diversified, bridging the formal and farmer seed systems in different ways depending on the crop and the country, for maximum benefit to farmers in terms of quality, access and availability. We address the question – what are the most important factors at the country level to take into account for improving the quality of farmer planting material?

The paper is divided into four sections. First, based on a review of the literature on seed systems, we propose a framework to analyze the formal/informal components of the national seed system as it could be applied to banana and plantain. We then review and prioritize the relevant biological and institutional factors which differentiate national systems for the deployment and multiplication of *Musa* cultivars. Thirdly, we test the applicability of the proposed framework by categorizing a sample of national systems in Africa, Asia and Latin America based on the proposed key factors. Finally, based on key groups of countries with differentiating characteristics, we discuss key steps to strengthening farmer access to increasingly better planting materials.

ROLES AND FUNCTIONS IN A NATIONAL SYSTEM FOR IMPROVED QUALITY *MUSA* PLANTING MATERIAL

The improvement of the quality of planting material used by farmers growing banana and plantain involves not only stocks and flows of genetic material, but also information and those actors who possess and transmit it (McGuire 2001). A systems perspective to innovations such as the quality of planting material is useful to identify the actors (individuals, organizations and institutions), their proposed function and the actual results they achieve through information generation and transformation and linkage with other pertinent actors (Engel 1997). Such a perspective takes into account all the diverse actors linked to the quality of planting material used by farmers.

In the case of *Musa*, farmers largely provide their own planting material. Such a system has been referred to as a local, farmer, informal or traditional seed system. In this system, production of planting material is largely a function of crop production with farmers selecting planting material from existing plantations (**Fig. 1A**). In selecting planting material for new plantings, farmers make decisions about the cultivar, the age and size of the sucker and other related characteristics, including pests and diseases present. Agronomic practices used in the plantation may affect the quality of planting material available. Farmers may also use specific practices to treat the planting material before planting a new field. Clearly in the informal system farm households are responsible for the quality, availability and access to planting material. Not all households have the same suite of cultivars or number of mats. Nor do they have the same knowledge or observation capacity about the management of planting material. Such differences lead to the exchange of planting material among households within the community or in more distant communities. Certain households and communities may serve as local experts or specialize in the production of planting material. The exchange among households and communities serves to maintain a greater diversity of cultivars and a community reserve to allow timely planting and better quality materials and to buffer any losses of planting material at the household level such as floods or diseases.

In the short term, the local system generally ensures the availability of reasonably healthy, viable planting material of preferred cultivars without undue effort or cost, and in a timely manner to ensure optimal land and labor use. This is the function of any viable seed system (Weltzien and vom Brocke 2001). However, the local system is not static. New generations establish their own households, land use is intensified, new crops are introduced and markets become more important for certain products. New pests and diseases may be introduced or become more important due to changes in production systems. These kinds of threats and opportunities test the capacity of the farmer seed system. For example, the first banana plants with symptoms of bunchy top disease were protected as an ornamental curiosity in certain villages of Bas Congo (Bakelana-ba-Kufimfutu pers. comm.). The threat this disease represents for food security was beyond the knowledge and experience of the informal seed system and yield losses have been above 80% in many villages.

In contrast to the farmer seed system with a close link between production and the selection of planting material, the formal, conventional or modern seed system developed based on scientific knowledge of genetics, crop productivity and pests and diseases interfaced with the marketing of seed as an off-farm production input. The common conception of the formal seed system is based on the steps in the breeding and release of seeded crops – characterization of genetic resources to identify pre-cultivars or breeding materials; breeding, screening and selection of new cultivars; multiplication of selected cultivars from breeder to commercial seed; and finally storage, distribution and marketing of seed. This process is characterized by named varieties, labeling and quality assurance usually carried out by entities with on-going involvement in the supply of planting material (Turner 1995).

Breeding clonal crops involves more steps than breeding true-seeded crops and improved bananas and plantains are even more difficult to breed than some of the other clonal crops (**Table 1**). Hand pollination is possible, but not all cultivars have viable male flowers, which limits the possibility of certain crosses. Resulting seed production is limited and seeds need to be subjected to embryo rescue to generate new plants. In addition, the presence of Banana streak viruses (BSV) in the AAB group of cultivars has proved an intractable challenge to breeders and tissue culture laboratories as will be explained in the next section.

For banana and plantain, the national formal seed system serves important functions even in the absence of formal breeding (INIBAP 2004). The genetic quality of planting material can be improved through the selection of superior mother plants and tissue culture multiplication, an approach already used in export banana production to achieve more uniform plants which can be planted at higher densities. Innovative macro-propagation techniques generate up to 50 plants from a single corm. The physiological quality can be improved through selection and nursery techniques to ensure vigorous and uniform planting material. Such material permits concentration of the harvest period and more predictable market scheduling. Finally, the sanitary quality of *Musa* planting material is probably the single most important issue for improved production. The formal seed system has diverse functions to reduce the problems associated with a diverse set of pests and diseases which affect *Musa* planting material around the world and another set which is still spreading (**Table 2**).

