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Mainstreaming the continuum approach to the management of plant genetic resources for food and agriculture through national strategy

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Abstract

Global food security could be imperilled by the combined pressures from the effects of continually evolving climatic conditions, demographics and other socio-economic factors, the demands of the livestock, bioenergy and fibre industries for food-based substrates, the static or decreasing availability of natural resources for agriculture and the impracticality of increased use of economically and environmentally costly agricultural inputs. The optimal harnessing of plant genetic resources for food and agriculture (PGRFA) in manners that translate their repertoire of hidden potentials into significantly enhanced crop productivities has been severally identified as crucial to achieving the required considerably significant increases in food production. The scope of the problems and the plausible means for addressing them compel the devising of novel and more efficient ways for deploying PGRFA in need-based crop improvement programmes. We posit a continuum approach to the management of PGRFA which links seamlessly the effective conservation and access to PGRFA through their use in developing superior and resilient crop varieties to the provision of their high-quality seeds and planting materials to the growers. To achieve the mainstreaming of this paradigm, we propose the institutionalization of overarching national PGRFA strategies that prescribe result-oriented action plans spanning above three components of the management of PGRFA for a country's priority crops. We also describe the strategy as a means for identifying and assigning responsibilities to critical stakeholders and providing for the governance of all aspects of PGRFA activities over specific time frames. Steps to developing and adopting a national PGRFA strategy are also suggested.

Keywords: Plant Genetic Resources for Food and Agriculture; PGRFA; National Strategy; Continuum; Crop improvement; Conservation; Plant Breeding; Seed; Stakeholder; Governance

Introduction

The challenges that constrain many countries' efforts to eradicate extreme hunger and poverty, one of the Millennium Development Goals (MDGs; http://www.un.orgmillenniumgoals/; United Nations, 2000), have been exacerbated by the consequences of climate change and variations, increasing populations, changes in dietary preferences, the conversion of foodstuff to substrates for

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bioenergy production and the increasing use of arable lands for growing livestock feeds and fibre. An estimated 70% increase in food production is required to feed the world in 2050 when the global population is projected to have increased by about 2 billion to over 9 billion people (FAO, 2009a). In a similar vein, the sharp increases in food prices starting in 2008 have spurred the international community to the consensus that the threats to agricultural productivity must be addressed definitively in innovative manners (Ejeta, 2009; FAO, 2009c; Fischer and Edmeade, 2010; Phillips, 2010; WEF, 2010; Foresight, 2011). Strong policy environments that enable the appropriate applications of science and technology will be key to innovating.

The optimal harnessing of plant genetic resources for food and agriculture (PGRFA) is critical to addressing the identified multifaceted threats to food security. This is because, with minimal scope for deploying either more arable lands or water resources to crop production and the steep economic and environmental costs of agricultural inputs, a significant proportion of the needed increases in crop production must be achieved through genetic gains, i.e. increased crop productivities. There is potential for about 50% increase in crop yields through the unlocking of the potentials of PGRFA in breeding (Duvick, 1992, 1995; Fernandez-Cornejo, 2004) 'smart' crop varieties that will yield even more with fewer inputs.

To varying degrees, many countries have capacities to conserve crop germplasm, to breed new crop varieties and to deliver their seeds and planting materials to the growers. However, evidence now abounds that addressing these three mutually enriching components of the PGRFA value chain in a concerted manner will lead to improved efficiencies which in turn translate to sustainable enhanced crop productivities. The plausibility of this premise is manifest in the interrelatedness of plant breeding and seed marketing activities of private sector entities especially in developed countries. Also, the overall management of PGRFA in some other countries, e.g. Brazil, China and India, which show significant improvements in the use of PGRFA to address crop production needs, is also characterized by very strong linkages between these three components (FAO, 2010).

We introduce the continuum approach – as distinct from earlier modular approaches – that is underpinned by national PGRFA strategies, as a means for contributing to enhanced crop productivities. This approach is predicated not only on best practices for, but also on synergistic linkages between, the individual three mutually enriching components of the PGRFA value chain – conservation, use and delivery. The ultimate aim is to ensure that the conservation of PGRFA provides adequate levels of the heritable variations required for value addition through plant breeding, and, in turn, that the outputs of this effective result-oriented crop improvement programme, high-quality seeds and planting materials of superior crop varieties have an efficient delivery mechanism to the growers.

Plant genetic resources for food and agriculture

PGRFA is 'any material of plant origin, including reproductive and vegetative propagating material, containing functional units of heredity of plant origin of actual or potential value for food and agriculture' (FAO, 2009c). Whereas PGRFA could, based on this definition, conceivably include plant deoxyribonucleic acid and other hereditary materials, we are, for the purposes of this paper, restricting our treatment of a country's PGRFA to living higher plants of value to food and agriculture. As described by the International Treaty on Plant Genetic Resources for Food and Agriculture (the International Treaty; FAO, 2011a), these commonly include whole plants, seeds and planting materials of some combination of:

(1) wild ancestors or related species of modern crops;
(2) non-related species from which genes may be sourced for use in crop improvement;
(3) landrace varieties;
(4) modern varieties developed by breeders.

In general, therefore, PGRFA may exist as part of germplasm holdings (*ex situ* collections) or they may be found in nature or on-farm (i.e. *in situ* collections). Breeding materials are also categorized as PGRFA. In essence, PGRFA therefore encompasses the full range of plants cultivated for food and varied agricultural purposes and other plants with potentials for use in like manner. The management of PGRFA in manners that permit their effective conservation, ready accessibility and their utilization both directly and to develop superior crop varieties which in turn are made available to the growers as high-quality seeds and planting materials therefore impacts on food and agriculture in general. The prevailing unacceptably high levels of food insecurity – exacerbated by the vagaries of climate change and variations, myriad demographic and economic pressures against the backdrop of inelastic natural resource base – dictate the imperative of urgently attaining greater efficiencies in food production beyond the current global levels. The strategic deployment of PGRFA is manifestly critical in attaining the desired enhancements.

