

Structure of a plant breeding programme

This section covers the steps in a (formal) breeding programme, from priority setting to production of a cultivar. As indicated, PPB as a concept itself is a product of the historical separation of farmers from breeding and then efforts at selective reintegration into an externally developed and controlled structure. However, even for a less structured programme, it can help us to see what different stages there may be and what may require consideration when starting off on a systematic, deliberate crop improvement or breeding programme. This section briefly touches on biodiversity conservation and maintenance for a diverse genetic base, and issues related to multiplication and dissemination of cultivars. These activities are interconnected with plant breeding/crop improvement, but are also fields of study in and of themselves. For the purposes of this paper we mainly consider points of direct relation with the breeding/crop improvement process.

Links between biodiversity conservation/maintenance and crop improvement

Biodiversity conservation and maintenance, use and variety improvement/enhancement are intertwined. Plant breeding/crop improvement depends on a wide base of genetic variability to work with, and there may be a need to build up this base. PPB may play an important role, both in contributing to widening biodiversity in a locality, and as an activity that follows on from conservation and maintenance. This reinforces the reality of ongoing, cyclical, rather than linear, processes of conserving, maintaining and enhancing genetic materials.

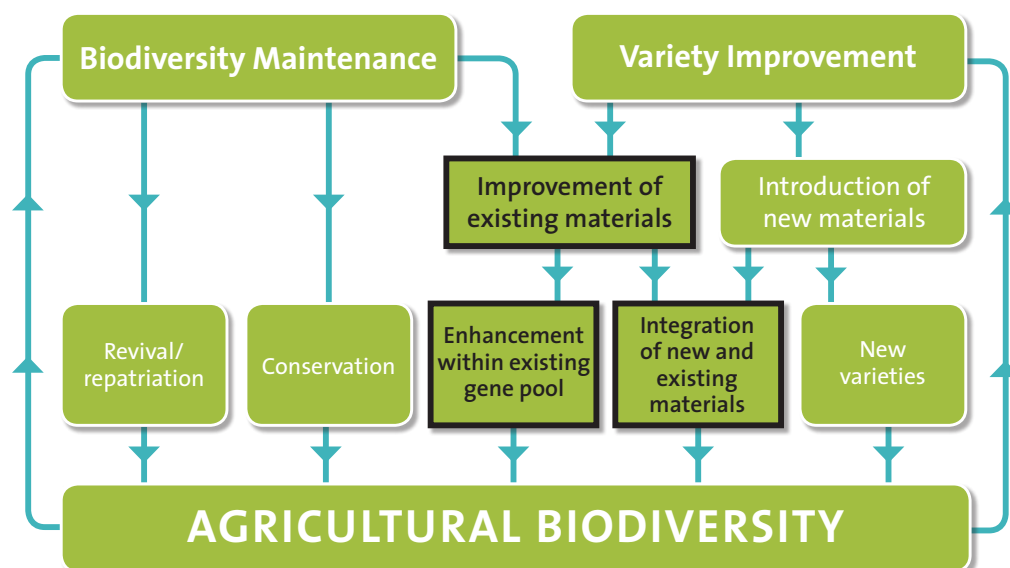
The objective of biodiversity conservation, maintenance and enhancement is a base of flourishing agricultural biodiversity. There are various sources of material that contribute to this diverse base (Figure 2). These include maintenance and enhancement within the existing gene pool, mixing of new and existing materials, and introduction of

finished new varieties. The focus of this paper is on improvement/enhancement of existing materials, both from within the locally available gene pool, as well as mixing of materials from the existing gene pool with introduced materials. The static preservation of crop diversity in ex situ gene banks is not a sustainable conservation approach. Seed continually needs to be exposed to dynamic local conditions and preferences in order to adapt. Crops are continually subjected to natural and farmer selection (Meldrum, 2013:98). National gene banks will have some local varieties but accession may be long ago and local varieties will have adapted to dynamic local conditions in the meantime. If gene bank material is not reproduced in real conditions, it is in danger of becoming sterile and useless.

For the purposes of this paper, revival and repatriation are considered to be elements of maintenance and conservation of the existing gene pool. Revival refers to the rescue of seed that is still in local use but only in small pockets or by few people, and where use is declining. This is especially the case for local varieties that are remembered as good varieties for specific characteristics but have been displaced over time. Repatriation is the process of reintroduction of materials from gene banks that came from a locality but have fallen out of use there.