For the case of bananas and plantains, the four components of the formal system based on true-seeded crops need to be re-interpreted. For clonal crops, the first major component is the conservation, characterization and safe exchange of germplasm. The organizations and individuals performing this function include curators and collectors of local germplasm, an especially important dimension in the diverse centers of origin, banana agronomists who track the development of new germplasm internationally and plant quarantine officers who calculate risk and ensure the safe introduction of new and interesting cultivars. They also track the spread of pests and diseases which may be introduced by planting material, contaminated soil or planting material of other related species. Links to international and regional sources of germplasm and information about pest and disease risks is an important dimension of the national system (**Fig. 1B**).

The second component is the screening and selection of useful new cultivars and superior clones of local cultivars.

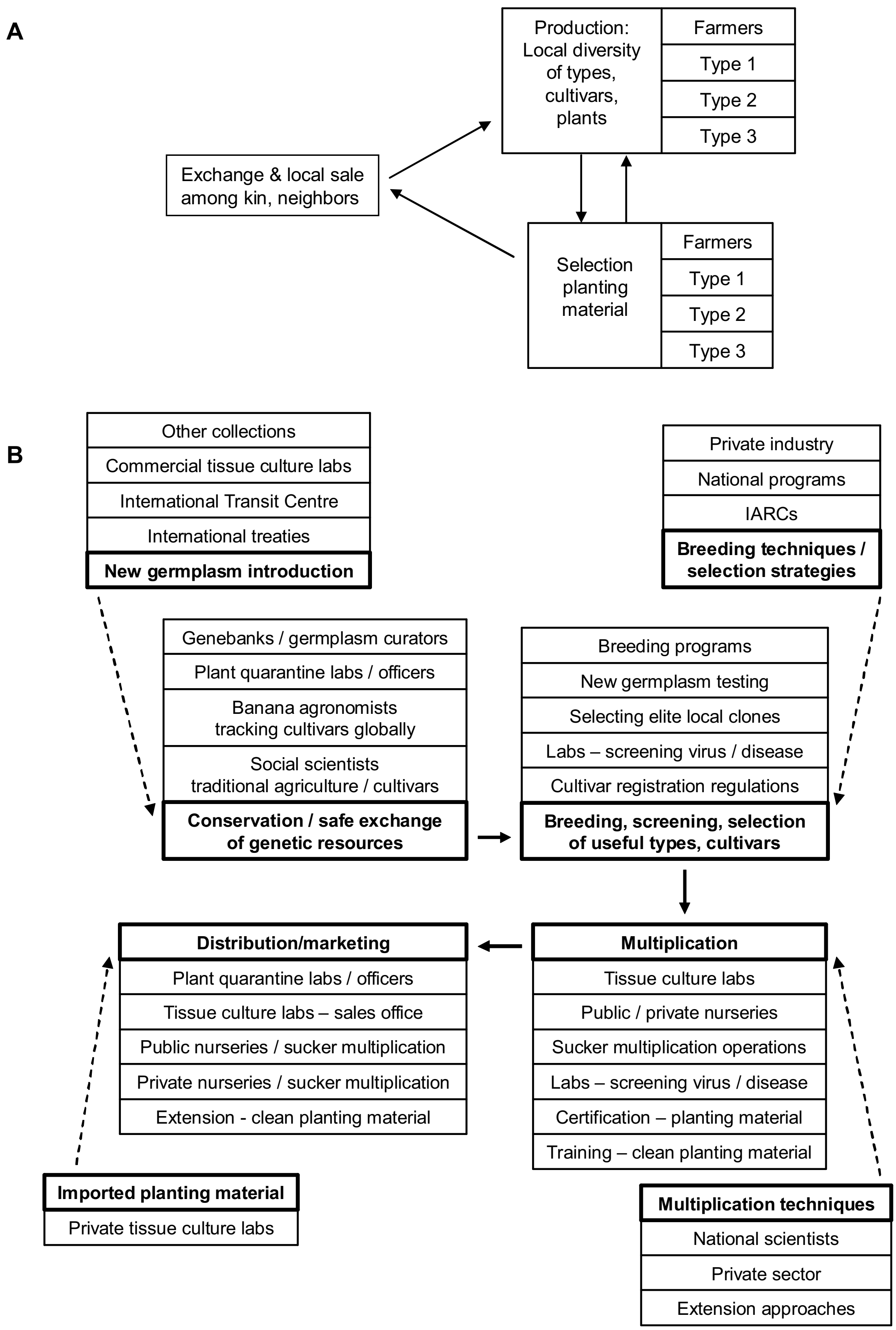

Fig. 1 (**A**) Functions and actors in informal or farmer system for *Musa* planting material. (**B**) Functions and actors in formal system for improving *Musa* planting material.

Only a few countries around the world – India, Brazil, Uganda and Cameroon, South Africa, Australia – have public banana breeding programs. However, routine screening and selection based on the diversity of types and cultivars available globally and on the within-cultivar variability can also be exploited to improve crop productivity. Cultivar registration is often associated with breeding, but can also be adapted to the release of introduced or locally selected cultivars. Research organizations, universities and private companies beyond national borders contribute new breeding or selection techniques to improve the effectiveness of national organizations and their professionals, but only if this information is accessed.