PGRFA as global commonwealth

Since inception, Food and Agriculture Organization (FAO) has consistently championed multilateral initiatives

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that underscore the vital importance of PGRFA in safeguarding food security. These efforts have resulted in several international agreements and instruments such as the International Plant Protection Convention (IPPC, https://www.ippc.int/). The FAO Global System on Plant Genetic Resources for Food and Agriculture, especially through the rolling Global Plan of Action (GPA) on the Conservation and Sustainable Use of PGRFA (FAO, 1996; http://www.globalplanofaction.org/), prescribes validated priority activities as means for aiding national governments in achieving the most sustainable benefits from PGRFA. It is expected that countries are adapting these to their own particular needs and circumstances and taking strategic decisions ranging from the deliberate sourcing of PGRFA even from beyond the country's sovereign boundaries to setting up crop improvement programmes for priority crops and supporting seed marketing enterprises, for instance. Another global instrument that is aimed at addressing the three components of the PGRFA continuum is the International Treaty (http://www.planttreaty.org/; FAO, 2009) with 127 contracting parties including the European Union. The objectives of the International Treaty are 'the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising out of their use' in harmony with the Convention on Biological Diversity (CBD) (United Nations, 1992; http://www.cbd.int/). These, along with the activities of several other partners, especially the Global Crop Diversity Trust (http://www.croptrust.org/main/), the centres of the Consultative Group on International Agricultural Research (CGIAR; http://www.cgiar.org/) enhance the capacities of countries to take the fullest advantages of PGRFA both within and beyond national boundaries. The global reach and contributions of these international instruments and bodies underscore the significant value the international community places on PGRFA (FAO, 2010).

The International Treaty, the latest and most comprehensive instrument dealing with PGRFA to date, exemplifies the concerted efforts by the FAO and partners to achieve greater efficiencies in the management of PGRFA. The core underlying principle is that the greatest benefit derivable from PGRFA – and hence the primer for its conservation – is its utilization to develop superior crop varieties whose high-quality seeds and planting materials are made available to the growers. Articles 5 and 6 of the International Treaty, for instance, specifically require that contracting parties facilitate the conservation and sustainable utilization of PGRFA and, by so doing, strengthen the linkages between the two aspects of the harnessing of PGRFA.

The challenge of feeding an increasing global population with limited resources

To be sustainable, the prescribed 70% increase in food production in the next 40 years (FAO, 2009b; Tester and Langridge, 2010) in the face of daunting challenges (FAO, 2008; Park *et al.*, 2010) will have to be achieved with minimal environmental footprints. This dire scenario implies therefore that for the foreseeable future, crop production strategies must rely most heavily on innovative and efficient approaches. The FAO (2011b), in prescribing a suite of policy guidelines to underpin a paradigm shift that rethinks the sustainable intensification of sustainable crop production, opines *inter alia* that, 'Farmers will need a genetically diverse portfolio of improved crop varieties, suited to a range of agroecosystems and farming practices, and resilient to climate change'. This policymaker's guide enunciates the challenges of feeding an ever-increasing human population and in addition to dealing with the specific interventions relating to crops and their varieties also addresses the themes of farming systems, soil health, water management, plant protection, and policies and institutions.

Complementary to the FAO's activities, the international community at large has been mobilizing resources and articulating the most appropriate means for a new agricultural paradigm that provides access, at reasonable costs, to food of sufficient quantity and quality. Some recent efforts have resulted in the 'Realizing a New Vision for Agriculture: A roadmap for stakeholders' by the World Economic Forum – WEF – (2010). In emphasizing the urgency of intervening in innovative ways, this roadmap, *inter alia,* also concluded that the 'world must produce more with less' as the current and previous approaches are clearly inadequate for dealing effectively with the scope of required increases in food production within the context of severely constrained resources. Among the prescriptions of this roadmap is a reinvigorated research and development regimen that focuses on 'orphan crops' and major crop breeding efforts.

The extensively researched Foresight (2011) of the government of the UK, also aimed at 'policymakers and a wide range of professionals and researchers', also concluded that the compellingly dire challenges facing global food security required new ways for collective action. Quite importantly, it also concluded that more food must be produced with less inputs; it called for a reversal of the low priority placed on agricultural R&D. Some of the solutions adduced in Foresight and other recent contributions to this theme (e.g. Ejeta, 2009; Fischer and Edmeade, 2010; Phillips, 2010) for attaining these goals included the unlocking of the hidden potentials of PGRFA in the breeding of new crop varieties and

the preservation of the widest possible genetic variations including variants of landraces and crop wild relatives. The conclusion from this sampling of major publications in the last 1 year that proffer policy advices for the management of PGRFA is that the harnessing of the inherent potentials coded into the blueprints of crops and their relatives holds immense potentials for providing food of sufficient quantity, adequate quality and appropriate levels of diversity for an increasing global population that must be fed with less inputs than had hitherto been the case.

Indeed, the quest for significant increases in crop productivity is not without antecedents as, historically, increases in crop production (e.g. the Green Revolution and the New Rice for Africa – NERICA) have been driven in equal measures by harnessing the inherent hereditary potentials of crops, on the one hand, and the deployment of improved agronomic practices, on the other hand. It is therefore quite feasible now to leverage advances in science and technology to tap into the considerable reserve of PGRFA to recreate these successes.