Conservation, maintenance and use are required to prevent existing agricultural varieties from degenerating through exhaustion and lack of evolution. This may occur where the genetic base for a particular crop gets too narrow. There is some urgency to the issue because traditional/indigenous varieties are being lost at a rapid pace, especially in the industrial era (Fowler and Mooney, 1990). "Continued cultivation of traditional crops, landraces, indigenous and heirloom varieties, which together represent the majority of the world's crop diversity, is essential to prevent their disappearance" (Meldrum, 2013:97–98).

An example of this is work on 'grassroots breeding' in Nepal. Here the focus is on rescue, identifying and spreading traditional and local varieties in danger of being lost, to increase diversity, especially for poorer farmers who may not know about these

Figure 2: Biodiversity maintenance and variety improvement

Source: Based on Almekinders and Louwaars, 1999

varieties. This may be cost effective and widen agricultural biodiversity, including amongst poorer households (Sthapit and Ramanatha Rao, 2007). Although the immediate focus is on spreading diversity without immediate action on improving/ enhancing the materials, the 'mere' use of rescued varieties and on-farm experimentation and adaptation shade into one another in practice. Rescued varieties are integrated into farming systems over time, as the new materials mix with existing varieties and farmers select seed from season to season (Sthapit and Ramanatha Rao, 2007). Institutionally, grassroots breeding is primarily driven by farmers, with no major role for extension, ARIs, etc. (Sthapit and Ramanatha Rao, 2007). This places it in the farmer-led mode of participation.

Grassroots breeding focuses on two basic breeding steps: participatory pre-breeding efforts (locating, assessing, multiplying and making germplasm available); and enhancing germplasm through simple selection, healthy seed production and deployment of seed through social networks. Without going into detail here, key methodologies are diversity fairs; community and household seed banks; in situ, living gene banks, with diverse materials that farmers can draw from as and when needed; and support for diversity in home gardens (Vernooy, 2003; Rios Labrada, 2005; Sthapit et al., 2012). Seed banks can be

used to hold varieties for ongoing sharing and use. They overcome the 'tragedy of the commons', where everyone assumes someone else is retaining a variety but actually no one is (Sthapit and Ramanatha Rao, 2007).

At the other end of the biodiversity spectrum is the introduction of entirely new varieties. This can add to biodiversity, although there may be cases where some materials replace others over time, which can (but does not necessarily) lead to loss of biodiversity. There may be concern at times with the displacement of many local varieties with few 'improved' varieties coming from the formal plant breeding system. Introduction of new materials should, therefore, be undertaken with caution (Sthapit and Ramanatha Rao, 2007). Fieldwork conducted by ACB and our partners in Southern Africa indicates that smallholder farmers seek both to retain diverse existing varieties and also to have access to new varieties appropriate to their contexts. A balance is required to ensure existing varieties and materials don't entirely fall out of use, thereby reducing choice available to farmers in difficult and changing production conditions.

Another way in which new materials may be introduced is through integration of wild plants into cultivation systems. This is an ongoing activity, especially by women,

with home/kitchen gardens as key sites for integration of wild/indigenous crops into agricultural systems for food and medicine. These can be considered to be indigenous experimental stations and gene banks. Home gardens contain many semi-domesticated species transplanted from the wild. Experimentation, especially with fruit trees and local foods, is inherently decentralised and embraces the evolutionary components of biodiversity. These activities highlight local level innovation/creativity, reproducing not only the genetic material but also the knowledge about its reproduction and use (Sthapit et al., 2012). Agricultural biodiversity should, therefore, not be separated from wider biodiversity and its maintenance and conservation.



Simultaneously with securing a diverse base of locally managed genetic material, farmers may want to improve or enhance the qualities of genetic material available to them. The focus of this paper sits between conservation and maintenance of the existing genetic base and introduction of entirely new materials, as highlighted in Figure 2. This includes enhancement of genetic materials already available to farmers, as well as enhancement through mixing of existing and introduced materials. Formal sector breeders may be able to assist in both of these.

Stages in a plant breeding programme

This section goes through the main stages in a plant breeding programme. This is based on the structure of a formal programme but identifies key considerations for plant

breeding/crop improvement activities even in less formal contexts.

After this, if the objective is not sale of cultivars, enhanced materials are distributed to farmers to use. If the objective is sale on a commercial scale, varieties must go through a number of additional steps once the final cultivar is developed (detailed below). Intellectual property (IP) issues arise around ownership on the germplasm used as source material, as well as registration and ownership of varieties developed through the process. These are dealt with in the relevant sections below.