The third component or function of the formal system is the multiplication of improved materials developed by breeders or selected by agronomists. This can be carried out by sucker multiplication and other macro-propagation techniques on research stations and commercial tissue culture labs which often give rise to public or private nurseries to grow out *in vitro* plants. Mechanisms may also be in place to certify the quality of planting material multiplied, based on lab tests or visual inspections. In addition to the actual multiplication of planting material, organizations may also have a training function on improved field and farm multiplication techniques, including new techniques developed beyond national boundaries which need to be locally validated and adapted. Such a research and training function is useful to improve the quality of farmer planting material even if the earlier steps in the formal seed system may be weak.

The organizations which undertake the final step of distribution and marketing of planting materials often overlap with the previous step. *In-vitro* plants can also be imported ready for growing out and planting from commercial labs outside the country, although national labs and quarantine facilities have an important role to play to ensure that imported materials are disease-free. Storage is an important function in true seed systems. For banana and plantain, storage is not possible and the pipeline of quality planting material is very limited. Planning demands for planting material from 6 to 24 months in advance to ensure the desired genetic and sanitary quality is advisable. This lag period for the production of high quality planting material often leads to the use of poor quality planting material in rural development projects with short planning horizons.

Not included in this description are many general policy and institutional issues such as rural infrastructure and education programs, the role of private enterprise in agricultural research and rural development and trade and taxation policies which might indirectly affect seed system development (Pray and Ramaswami 1991; Tripp 2003).

For certain areas such as diversity conservation and quality control, the formal and farmer systems have different approaches for similar functions. Even equity of access, which can be addressed through public seed distribution programs, may also have parallel mechanisms in local seed systems based on culture and tradition. However, there are also functions which the formal system may address more effectively. Quarantine and inspection of introduced planting materials at the national borders, monitoring of international pest and disease threats and even internal quarantines to limit the spread of threatening pests and diseases are public functions. Tripp (1995) proposed that in addition, the public sector has important functions in information review for priority setting, technical support and training and monitoring of equity of access to genetic resources, even when functions of cultivar development, multiplication and distribution are assumed by the private sector.

Thiele (1999) analyzed the relative merits of the formal and informal seed sectors for potato and concluded that strategies for improving the quality of farmer planting material must take both into account. In this view, the national seed system is made up of all individuals, organizations and institutions, formal and local, which are linked to the genetic make-up, the quality and the supply of planting material. A simple indicator of state of the national system for cultivar deployment and seed multiplication is the total vegetative planting material which is used each year to replace existing plantings and to expand production areas. Critical questions need to be addressed in this context: among which groups of farmers, which production systems and for which cultivars can investments be made to improve the quality of planting material?; what changes are needed in the system to achieve these changes? Even when almost all planting material is generated through the farmer seed system, there are interaction points between the formal system and the local system which are important to respond both to threats and opportunities. In the next section we review both the challenges to the supply of improved quality planting material and the response capacity of national systems before testing the approach with a group of over 30 countries.

CHALLENGES TO IMPROVING THE QUALITY OF PLANTING MATERIAL FOR *MUSA* – AN OVERVIEW

Over 130 countries around the world produce bananas and plantains, although only about half of these produce over 100,000 tons each year (Lescot 2008). These countries represent different combinations of factors important for the development of priorities and strategies by public organizations to improve farmer planting material. These can be viewed as factors related to demand for and supply of planting material (Pray and Ramaswami 1991). We analyze first the most relevant factors in terms of the demand: the diversity of *Musa* types and cultivars produced both for home consumption and the market; the pests and diseases present which infect planting material, and the size and nature of the potential market for planting material. On the supply side, we review the dimensions of the current national infrastructure, including both public and private, to implement appropriate strategies for improving the quality of planting material.

A major challenge for the formal seed system is the diversity and genetic quality of planting material. *Musa* centers of diversity are found in Asia, the Pacific and Africa, depending on the type (**Table 2**). The national seed systems in countries with high native cultivar diversity face a double challenge of improving the quality of planting material for the most preferred cultivars, while at the same time conserving cultivar diversity as agreed among the signatories of international treaties on biodiversity and plant genetic resources. In many countries in Latin America and outside the centers of origin in Africa, rural communities produce a wide variety of triploids: AAA, AAB and ABB, as well as occasional diploids, commercially and for home use. Certain cultivars are predominant in the market, but many more are found in local production systems. In subtropical areas of Asia, Africa, Europe and Latin America, countries produce primarily AAA dessert bananas primarily for national urban markets. Depending on the number of types and cultivars present, the national system faces a relatively simple or vastly more complex task in responding to demand. Priority actions may reside in the conservation and safe movement of genetic resources, cultivar screening and selection or approaches to multiplication and distribution.

From the demand side the sanitary quality of planting material is also an important challenge (**Table 3**). This may be a latent demand, since often farmers do not appreciate the importance of new diseases or even common pests and diseases. Planting material is an important and often the primary vector for insect pests and diseases. However, each pest or disease represents a different risk for planting material quality and for the response by the national system. Weevils and nematodes are virtually pantropical in their dis-

Table 2 Centres of diversity for the cultivar types of banana and plantain (modified from INIBAP 2006 p. 7).