The global status of the management of PGRFA

The FAO, through its Commission on Genetic Resources for Food and Agriculture, recently published a compendium that details the current global status of PGRFA (FAO, 2010). Titled the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (SoWPGR-2), it reviewed the states of diversity, *in situ* management, *ex situ* conservation, use, national programmes; collaborations (regional and international); access to PGRFA, the sharing of benefits and farmers' rights; and the contribution of PGRFA to food security. A key deduction was that while much progress has been made in the 15 years since an earlier report (FAO, 1996), there still existed substantial room for improvement in many aspects of the management of PGRFA. SoWPGR-2 also identified the breeding of crops with adaptations to climate change and variations as an increasingly important crop improvement objective. However, the worrisome trend of pervasive suboptimal capacities for plant breeding in many countries implied that PGRFA was not being used optimally to attain maximum benefits. This deduction, based on submissions from over 100 countries, accorded with the results of the surveys of plant breeding capacities in over 80 countries with subsequent detailed studies in six of them by the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB, http://km.fao.org/gipb/; GIPB, 2011). Morris *et al.* (2006) and Miller *et al.* (2011) have also identified this regrettable global critical shortage of plant breeders, with Bliss (2007), Gepts and Hancock (2006), Miller *et al.* (2010) and Traxler *et al.* (2005) further observing that too few students are enrolling in plant breeding programmes in universities. This trend of diminishing capacity for crop improvement, which leaves retiring plant breeders and university faculties unreplaced, if unchecked, has the potentials for undercutting the efforts to harness PGRFA for food security. Interestingly, this trend of diminishing capacities was evident largely in the public sectors. Across all the continents, the involvement of the private sector in PGRFA management, especially plant breeding and seed systems, increased significantly between 1996 and 2009 (FAO, 2010).

Some of the critical recommendations of SoWPGR-2 for attaining the optimal harnessing of PGRFA in developing crop varieties that contribute to enhanced food security – even as populations increase, resources are limiting and there are competing needs for diverting foodstuff to other industrial and commercial purposes – include:

(1) Increased plant breeding and seed delivery capacities worldwide.
(2) Increased use, through enhanced linkages between germplasm curators and plant breeders, of a wider range of well-characterized and documented germplasm accessions including under-utilized species and crop wild relatives.
(3) Use of the most appropriate technologies and tools, including biotechnologies and information technology platforms, for the characterization and evaluation of germplasm as well as their use in crop improvement activities.
(4) Development of overarching national strategies for PGRFA that link conservation of genetic resources through their use in crop improvement to the delivery of high-quality seeds and planting materials of improved varieties.

Managing PGRFA as a continuum of three components

Several of the FAO's field activities, complemented by those of partner development organizations like the World Bank, the International Fund for Agricultural Development, centres of the CGIAR, national governments, regional organizations, donor agencies and the civil society, have resulted in significant enhancements to the capacities of countries to address the aforementioned three main components of PGRFA management, i.e. the conservation of crop germplasm, plant breeding and the delivery of seeds and planting materials to the growers and end-users. Commonly, an unintended effect of these interventions has been

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national programmes with overly strict compartmentalization of the activities relating to these three components as if each component constituted an end in itself rather than an intrinsic part that is linked functionally to the other two components. These strict divisions, invariably symptomatic of the poor PGRFA management practices in many countries, obviate collaborations and prevent the pooling of resources and adequate sharing of information, especially the translation of growers' needs to breeding objectives. The resultant effect of this modular approach on the management of the PGRFA value chain is that the farmers do not get the most suitable crop varieties in the most timely and efficient manners.

The main thrust of a significant component of the FAO's PGRFA-related activities currently targets the addressing of the above three components in a concerted manner in order to attain a continuum of uninterrupted series of interventions. The logic is that while enhancements in capacity for plant breeding, for instance, would undoubtedly lead to incremental improvements in crop productivity, such improvements are demonstrably even greater in situations where comparable attention is paid to germplasm conservation and seed systems while at the same time developing effective interfaces between the components. The three components sustain one another symbiotically. Just as the conserved crop germplasm that remains unused is of no greater value to food security than a museum, the most promising new varieties are worthless if their seeds and planting materials are not distributed to the growers. By the same token, a seed dissemination mechanism is not viable unless its source of elite varieties is assured by an equally vibrant breeding programme, which in turn relies on the heritable variation housed within germplasm holdings to generate the most suitable varieties. The plant breeding programme on its part must be need-based and demand-driven, i.e. it should, taking advantage of the best science and technologies available, be geared primarily to meet the needs of the growers. Linkages between the seed distribution entities and the plant breeding community will ensure therefore that the breeders' work is driven by the identified needs of the growers which in turn are discernible from the demands of the seed sector. In essence, the three components are mutually enriching and so must be dovetailed into a seamless continuum just as is the case with the private sector plant breeding and seed marketing enterprises especially in developed countries.

The proposed continuum approach mirrors salient elements of the PGRFA management models of Brazil, China and India that have recorded remarkable progress, sometimes at par with the private sector enterprises that breed and market improved crop varieties in food-secure developed nations. The continuum approach also builds upon earlier and ongoing regional and national interventions by several partners to harness PGRFA optimally. For example, the Global Crop Diversity Trust, the International Center for Agricultural Research in the Dry Areas, Bioversity International and national institutions had in 2008 articulated the 'Regional Strategy for the Conservation, Replenishment and Use of Plant Genetic Resources for Food and Agriculture in Central Asia and the Caucasus' to guide the implementation of PGRFA activities until the year 2015 (Global Crop Diversity Trust, 2008).