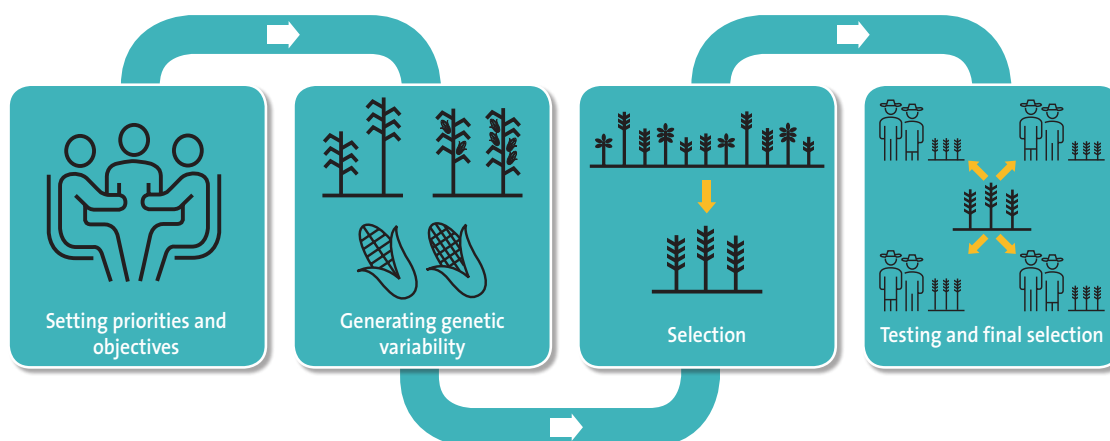
Setting priorities and objectives

The first step is to set the priorities and objectives of the programme. Priority setting needs to consider: goals (specific, not too complex); target groups and target environments (the production conditions under which new varieties should perform better than existing cultivars); the specific needs of the target group of farmers (and potentially other users); priority traits to be used for selection criteria; appropriate choice of germplasm base; variety type that is best suited for objectives; intra-varietal diversity requirements; and key roles and responsibilities of partners.

What will be done?

In the context of limited time and resources, it is necessary to prioritise. The question is how to find out what the priorities are, which could be done in a top down/external or bottom up manner, or some combination of the two. Because PPB involves interactions with the formal system, it will generally be a combination of some sort. Whatever the extent of farmer involvement, the first step in a breeding programme is to define what the priorities are in particular contexts. Priorities can arise from many places, such as industrial processing needs, farmers' specific production and consumption needs, other end user needs, or from the researchers themselves, based on their work to date. Setting priorities may best be considered as an iterative and progressive process that occurs throughout the breeding programme, because options may emerge in the course of the research (Weltzien and Christinck, 2009:79).

Figure 3: Main stages in a plant breeding programme



(Adapted from Ceccarelli, 2009:64)

A standard breeding programme can take anywhere from 3 to 13 years, depending on the objectives. The norm is 8–10 years for a full cycle following all the procedures.

Farmers' active participation in setting priorities and objectives is one of the key features of PPB. There can be no PPB without direct and active farmer engagement in establishing priorities for breeding, including identification of priority traits. A key issue in identifying priorities and objectives is the locus of control of decision-making about the objectives of the plant breeding and the kinds of results and data required to support these (Sperling et al., 2001). A wide range of participatory methodologies have been developed over the years, both to inform farmers about the topic and elicit interest, as well as to identify priority crops and traits for breeding purposes (Action Aid, 1996; Chambers, 1997, on participatory action research methods; Sthapit et al., 2012; Trouche et al., 2012; Otieno, 2016, on participatory identification of priorities on seed).

Selection of methodologies will be shaped by the broad needs, for example, whether availability, access, diversity or quality are key issues facing farmers in a particular context (Sthapit and Ramanatha Rao, 2007). Issues to be discussed will include: varietal preferences, plant types or desired traits to be maintained or introduced; trade-offs farmers are willing to make between characteristics in designing the ideotype; which characteristics are most important to farmers and why; and the range of acceptability within a characteristic (for example, stem height, length of cycle) (Gabriel et al., 2004). There will usually be a

large number and diversity of desired traits (Gibson et al., 2011).

A review of experience (detailed below) indicates that farmers generally prefer a bundle of traits, rather than an emphasis on a single trait. Increasing productivity and yield is usually a key goal of breeding programmes. However, there are other objectives, including improvements to organoleptic traits (having to do with the senses, for example, taste, colour, texture), storability, processing and other characteristics. Simple breeding strategies, such as improving yield by increasing the ratio of the edible part of the plant at the expense of other plant organs (foliage, roots) do not generally work under conditions where 'minor' characteristics may be related to environmental adaptation, or non-edible plant parts may have a high value in particular situations (for example, biomass for animal feed) (Weltzien and Christinck, 2009:76–77). Trade-offs will, thus, also be required in the technical sphere.