Cultivar types	Genome group	Centres of diversity
Edible diploids, triploids and others	AA, AAA, AS	Indonesia-Philippines-Melanesia
	AAS, AAT, ABBT	Exceptional diversity of AA in New Guinea
East African Highland Banana	AAA	Great Lakes region in East Africa (Burundi, Kenya, Rwanda, Tanzania, Uganda)
Plantains	AAB	West and Central African rainforest + India
Maia Maoli-Popoulu and Iholena	AAB	Polynesia, Melanesia and Micronesia
Edible diploids	AB	South India
Eastern ABB (BBB) subgroup	ABB	Philippines and North Vietnam
Western ABB subgroup	ABB	Northeast India and South India

Table 3 Major banana and plantain pests and diseases transmitted through planting material

Pest/ disease	Distribution	Yield loss	On-farm techniques applicable	Need for quarantine vigilance	Public sector capacities to promote quality
Weevils	Virtually pantropical	Low to moderate	Yes	No	Farmer training
Nematodes	Pantropical	Low to moderate	Yes	No	Farmer training
CMV	Pantropical	Low to moderate	No	No	Virus cleaning
Foc other races	Pantropical	Moderate to high	Some risk	Useful	Farmer training
Bacterial wilts	Depends on species/ strains	Moderate to high	Some risk depending on virulence of strain	Very important at national borders and internally	Strain identification, farmer training
Foc Tropical Race 4	Primarily Asia	High	High risk	Very important at national borders and internally	Monitoring presence, VCG detection
BSV	Pantropical endogenous to AAB types; localized in AAA	Low to high	Yes in AAB, No in AAA	Limit introduction of exotic plantain cultivars to reduce risk of new strains or strain hybridization	Farmer training, virus screening
BBrMV	Asia	Uncertain	No	Very important at national borders and internally	Monitoring presence, virus screening
BBTV	Asia, Pacific and Africa	High	No	Very important at national borders and internally	Monitoring presence, virus screening,

VCG, vegetative compatibility group

tribution, but can be managed with simple practices applied on-farm. Diseases like the bacterial wilts and *Fusarium oxysporum cubense* (Foc) Races 1 and 2 and *Cucumber mosaic virus* (CMV) can also be managed on-farm, although practices are more difficult to apply, the risk of spread is higher and yield losses are more severe. *Banana bunchy top virus* (BBTV) is impossible to manage on-farm and requires a formal seed system with infrastructure to produce virus-free planting material.

Banana streak virus (BSV) is a special case, forming part of the genetic make-up of the B genome and particularly problematic in AAB (Teycheney and Iskra Caruana 2002). The endogenous pararetrovirus sequences of BSV are usually silent, resulting in normal production in plantations of plantains originating from suckers. However, abiotic stresses such as tissue culture multiplication procedures and temperature fluctuations can activate the BSV sequence and result in plants with different levels of symptoms and reduced production (Côte *et al.* 2010). The cleaning of viruses such as BBTV in plantains is complicated by the presence of BSVs, since the elimination of BBTV results in the activation of BSV. This limits the use of tissue culture procedures for the multiplication of AAB cultivars. BSV under certain conditions, especially with insect vectors present, can also infect AAA cultivars, but in such cases virus cleaning and tissue culture multiplication are effective and necessary.

Certain diseases and insect pests are not yet present in all *Musa* growing regions. Extreme vigilance is therefore essential in certain countries to prevent the spread of these phytosanitary problems. These diseases needing quarantine include bacterial wilts (*Ralstonia* and *Xanthomonas*), Foc Tropical Race 4, BBTV and Banana bract mosaic disease (BBrMV) (Ploetz 2009). In these cases quarantine procedures at national borders are essential and internal quarantine may also be useful to prevent the spread of the problem if one of these diseases is inadvertently introduced.

The size and nature of the market for improved quality planting material is the final demand side factor. Tripp (2003) proposed that a commercial seed sector can only arise with demand from market-oriented farmers who are willing to pay for quality planting material either in terms of production potential, price of seed and associated risks with yield and market. A small market is characterized by farmers who produce primarily for a limited local market, invest relatively little in seed and in general do not make use of commercial agricultural inputs. In such situations the distribution system for any type of agricultural inputs is likely to be underdeveloped. A large market for improved seed is often found to respond to large internal domestic or export markets for a diversity of crops, a greater return from the use of improved quality seed and a thriving distribution system for agricultural inputs in general based on knowledgeable and discriminating market-oriented farmers (Trigo 2003).

From the supply side, the in-country capacity to implement strategies to improve the quality of farmer planting material is a major factor. Trigo (2003) categorized country capacity to access and use biotechnology. Low capacity countries were characterized by non-selective, spontaneous and individual initiatives, while those with a slightly greater capacity imported technology more selectively based on incipient development strategies. Those countries with increased capacity had advanced to the use of technology routinely, while a few countries had reached a stage of innovation of new technologies in new crops. Trigo (2003) used various indicators to categorize 63 countries, including whether actions were project based or on-going, the nature of conventional breeding programs, the extent of lab facilities and the use of diverse molecular techniques.