The concept of a national PGRFA strategy

A national strategy for plant genetic resources for food and agriculture is the plan of action that outlines the scope and direction of a country's result-oriented management of PGRFA in a continuum, i.e. it prescribes the means for linking the conservation of the genetic resources through their sustainable use to the delivery of high-quality seeds and planting materials to the growers. The strategy prescribes the priority activities and their time frames and also identifies the relevant stakeholders. Designed for periodic revision, it is a blueprint that unifies all mechanisms, including research and development activities, legislations, policies and regulations, for harnessing PGRFA into a single overarching framework aimed at attaining clearly defined country-specific goals for crop production and biodiversity conservation.

In essence, the strategy, usually developed in a collaborative manner to ensure the widest ownership and adoption possible, is the reference document for ascertaining the mechanisms for addressing all aspects of the three main components of PGRFA management, in order to have:

(1) easily accessible, adequately conserved and well-characterized germplasm collections;
(2) need-based crop improvement programmes that respond to the identified needs of the growers;
(3) mechanisms for the delivery of high-quality seeds and planting materials of the most suitable varieties to the growers.

The national strategy, by bringing together all the national activities relating to the above three components, therefore provides the overarching framework for linking these three components seamlessly into one uninterrupted PGRFA management continuum.

As a management tool, the strategy provides the basis for developing and implementing policies, streamlining

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and prioritizing activities, identifying relevant stakeholders, leveraging complementarities, and in assigning responsibilities and resources. A cogently articulated national strategy should therefore provide the guiding principle and impetus for the conservation and sustainable use of PGRFA. In general, a national strategy consists of six elements: the measures; governance mechanism; enabling tools; capacity framework; partnerships; monitoring and evaluation.

Importance of a national PGRFA strategy

A comprehensive national PGRFA strategy is a useful means to get the most benefits from PGRFA in the most environmentally and people-friendly way. Predicated on an ecosystem approach, it mainstreams PGRFA management within a country's overall agricultural policy and development agenda in a sustainable manner. This is because it is demand-driven, implemented by the widest range of stakeholders possible, provides the basis for the assignment of inputs and resources to priority activities and is articulated within the context of relevant international instruments, regional agreements, national legislation, and partnerships. It is also very useful for strengthening the linkages between the agricultural and environmental sectors, especially through its prescription of measures for the conservation of agricultural biodiversity, a subset of a country's overall biodiversity inventory. Also, the articulation, adoption and the judicious implementation of the provisions of a national PGRFA strategy ensures consistency of purpose and, vitally important, the much-desired continuity in operations even – as usually happens – with changing governments and functionaries.

The importance of a national PGRFA strategy is also underscored by the several international instruments that contain provisions requiring its development. For instance, the CBD requires that each party 'shall develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity' (United Nations, 1992). Similarly, the GPA identifies the strengthening of national programmes as one of its primary objectives. One of the 20 priority activities of the GPA is the 'building of strong national PGRFA programmes' (FAO, 1996). The second GPA, agreed to at the Thirteenth Regular Session of FAO's Commission on Genetic Resources for Food and Agriculture (FAO, 2011c), contains similar mandates for countries. Also, Articles 5, 6 and 7 of the International Treaty contain clauses that mandate contracting parties not only to conserve and use PGRFA sustainably but also to develop policy instruments to underpin such activities (FAO, 2009a).

Overall, the articulation of a national PGRFA strategy will provide countries readily with the elements to develop policies and plans to meet national objectives for the conservation and use of PGRFA. It also facilitates the coordination of relevant PGRFA activities within the country regionally and internationally, thereby maximizing national benefits from PGRFA (Spillane *et al*., 1999). Ultimately, the greatest utility for the strategy, therefore, is in mainstreaming mechanisms for farmers and end-users to receive the maximum value addition to PGRFA, i.e. high-quality seeds and planting materials of the most suitable crop varieties.

Quite importantly, the use of a strategy in the adoption and implementation of the continuum approach enables a country to identify exactly how it intends to address the three PGRFA management components for its priority crops most effectively and efficiently. In some cases, for instance, it may be more worthwhile to pool resources in the conservation of PGRFA among neighbouring countries. An example is the Plant Genetic Resources Center of the Southern Africa Development Community (SPGRC) located in Lusaka, Zambia and serves as back-up repository of crop germplasm for the 13 member countries. What is critically important is that each element of the strategy be articulated with inputs from the widest stakeholder base possible and adopted by the country's relevant policy makers.

Key steps in the development of a national PGRFA strategy

Spillane *et al.* (1999) identified the development of a national strategy for PGRFA, which conveys a country's shared vision and guiding principles for the conservation and sustainable use of PGRFA, as one of the critical means for attaining a sustainable PGRFA management regimen. The following steps are necessary for developing a national PGRFA strategy:

(1) Assessment of the country's status in the management of PGRFA with regard to:

   (a) national needs and opportunities (including capacities such as infrastructure, human and financial resources) for activities in, and linkages between, the three PGRFA components (conservation, use and dissemination);
   (b) inventory of all relevant activities; initiatives; policy frameworks, including national policies and legislations, memberships of regional and international forums and status with international PGRFA instruments,

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conventions, treaties, etc.; national, regional and global networks;
(c) identification of relevant institutional stakeholders, including different entities from various government ministries or departments, the civil society and the private sector whose mandates are relevant to at least one aspect of the management of PGRFA;
(d) identification of priority crops relevant to food security and/or income generation or enhanced competitiveness based on predetermined criteria;
(e) identification of needs and opportunities, including available resources.