Goals are the guiding principles for priority setting. A situation analysis should precede the definition of goals. This analysis will include details of the production environment, including existing varieties and how farmers use them; anticipated changes and farmers' needs; preferences and relevant resources (for example, local knowledge, skills and germplasm); and major constraints to production increases and income generation.

Participatory methods can be used to carry out this situation analysis (Weltzien and Christinck, 2009:80–81).

Apart from instrumental outcomes/product goals, overall objectives may also include process goals, such as farmer empowerment through increasing technical skill, knowledge, and shifting power relations towards farmers in the breeding/crop improvement process. Another objective may be making breeding programmes more cost-efficient, particularly through decentralisation, targeting niches. Yet other goals may include conservation of local diversity, policy and regulatory changes, increasing research efficiency, or benefits to specific users (Weltzien and Christinck, 2009:79). It will be helpful to set measurable indicators for monitoring (see Sperling et al., 2001:445–446 for suggestions). In the context of resource and time limits, trade-offs in goals will be required.

Goals and objectives are not set in a vacuum. Practical and technical considerations must be taken into account. For example, the programme will need to decide whether to go for broad or narrow adaptation, that is, populations that perform well under a wide range of conditions, or different cultivars for different conditions. Setting breeding goals is a recurring activity and must include variety type, farmer preferences and end user needs (for example, millers and consumers) (Smolders 2006:24), as well as an assessment of the potential and limitations of available breeding materials (Gyawali et al., 2010:70).

This stage of defining objectives may also include defining and developing quality controls as required. If objectives include the official release of a variety, formal quality control procedures as spelled out in laws and regulations will need to be followed. But even where the objective is only to produce enhanced materials for local use, quality controls will be used throughout the process and these should be developed up front. Formal researchers/technicians can assist in identifying key control points. Training/skills development may be required throughout the process, including organisation, farmer-to-farmer methods, genetic resources management, and technical/breeding. These will need to be structured into planning at the beginning.

Who and where?

There is always the question of who initiates the process. Ideally, farmers would approach researchers with a request for assistance and support. This is a farmer-led, demand-driven approach. However, in reality, entry points to the formal system are few, research institutes and universities are physically distant from farmers, and many farmers are not organised and do not have sufficient information. Farmers may be unaware of possible forms of support from the public sector and other research institutions. The ruling ideology is that what smallholder farmers do with regard to seed is inferior and obsolete. Farmers themselves may not value this work, having absorbed these ideas. There may be need for externally initiated interaction to bring these dimensions of seed to the surface, to raise awareness that the seed and knowledge farmers have are valuable assets and should be protected and supported as the foundation of an indigenous economy.

Smallholder farmers are part of the broader society and play a central and critical stewardship role for biodiversity that all humanity is dependent on. This specifically applies to smallholder farmers, since large-scale commercial farming is based on a mono-cropping model of planting the same thing across large areas. The biodiversity in areas of production is, consequently, extremely low. As commercial production systems encroach on diverse agro-ecological systems, they reduce and push biodiversity to the margins. This is the same biodiversity that commercial breeders rely on to produce constant remixes. Corporate-sponsored digitisation and dematerialisation of genetic information seek to eliminate dependence on this genetic diversity tended outside corporate control. Farmers may not be aware of these dynamics.

In practice, it is very difficult for farmers to initiate work directly with breeders, without facilitation to link the two. Public sector extension services exist, but are denuded and reactive, rather than proactive. Structural adjustment programmes and neoliberal policies have removed resources from public sector extension. These services are increasingly replaced with closed private sector services for particular commodities or projects, tailored to the specific needs of



the project but closed to other participants. These are invariably commercial projects where seed development is driven by profitability interests. They also focus attention in higher potential production areas, leading to marginalisation of areas with lower commercial productive potential, which are nevertheless still areas in which significant production takes place outside formal commercial markets. The many smallholder farmers in these areas will not receive meaningful extension services and will find it more difficult to engage with the formal sector, even if they choose to.

The role of farmer associations and NGOs is important in organising farmers and in widening farmer networks, with links to formal breeders and other organisations. Good farmer associations and NGOs will have a history of working with farmers at field level. Ongoing engagements between these organisations and farmers may result in the identification of farmer interest in work on breeding/crop improvement. Otherwise, we can anticipate that PPB programmes will be initiated from outside, by breeders.