In the case of *Musa*, following the model provided by Trigo (2003), certain challenges are relevant to categorize country capacity to improve farmer planting material. To what extent has national germplasm been catalogued and priorities for improvement identified? Are human resources and infrastructure in place, including laboratories for virus detection and routines for inspection and quarantine to limit the introduction and internal spread of materials with high risk of pest and disease? How active are programs for the selection, release and multiplication of new cultivars targeted to specific problems and uses? What is the presence and size of semi-commercial and commercial tissue culture laboratories and what are their strategies for quality assurance?

CATEGORIZING NATIONAL SYSTEMS BY MAJOR CHALLENGES – A TEST FOR THE PROPOSED FRAMEWORK

As a strategy to group countries for targeting actions for improving the quality of farmer planting material, we developed a decision tree based on the major challenges identified in the previous section (**Fig. 2**).

(1) The diversity of germplasm was selected as the first important distinguishing characteristic. Three categories were established: countries with centers of diversity for *Musa*; countries with multiple types and cultivars used by farmers, and countries with only a very few types.

(2) The relative importance of AAB types was targeted as the second distinguishing characteristic, largely due to the link to BSV, and the restrictions this virus places on multiplication and improvement techniques.

(3) The third factor to appear is the presence or absence of

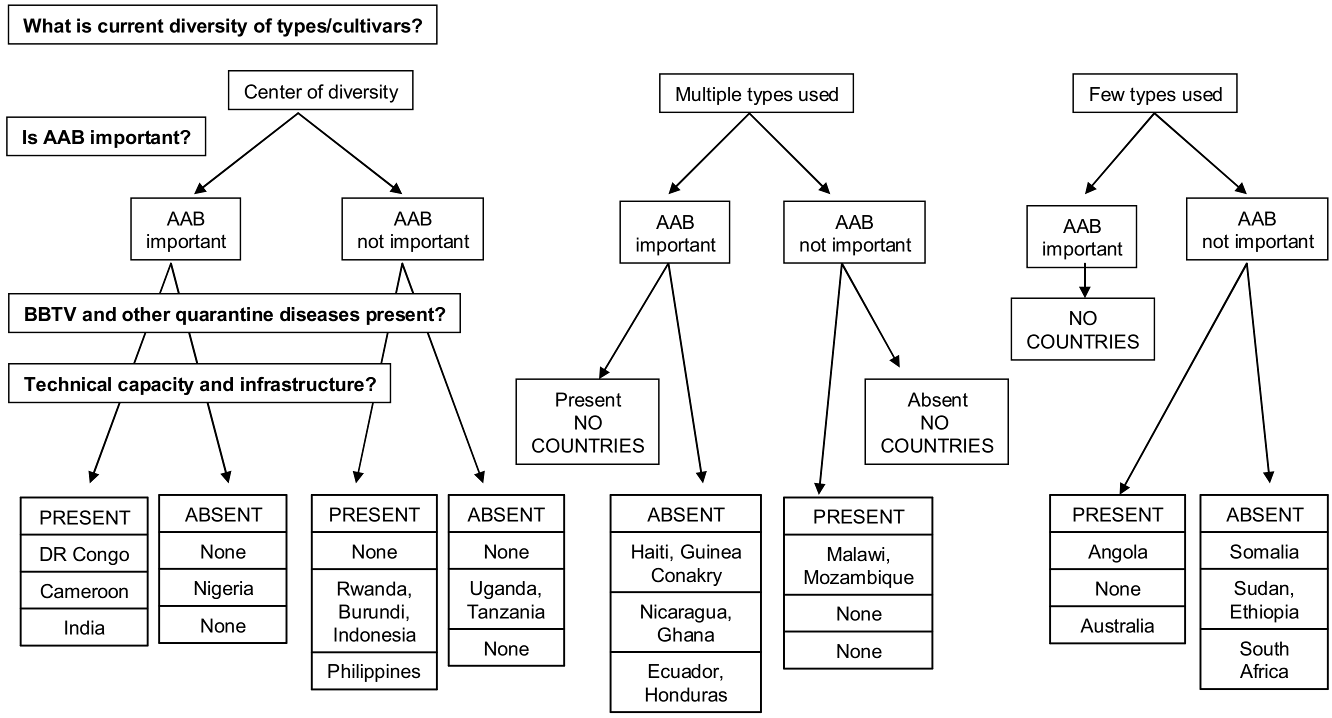

Fig. 2 Decision tree to categorize countries by priorities for strengthening national system to improve quality of farmer planting material (see text for explanation of categories).

BBTV and Foc Tropical Race 4, two of the biggest threats to a wide diversity of cultivar types. The presence of bacterial wilts was not considered of the same magnitude of importance and was not included as a decision factor.

(4) The final factor proposed is the infrastructure and technical capacity for the improvement of the quality of farmer planting material. Three categories are proposed: minimal with limited capacity for quarantine, virus detection and research on multiplication, incomplete collections, limited extension coverage and very little market for seed and agricultural inputs; moderate with small scale semi-commercial and commercial tissue culture, more extensive germplasm collections, greater quarantine and research capacity and an incipient market for improved quality planting material; high with large scale commercial tissue culture labs for banana, more fully implemented quarantine procedures and a commercial market for improved quality planting material.