National stakeholder workshop to validate the national assessment through a participatory process. Continued consultations with key stakeholders aimed at identifying emerging challenges and key recommendations towards the design of the national PGRFA strategy. Elaboration of the draft strategy through a participatory process and with the involvement of international specialized consultants. Stakeholder policy dialogue to present and discuss the draft national strategy. Finalization of the national strategy by national and international consultants. High-level meeting to present and formally adopt the national strategy. Continued communication of the national strategy to the widest possible audience and stakeholders

The stakeholders critical to the functioning of a national PGRFA strategy

The typical stakeholders whose buy-in and active participation are critically important for a national PGRFA strategy to function adequately include:

(1) Relevant government ministries and departments (e.g. agriculture, forestry, natural resources, environment, science and technology, planning, finance, trade, research and education).
(2) Local authorities.
(3) Universities, research and other educational institutions, extension services with participation of genebank curators; germplasm users – including plant breeders.
(4) Non-government organizations (NGOs), farmers' organizations, indigenous and local communities, rural women's groups, civil society, religious organizations.
(5) Private sector and parastatal companies, export promotion agencies, etc.
(6) Regional and international organizations, research centres and networks.

Key elements of a national PGRFA strategy

Every national PGRFA strategy is unique, as it is developed to address the particular needs of a country within the context of its peculiar circumstances of goals, needs and available resources. In order to address adequately those needs, the provisions of the strategy must encompass the following elements:

(1) *Measures*. The clear definition and identification of national priorities with regard to PGRFA is essential to developing the requisite set of measures for the result-oriented management of PGRFA as a continuum of activities spanning the conservation of PGRFA; its use both directly by the growers and plant breeders in crop improvement; the delivery of seeds and other planting materials to farmers; and the establishment of effective linkages between these three components of the continuum. Research and development activities and policy frameworks relevant to all aspects of the management of PGRFA are therefore addressed. In defining the measures, the national strategy should also provide the template for resource mobilization, the assignment of roles and responsibilities to the counterpart institutions and entities and also stipulate the time frames for activities. The *measures* adopted within the national strategy should address the following critical requirements for a successful result-oriented management of PGRFA:

(a) *Efficient conservation of PGRFA*. This covers requirements for long-term facilities for maintaining *ex situ* collections including field genebanks for perennial crops and *in vitro* storage for vegetatively propagated crops. The measures should also address mechanisms for the management and monitoring of *in situ* conservation including due attention to crop wild relatives. Measures for ensuring the efficient documentation and retrieval of PGRFA data must also constitute essential elements of a national PGRFA strategy.
(b) *Strengthened linkages between PGR collection holders and users*. Measures must be prescribed to facilitate close collaborations between genebank curators and plant breeders especially with regard to the characterization and evaluation of existing *ex situ* and *in situ* germplasm collections. Pre-breeding

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activities for generating trait-specific populations that could be further used in crop improvement is a practical means for fostering this linkage, for instance. Also, this element of the national strategy, as most aspects of the management of PGRFA, must prescribe mechanisms for mainstreaming the rights of the farmers to access and use PGRFA as well the safeguarding of traditional knowledge as stipulated in Article 9 of the International Treaty (FAO, 2009a).

(c) *Improved utilization of PGRFA to address national crop improvement goals*. Measures to facilitate the development and strengthening of demand-driven plant breeding programmes for the priority crops and which are underpinned by the best possible scientific and technological tools must be enshrined in the strategy. In this regard, partnerships, including public–private sector synergies, must be fostered.

(d) *Strengthened linkages between crop improvement and the seed delivery sectors*. Plant breeding and seed delivery programmes must operate lockstep in order that PGRFA is leveraged effectively to respond adequately to the needs of the growers. Varietal registration and release processes provide an effective means for fostering mutually beneficial synergies for both sectors. A practical means for attaining this is the establishment of crop- or farming system-specific taskforces, networks and associations as a platform for the collaboration between the breeders and seed producers.

(e) *Implementation of national rules and legislations*. An increasing number of countries are now parties to international instruments related to PGRFA, including the Convention on Biological Diversity, the IPPC, the International Union for the Protection of New Varieties of Plants, the Cartagena Protocol on Biosafety, and the International Treaty on Plant Genetic Resources for Food and Agriculture. To meet their international obligations, countries should adopt national regulations and policies that cover seed laws, varietal registration and release, intellectual property regimes, farmers' rights, access and benefit sharing, nature reserves, biosafety frameworks, etc.

(f) *Increasing public awareness*. An enhanced level of the perceptions of ownership is critically important for the successful, sustainable and result-oriented management of PGRFA. In this regard, the institutionalization of measures for creating awareness through appropriate media on the values and value addition implicit in the conservation and sustainable use of PGRFA is sacrosanct.

(2) *Governance of the national PGRFA strategy*. The establishment of a high-level coordinating committee dedicated to PGRFA management at the national level is an imperative. The constitution of the high-level committee must be reflective of the country's needs and goals. Typically, such a committee would be established at the highest levels with representatives designated by each of the key stakeholders which may include the Ministries (or equivalent cabinet-level designations) of Agriculture, Natural Resources, Science and Technology, Commerce, Education, etc. Representatives of indigenous and local communities, farmers' organizations, the private sector, civil society, and other interest groups would typically be part of this committee. National Academies of Science, Culture and Heritage, etc. may also be represented as need be. The main task of this committee is the coordination of, and oversight over, the implementation of all PGRFA-related activities. Its responsibilities could include development and periodic updating of the national strategy on PGRFA, setting priorities, allocating budgets, driving advocacy for national support, facilitating collaborations and partnerships, etc. Regional and international organizations may also participate in this committee in advisory and mentoring capacities.

This committee, with overall responsibility and accountability, would operate through a series of specific networks, task forces and consortia mandated with legal, policy, technical and economic issues as appropriate in the most transparent and collaborative manner. Convenient yardsticks for delineating these subsidiary arms with clearly defined oversight roles may be agroecological affinities and, hence, farming systems. Subsidiary coordination hubs may also be created on a single crop basis or on the basis of similarities between crops, e.g. fruit trees, legumes, cereals, root and tubers, oil crops, bioenergy crops, etc. The committees may also be thematic and therefore delineated according to national programmes, e.g. for biosafety, biotechnology, biofuel, conservation of genetic resources, crop improvement, seed systems services, etc. These subsidiary networks and taskforces are necessary for the enhanced efficiency that would arise from the decentralization of activities and decision-making processes.

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Whatever steps are taken to partition coordinating roles to more homogeneous entities, every care must be taken to ensure the participation of farmers and end-users and the civil society; this is important for enriching the deliberations and priority setting with need- and evidence-based perspectives including those deriving from indigenous and traditional knowledge. These are important for ensuring the buy-in of the widest stakeholder base possible. The use of networks, task forces and consortia or similar communities of practice also facilitates the National Coordinating Committee's task of monitoring and implementation and assessing impacts.

(3) *Tools*. The FAO and partners have over time developed several tools to aid countries in the achievement of the greatest benefits from the conservation and sustainable use of PGRFA. These include the guidelines and myriad instruments whose frameworks provide the basis for developing national programmes on PGRFA. A national PGRFA strategy is premised on the management of PGRFA as a continuum of interlocked interventions and therefore requires a set of tools that can be accessed for addressing the full range of management components: conservation; exchange of local varieties among farmers; genetic improvement through the application of the full range of techniques and tools, e.g. farmer participatory breeding, molecular breeding, multidisciplinary approaches and comprehensive information management; the effective delivery of the seeds and planting materials of suitable crop varieties. A good example of a relevant tool is the Global Plan of Action for the Conservation and Sustainable Use of PGRFA (FAO, 1996), which stipulates a wide-ranging set of interventions for different aspects of the management of PGRFA. Additionally, the provisions of the IPPC (FAO, 1997), the Convention on Biodiversity (UN, 1992), the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2009), etc. serve as references for developing national PGRFA strategies.

(4) *Enabling capacities*. Capacities for managing the complexities of the spectrum of activities covered under the national PGRFA strategy including the sustenance of the involvement of, and synergies between, key stakeholders – from the public and private sectors and the civil society – are vitally important. The four functional capacities that underpin the FAO's capacity development framework (http://www.fao.org/capacitydevelopment/fao-capacity-development-framework/en/; FAO 2011d), for instance, are especially relevant to the planning, development, adoption, implementation and sustenance of this concept of a national PGRFA strategy that is overarching. These functional capacities that are required for a result-oriented national PGRFA strategy to drive the management of all aspects of PGRFA in a country are:

(a) *policy and normative* capacities in order to formulate and implement policies and lead policy reform;
(b) *knowledge* capacities so as to be able to access, generate, manage and exchange information and knowledge;
(c) *partnerships* capacities to enable the engagement in networks, alliances and partnerships;
(d) *management* capacities so as to implement and deliver programmes and projects, from planning to monitoring and evaluation.

Quite importantly also, the requisite technical capacities would include the scientific and technological know-how and the facilities and infrastructure needed for:

(a) conserving germplasm in manners that permits access to, and deployment of, the heritable variations housed in the gene pool;
(b) fostering linkages between germplasm conservation and crop improvement;
(c) demand-driven plant breeding programmes that respond adequately to the needs of the growers;
(d) fostering linkages between crop improvement and the delivery of high-quality seeds and planting materials of suitable crop varieties;
(e) efficient seed systems that enable access of the growers at reasonable costs to the seeds and planting materials of suitable crop varieties.

It is therefore essential to be cognizant of the required capacities and to develop, strengthen and upgrade them continually. Regular updating of the required skills of personnel in relevant disciplines and the upgrade of infrastructure should therefore form part of the research and development culture of the national programme on PGRFA. The interventions aimed at developing and sustaining capacities are therefore multi-faceted and applicable to the overarching enabling policy environment, to the stakeholder institutions and even to the individual functionaries.

(5) *Partnerships needed for effective PGRFA management*. An efficient overarching national strategy should encompass all PGRFA activities from conservation

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through use to the delivery of seeds and planting materials of the most suitable varieties to farmers. This broad scope of activities is carried out by a considerable number of stakeholders, including public institutions, private commercial enterprises, NGOs, farmer cooperatives, indigenous and local communities and individuals from the agricultural, scientific, educational, environment and research and development sectors. The integration of such different PGRFA activities into one unified framework of a national strategy provides the opportunity to add value to these diverse efforts, pool resources and enhance efficiencies through the strategic promotion of mutually beneficial synergies. As such, the success of a national strategy requires strong partnerships, cooperation and communication among all PGRFA stakeholders. It is imperative therefore that those cross-sectoral linkages be forged especially between stakeholders involved in agriculture and those whose mandates address biodiversity conservation with an environmental protection perspective. Partners from the commerce and industry sectors also have key roles to play especially in order to cover aspects of the PGRFA value chain relating to post-harvest and markets.

The winning synergies being advocated should include fairly complex multi-country international and regional partnerships and, within the country, should range from the straightforward inter-ministerial, inter-departmental and cross-sectoral collaborations to the much simpler synergistic relationships that govern inter-institutional and community-level interactions. The national strategy should therefore provide for mechanisms to facilitate this multi-tiered synergistic management of PGRFA.