More permanent characteristics were considered first with characteristics more likely to change at lower levels in the decision tree. Countries are unlikely to shift categories for the first two factors, but could move from absent to present for the quarantine diseases and can improve their infrastructure/technical capacity, or in a few cases lose already acquired infrastructure or human resources.

To validate the decision tree, a workshop was held with representatives from 15 countries in Sub-Saharan Africa in conjunction with Banana 2008 – International Banana Congress in Mombasa, Kenya (see http://www.banana2008.com/cms/details/index_details.aspx). Based on the hierarchy of questions, participants identified the status of their country. Countries with similar situations discussed priority strategies in response to their situation. After this initial test, a data base of country seed system profiles, developed with the workshop participants, 13 country participants in five research and development grants in Africa and Latin America and for 9 countries in Asia was used to broaden the number of countries categorized. The seed system questionnaire inventoried the status of collections, laboratory and virus detection capacity, commercial seed multiplication enterprises, the primary pests and diseases, farmer seed quality and regulatory statutes for clonal crops.

The array of factors provided a simple approach to differentiating countries. The 32 countries from Africa (19), Latin America (5) and Asia/Pacific (8) were classified into 17 different groups (**Fig. 3**). Of the 36 potential categories, 19 were unoccupied. No countries were classified with minimal diversity in which AAB is important and only one country, Malawi, was categorized in the group of multiple types used in which AAB is not important. Two groups were vacant at the level of the presence of quarantine diseases, while 7 categories were vacant at the level of capacity.

During the workshop and the classification of all countries in the database, certain issues arose which contributed to clarifying the results. Although wild relatives are an important genetic resource, these were not included in the categorization criteria. There were also differences of opinion about whether plantain should be included as a deciding factor. While BSV does not present major challenges to the farmer seed system, for the formal seed system numerous issues remain to be resolved to improving the quality of farmer AAB planting material. Similarly, numerous countries in East Africa were perplexed by how much importance should be given to minor types, such as plantains which are present, but not a major component of the banana production system. Since currently no major initiatives in the formal seed system address the quality of AAB planting material, the countries of East Africa were categorized as AAB not important. Further down in the decision framework, workshop participants in certain countries could not state whether BBTV was present. Recent surveys by IITA (Lava Kumar pers. comm.) indicate that the problem is present, but not yet officially announced. We also grappled with how much importance should be given to other diseases meriting quarantine measures. The option to add additional levels was considered, based on the difference in the approaches to managing the difference problems in the field. However, additional levels quickly multiply the number of categories beyond the current level of 36. At the lowest level, the possible option of only two categories based on current capacity was reviewed. Since the capacity of the seed system is an important area of development investments, the three groups were maintained to capture the quite large differences at the lower end of the scale between

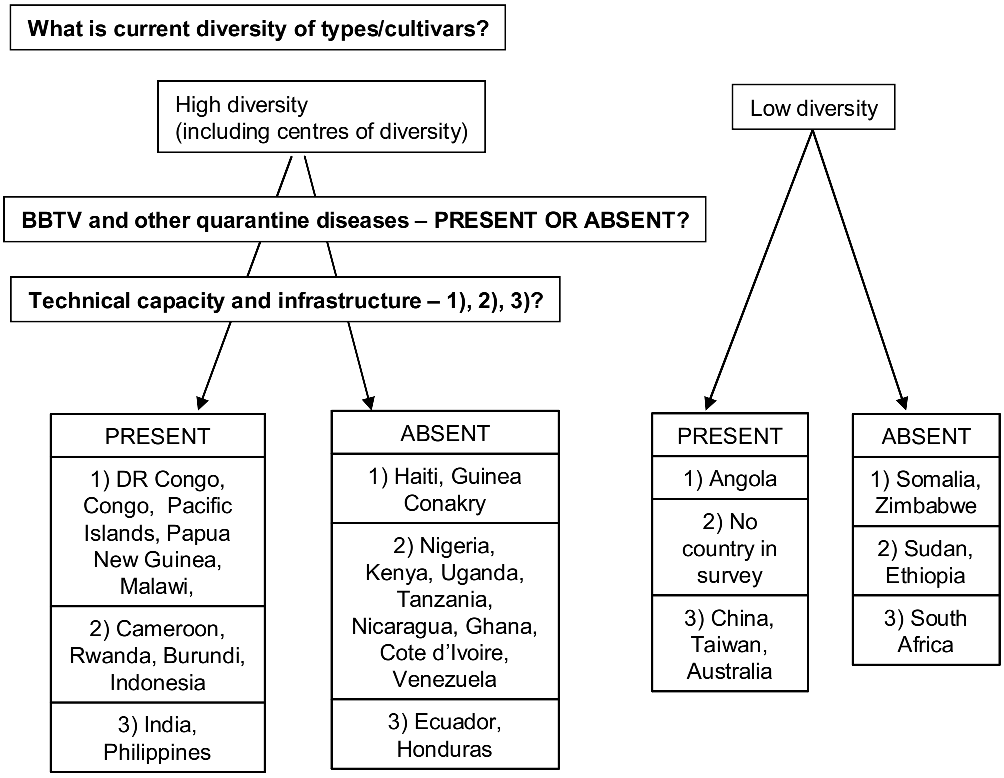

Fig. 3 Simplified decision tree to categorize countries for priority actions in seed system strengthening.

countries with very limited capacity and those with more organized, although incipient efforts.