(6) *Monitoring and evaluation*. A national strategy needs not only committed action and dedicated human and material resources for its implementation but should also be periodically adjusted to address changing needs and priorities as necessary. A national strategy should therefore identify the indicators and prescribe a monitoring system to measure the progress made in its implementation as well as a mechanism to adjust its priorities and measures as the evolving national needs may dictate.

A national PGRFA strategy is considered an all embracing prescriptive document that outlines a country's vision, prioritized actionable plans, time frames, resources, partnerships and roles needed to attain an efficient conservation of PGRFA and its sustainable use. The strategy, through its prescription of measures, provides the framework for devising enabling policies and legislations. The development of the strategy, which in essence is a visioning document, does not therefore obviate the need for policies, laws and regulations required to put those visions into practice. Also, the strategy should not be seen as an isolated instrument but rather as a template that fits into the overall agricultural development plans of a country; in this regard, it should be amenable to cross-sectoral synergies with the overall aim of coalescing the different sectors towards the common aim of attaining a country's food security and biodiversity conservation goals.

Advantages of the strategic management of PGRFA

By unifying all of a country's PGRFA-related activities into an uninterrupted continuum that is underpinned by clearly enunciated measures that are implemented under a single overarching strategic framework, the following advantages are accruable:

(1) Overall enhanced efficiency in the efficient conservation and sustainable use of PGRFA to attain food security and address other agricultural development goals.
(2) Clearly articulated guidelines facilitate the most cohesive linkages between research and development for conservation of germplasm and crop improvement, extension services and seed delivery systems.
(3) The prioritization of activities and the optimal assignment of resources leads to implementation of activities at scale and prevents the inefficient fragmented and piecemeal activities that are often unrelated to priority goals.
(4) The most suitable crop varieties that respond to the identified needs of the growers and end-users, including for sustainable production intensification regimens, are produced in the most efficient manner by taking advantage of the most appropriate sources of heritable variations.
(5) Increased access to high-quality seeds and planting materials by farmers as the growers' and end-user perspectives dictate the breeding objectives.
(6) As a single comprehensive visioning document, the strategy avails the policy makers a 'one-stop shop' platform for the definition of development goals, evidence-based prioritization of activities, assignment of resources, alignment of activities to international norms and the enhanced leveraging of both domestic synergies and external partnerships to achieve sustained agricultural development and biodiversity conservation goals.

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Discussion

Unprecedented pressures from diverse drivers imperil global food security and demand mitigating interventions of considerable magnitudes. For instance, the recurring spikes in prices of food commodities and the accompanying civil strife in many parts of the world are emblematic of a worsening global food security outlook that is all but certain to fall short of the milestone of the MDGs. It is imperative that more food of adequate quantity and quality is produced at hitherto unattained annual incremental rates in order to feed the expected human population of over 9 billion in less than 40 years. This daunting task is made even more difficult by the inelasticity of arable lands and water resources; indeed, these resources are dwindling in many parts of the world. This implies therefore that there is not much scope for expanding the areas under cultivation or indeed for injecting more inputs into agriculture without incurring irreparable damage to the planet Earth. A resource that remains largely untapped – even as it is being lost due to neglect – is plant genetic resources. The best possible scientific and technological tools should be brought to bear upon the unlocking of the hidden potentials of PGRFA including the non-adapted genetic materials – such as landraces and wild relatives of cultivated plants. These historical progenitors of the plant species grown for food today represent veritable troves of heritable variations that can be harnessed to develop 'smart' crops that will yield more with even less inputs; this is critically important for attaining the unprecedented increases in food production required to ensure global food security while safeguarding the environment. Increased crop productivity under ecosystem-based approaches holds the key for stemming food insecurity that threatens global stability, therefore. There is considerable urgency, therefore, to harness PGRFA in manners that unleash the full repertoire of potentials encoded in their heritable blueprints in order to produce more food efficiently.

Maximizing this sought-after benefit from PGRFA will require a comprehensive reorientation of crop improvement programmes and that of the intrinsically interrelated conservation of PGRFA and the delivery of the seeds and planting materials of improved crop varieties to the growers. This reorientation, aiming ultimately at the mainstreaming of best practices, should be predicated upon a need-based, demand-driven and responsive crop improvement programme, being the primer for germplasm conservation. Equally, a functional seed delivery sector must be in place to ensure that the improved crop varieties, which respond adequately to the needs of the growers, are disseminated efficiently. Interventions must target these three aspects of PGR management in tandem; sadly, this has not been the case. Spillane *et al.* (1999) identified the existence of a national PGRFA focal point, committee and strategic plan as being important for the attainment of efficiency in the conservation and sustainable use of PGRFA. The FAO's tasks in facilitating this reorientation will benefit greatly from relevant actionable policy items that are packaged for mainstreaming in member countries. Prior piecemeal efforts have led to the development of genebank standards for many crops, for instance. Equally, national seed policies are being developed by a number of countries.

In advocating the seamless dovetailing of national PGRFA activities into a single uninterrupted continuum, we recognize the inherent difficulties and peculiarities that constrain the effectiveness of many national programmes. Suboptimal research and development capacities are still prevalent; policy environments are weak while the modular approaches fostered over several decades of national and donor agency funding profiles prevent effective collaborations across institutions and organizations. Daunting also is the challenge of overcoming the multifarious hurdles to the building and leveraging of the appropriate scientific and technological skill sets and knowledge base needed to harness PGRFA adequately. Granted, there have been significant gains in countries in acquiring the requisite scientific and technological capacities for managing PGRFA but such gains are far from becoming the norm. Even where the skills exist, significant institutional rearrangements are needed for the outputs of the scientific endeavours to take root.

These scenarios of inadequate capacity levels call therefore for the imperative of redesigning the management of PGRFA at the national, regional and global levels. The abilities of countries to take advantage of the novel powerful tools of molecular biology and the more recent phenomics, for instance, in dissecting complex traits and mining germplasm for novel traits must be strengthened. Additionally, in applying the prevailing intellectual property right regimes that curtail access to plant germplasm and technologies, the imperative of generating public goods must always be borne in mind. Mindful of the foregoing compelling needs, their associated challenges and the peculiarities evident across countries, especially the suboptimal capacities for adding value to PGRFA in a sustainable manner, the large-scale adoption of the model of the multi-stakeholder platform, GIPB, deserves serious consideration. Convened primarily to address the declining capacity for crop improvement, a major hindrance to the implementation of Article 6 of the International Treaty that deals with the sustainable use of PGRFA, GIPB provides an example of an innovative coalition with the potentials for supporting requisite capacity enhancements for the overall management of PGRFA especially in developing countries. The inadequate

levels of capacity are evidenced in the generally low numbers of plant breeders and very weak or, even commonly, the absence of meaningful breeding programmes for a number of food security crops as uncovered through GIPB's surveys of over 80 countries for capacities to manage PGRFA (GIPB, 2011). Most critical in developing countries, this depleted institutional and human capacity portends dire negative consequences for optimizing the management of PGRFA and hence food security. GIPB's intervention mechanism has been characterized by benchmarking through comprehensive need assessment and the follow-through capacity building in scientific and technological skills. Equally prominent in the platform's activities has been the provision of enabling policy environments; these are innovative, deserving of increased support and provide a model for scaling up.

A missing critical lever in the current overall efforts to optimize the harnessing of PGRFA is the assemblage of the body of knowledge to constitute the suite of best practices that enable a result-based crop improvement programme underpinned by appropriate innovations and which dovetail seamlessly with germplasm conservation and the seed sector. Such a suite of interventions, packaged in a manner that permits ready adaptation to fit into specific country needs, will contribute greatly to the current efforts by myriad development partners to rethink agricultural development, including crop production, in the face of significantly strong drivers for food insecurity. A means for redressing this lack of a critical capacity enhancement resource could be the convening of an expert consultative forum which synthesizes the best practices that are in turn translated into policy elements and subsequently disseminated to countries in ways that guarantee significant buy-in and adoption. In parallel, the GIPB multi-stakeholder platform is also partnering with the International Treaty to develop a Toolbox for the Sustainable Use of PGRFA to serve as a 'one-stop-shop' for accessing information, technical know-how, tools, guidelines, policies, partnerships, etc. required for need-based value addition to PGRFA to generate the most suitable crop varieties in countries. An overarching national PGRFA strategy is therefore needed for situating the outputs of these and similar initiatives so as to, quite importantly, provide the framework for managing all aspects of PGRFA activities in order to ensure consistency in the investments of efforts towards developing the 'smart' crop varieties that will contribute to addressing the current generational challenges to food security. Globally, the International Treaty and the GPA especially provide frameworks for action. Being, however, that many countries have remained incapable of implementing the provisions of these instruments, efforts must be invested in capacity building at the national levels. Without such requisite capacity, the goals of the international frameworks will remain unattained and constrain the actualization of the vision of PGRFA as global commonwealth.

It is postulated that the mainstreaming of the continuum, facilitated by widely adopted and implemented national PGRFA strategies, will lead to robust demand-driven use of PGRFA to develop and disseminate crop varieties. The aim in this is to mirror the situation in developed countries where plant breeding and seed delivery activities are organically bound together in the same organizations. In these countries, it is becoming commonplace for a profit-oriented private sector entity to assume the dual roles of the plant breeder and seed distributor. As efficient as the private sector may be in this regard, it could never fully replace the public sector as the scope of the former's activities will always be circumscribed by considerations of the profit margins attainable. The management of the PGRFA of food security crops in many developing countries, which *ab initio* do not have well-developed economies, is not sufficiently lucrative to attract the private sector investments and will therefore for the foreseeable future remain the exclusive purview of the public sector. Capacity enhancements and the development of the nurturing environments to carry on the tasks of PGRFA management need therefore to continue to receive adequate attention from policy makers. The models deserving emulation for developing countries include the Brazilian Agricultural Research Corporation (Embrapa, its Portuguese acronym), the Chinese Academy of Agricultural Sciences (CAAS) and the Indian Council of Agricultural Research (ICAR) that all have institutional mechanisms of PGRFA management that strategically match germplasm conservation with value addition in crop improvement and ultimately the delivery of seeds and planting materials to the end-users. The success stories of Embrapa, CAAS and ICAR can be replicated in many developing countries as the international community strives to situate PGRFA management within the nexus of interventions for enhancing crop productivities.

The international community's roles in the redesign of the management of PGRFA to be more result-oriented will include both institutional and human capacity building and the removal or reduction of the several obstacles to reasonable access to PGRFA and the requisite scientific and technological tools. Countries will need assistance in training a new generation of PGRFA specialists and in developing the enabling policy frameworks. Also, barriers posed by stringent intellectual property rights over efficiency-enhancing biotechnological tools, especially in relation to recombinant DNA technologies, will need addressing, for instance. The international community's assistance will also be crucial in enabling countries

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to build up the partnerships needed for addressing at scale all the aspects of the PGRFA value chain. It is therefore important to allocate resources for building the enabling policy and strategic environments for the outputs of the considerable resurgent funding of R&D to thrive and contribute meaningfully to enhanced crop productivities and hence, improved food security.

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