STRENGTHENING CULTIVAR DEPLOYMENT AND MULTIPLICATION SYSTEMS – WHERE TO START

In this final section we address the issue of whether the categorization of countries as proposed above contributes to more targeted development of strategies and actions. We first review the results of discussions groups in the Mombasa workshop in 2008 to determine if unique priorities were identified according to country characteristics. We then propose specific actions for groups of countries, asking whether priorities diverge by group. We conclude with an identification of the principal issues for building a national priority setting framework for *Musa* seed system strengthening and for developing a more detailed planning approach.

A review of the results of three distinct discussion groups in the workshop in Mombasa provides insight into the challenges for targeting priority actions in the improvement of the quality of farmer planting material. Three discussion groups were formed among the representatives of 15 countries – countries with *Musa* centers of origin and multiple types used where BBTV is present; countries with centers of origin and no BBTV; and countries with multiple types used and no BBTV. Each group was provided a general guide to orient discussions to priority actions nationally and to different stakeholders. The results permit only a qualitative comparison. Two of the three groups (both with and without BBTV) prioritized diagnostic and indexing labs and quarantine, although not differentiating the role. Only one group highlighted conservation and characterization of *Musa* diversity, although two groups included countries with centers of origin. Farm and village level multiplication methods were mentioned by two groups, although in the case of countries with BBTV, this may not be a feasible option, unless coupled with virus testing or some source of clean material. New cultivar introduction and evaluation was highlighted by two groups – one with center of origin and the other with multiple types used. Training for farmers and other capacity building actions were mentioned by two groups, although the third group, which identified many specific priority actions, did not refer to training as such. In general, the results suggest that the over 30 scientists in the workshop from national and international centers operating in sub-Saharan Africa had a good grasp of the key issues linked to improving the quality of farmer planting material, including the role of diverse stakeholders. However, the three groups representing contrasting challenges for seed system development did not identify distinct strategies depending on the specific set of characteristics reflected in their countries. This suggests that opportunities exist for further studies on and capacity building for seed system strengthening for banana and plantain.

The primary objective of grouping countries is to target actions for improved seed systems by country characteristics. To test whether different strategies could be proposed for the 17 categories of countries (**Fig. 2**), we compiled actions corresponding to five priority themes - public awareness, public infrastructure needs, role of private sector, applied and basic research and small farmer training themes. The results (**Table 4**) show that fewer categories are needed to cover major strategy differences. Three categories are omitted in **Table 4** – all countries with well developed capacity in seed systems with either few cultivars and presence of quarantine diseases (South Africa, China, Taiwan, Australia) or wide diversity of cultivars and no Foc Tropical Race 4 or BBTV (Ecuador, Honduras). For the remaining six categories, 17 distinct actions were identified of a potential 36 entries, indicating substantial overlap among actions by category of country. In all priority themes, at least two contrasting actions were identified, with only two areas breaking down into four different actions. In no cases were different actions proposed for each category of country. The fewest differences in priority actions were found among categories of countries separated based on the importance of AAB types. Countries where AAB types are important face additional research challenges to clarify the challenges presented by BSV for the safe movement of AAB germplasm, for low-cost tissue culture protocols and for designing formal-informal systems for clean planting material in the presence of BBTV.

For public awareness, a need for stronger mechanisms of quarantine was identified across all countries, including

Table 4 Priority actions for strengthening quality of farmer banana and plantain planting material by country characteristics.

	High AAB diversity, BBTV present, Minimal and some infrastructure	**Diverse types/cultivars, AAB not important, BBTV/Foc TR4 present, Minimal and some infrastructure**	**Few cultivars, AAB not important, BBTV present, Minimal and some infrastructure**	**High *Musa* diversity, BBTV/Foc TR4 present, Quarantine infrastructure, Commercial tissue culture**	**Diverse types/cultivars, including high diversity BBTV/Foc TR4 absent, Minimal and some infrastructure**	**Few types/cultivars, AAB not important BBTV/Foc TR4 absent, Minimal and some infrastructure**
Countries	DR Congo, Congo, Cameroon, Pacific Islands	Rwanda, Burundi, Indonesia, Malawi, Papua New Guinea	Angola	Philippines, India	Nigeria, Uganda, Haiti, Tanzania, Ghana, Guinea Conakry, Kenya, Cote d'Ivoire, Nicaragua	Sudan, Zimbabwe, Somalia, Ethiopia
Public awareness	BBTV/Foc TR 4 symptoms and epidemiology; Risks of moving planting material; Risks of introduction of viruses, FOC TR 4, virulent bacterial wilts affecting *Musa*				Risks of introduction of BBTV and other viruses, FOC TR 4, virulent bacterial wilts	
Public infrastructure needs	National quarantine to avoid introduction or reintroduction of pests and diseases; Quarantine controls within country between infected and non-infected zones; Local and regional labs for BBTV detection; Missions to collect local cultivars; Screen houses to conserve virus-free local genetic resources		National and internal quarantine to avoid introduction, reintroduction and spread of pests and diseases; Local and regional labs for BBTV detection	Collection missions emphasizing within-cultivar variability; Screening for BBTV and other viruses in minor cultivars; Screen house to conserve virus-free local cultivars	National quarantine to avoid introduction of new pests and diseases	
Private sector role	Semi-commercial and commercial virus-free tissue culture labs producing most important cultivars		Importation of tissue culture from abroad	Commercial tissue culture labs producing minor cultivars	Growers specialized in production of planting material	
Applied research themes	Re-infection rates by BBTV for clean planting material; Feasibility of protected macro-propagation techniques; Strategies for supply of low-cost planting material based on tissue culture			Strategies for the supply of planting material based on tissue culture to small farmers	Potential for yield and quality improvement through selection of superior mother plants; Validation, adaptation and cost comparisons of macro-propagation techniques	
Basic research themes	Characterization of BSV types and risk of hybridization; Tissue culture protocols to reduce BSV activation; Protocols for safe movement of AAB germplasm			Tissue culture protocols to reduce BSV activation; Characterization of BSV types and risk of hybridization; Protocols for safe movement of AAB germplasm	Protocols for safe movement of AAB germplasm	
Priority themes for small farmer training	Diagnosis of BBTV/Foc TR4 early symptoms; Mechanisms of BBTV/Foc TR4 spread; Early eradication of plants with symptoms; Need for clean planting material; Strategies for multiplication of clean planting material when BBTV/Foc TR4 infestation low; Protected macro-propagation from clean material; With availability of low cost commercial tissue culture plants (Philippines/India), frequent replanting in case of market oriented production				Selection of superior mother plants; Techniques to ensure clean planting material; Macro-propagation techniques to multiply superior plants	

awareness of the threat and the primary risks of introduction, while for those countries already affected by such diseases as BBTV and, Foc Tropical race 4, public awareness should be expanded to reduce the internal movement of the disease. In the case of public infrastructure, actions are prioritized both by current capacity and by diseases currently present. All countries with only minimal or incipient capacity to improve the quality of farmer planting material need to strengthen national quarantine capacity, while those with BBTV need infrastructure for detecting BBTV and conserving virus-free germplasm.

Countries with centres of diversity for *Musa* face the additional challenge of conserving germplasm diversity, even more difficult when BBTV and/or Foc Tropical Race 4 are present. Countries such as India and Philippines with well established national programmes for germplasm conservation may prioritize the conservation of within-cultivar diversity, since they already have large germplasm collections. The priority actions for the private sector, and in applied research, depend on current country capacity, the extent of cultivar diversity and the presence of diseases such as BBTV. Countries with BBTV present and minimal current capacity need to target clean seed of major cultivars through links with tissue culture labs and local seed multiplication depending on the local re-infestation rates of BBTV, while countries with stronger national capacity can expand the coverage of commercial tissue culture labs to cover less commercial cultivars and more marginal rural communities. For countries without BBTV or Foc Tropical Race 4, private sector and applied research can focus on techniques for improving the on-farm multiplication of planting material. In the area of small farmer training, two major categories were identified. First, when serious disease threats are present in country, small farmer training must focus on early diagnostic, eradication and options for management of the threatening disease. Second, in the absence of the disease, training can focus on quality based on superior mother plant selection and planting material clean of pan-tropical pest problems like nematodes and weevils.

The tests of the categorization system and its usefulness in the identification of priorities suggest that for overall priority setting a simpler format should be adequate (**Fig. 3**) with 12 categories instead of 36 (**Fig. 2**). Countries can first be grouped by those with a higher diversity of types and cultivars and those with relatively little diversity- two categories instead of three, followed by categorization based on the presence or absence of diseases like BBTV and the current capacity of the formal system. More in-depth characterization of national seed systems and a broader range of countries are needed to test this proposed framework.

Moving forwards to more targeted projects for capacity building and rural development, especially in situations of extremely limited national resources, calls for a more detailed analytical framework for priority setting and strategy building within country. Tripp (2003) proposes that demand from knowledgeable market-oriented farmers is an important driver in improving seed quality. This suggests that within country strategies should be built around the categorization of rural communities by their natural resource base and their distance from market (World Bank 1994). Public-private projects for improving the quality of planting material might then be more effectively targeted. Targeting would be towards rural communities with both greater production potential in terms of natural resources and easy market access based on distance and available infrastructure. An incipient self-financing system to improve the quality of planting material could then be expanded to progressively cover more and more farmers as costs decline and capacity increases. Such projects might also be designed for the additional purpose of contributing to national quarantine capacity. The ever-growing menace of such diseases as BBTV, Foc Tropical Race 4 and more virulent strains of bacterial wilts as well as the income opportunities from banana and plantain for growing urban populations calls for further research and action in the area of seed systems for clonal crops.

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