‘Smallholder farmers’ is not a uniform category anywhere in the world, and, within

the category, there are class and gender dimensions, in particular. Ethnic, and, in some instances (like South Africa), racial divisions affect access to resources and opportunities. At ‘community’ level, people belong to different social groups, even when they are working under similar agro-ecological conditions. They may have different requirements for seeds and varieties, so there is a question about which farmers are brought into participatory programmes and how they are identified (Weltzien and Christinck, 2009:81–82). Evidence from case studies shown below indicates women tend not to be actively involved in PPB programmes, even though they are the main custodians of seed.

In a formal PPB programme, farmers do not define priorities in isolation, but together with breeders and extension and technical support services; other users, including individual consumers, vendors and other commercial buyers; and rural co-operatives (Sperling et al., 2001:439). Even PPB that does not seek the registration of a new variety on a formal list can involve multiple stakeholders, including consumers (of both seed and the agricultural products arising from the seed). This allows consumers to also

have a say in shaping the variety to meet their requirements. Again, ideally this will involve collective consumer organisations.

Close interaction, exchange visits and joint planning workshops held at the sites of the different partners (for example, research station, village, trading place) are important for achieving mutual understanding of different partners' perspectives. These may alter in the research process. It is also important for partners to understand that breeding is just one process and is not the cure-all for all issues (Weltzien and Christinck, 2009:79–80). As indicated, breeding is situated as part of a wider process of biodiversity conservation and maintenance, seed production and dissemination, and is integrated into wider agro-food systems, from local to global. These, in turn, are located in wider financial, ecosystem and demographic dynamics.



According to Ceccarelli (2009a:218) institutionalising PPB (that is, mainstreaming and scaling up) should be one of the main objectives when setting up a participatory breeding programme. Institutionalisation is needed because PPB is a long-term process that ultimately needs to link to public sector programming to be sustainable (Hardon et al., 2005; Aguilar-Espinoza, 2007). This is because it is very unlikely that individual, small-scale PPB projects, even though very successful at local level, will ever determine impact at national level. This constitutes a limit to progressive food movement strategies limited to individual projects.

Restrictive IP laws constitute a significant obstacle to government participation and upscaling. Changes in the organisation and execution of national breeding and extension will be required (Hardon et al., 2005). PPB can be an inherently political process, starting with a technical intervention, which is, in itself, political, in terms of opening opportunities for farmer empowerment/organisation and for making policy interventions (Hardon et al., 2005).

Skills and knowledge sharing is an important part of PPB. Farmers may require additional information, knowledge and skills, but they also bring these into a breeding programme. The process may be better understood as mutual learning and sharing, recognising farmers as active contributors to the processes. Sharing skills and knowledge is of value if done in partnership; especially technical and formal research methods. In some cases, permanent technical assistance to farmers may be needed, especially in the early stages of the breeding process but also in the later stages (Gabriel et al., 2004).

Generating genetic variability and sources of germplasm

A plant population needs genetic variation and diversity, otherwise it will not continue to evolve. Genetic variation is introduced through natural mutation; introgression (naturally occurring cross-pollination) from wild or weedy relatives; the physical mixing of seeds from other varieties; and hybridisation with other varieties (deliberate cross-pollination between stable parents) (Almekinders and Louwaars, 1999:4–5). There are dynamic, constantly evolving processes between the local gene pool, farmers' practices and the environment. Genetic variation and diversity require deliberate maintenance of the gene pool (Almekinders and Louwaars, 1999:6). Materials from outside can be introduced in the form of germplasm (unfixed varieties) that can be mixed with local varieties in a deliberate process of variety improvement. Sources of this material could be from other farmers or from the formal system.

An important source of parent material is farmer germplasm. In the formal system, farmer involvement in the collection of varieties ends with germplasm going to

BOX 3: Germplasm ownership and access

There may be ownership rights on genetic materials used in PPB. In most cases, materials come from farmers and from public sector and CGIAR collections. In most of these cases, where IP rights exist, these are waived. However, there are still rules and procedures on accessing these materials, and on benefit sharing, if improvements are commercialised.

The germplasm introduced through the formal system is governed by international and national policies, laws and regulations on ownership and use of materials. For signatories, there are obligations related to the legally binding international agreements concerning germplasm, in particular the Convention on Biological Diversity (CBD) and its Nagoya Protocol, and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). Being a signatory to these agreements also implies having or creating national procedures for effective implementation (Vernooy et al., 2016a). Some countries are not members and then rules differ from place to place. In some cases, germplasm may be fairly easily exchanged through farmer-to-farmer means, including community seed bank networks. These are often 'exempt' from (not regulated by) national access and benefit sharing laws. Elsewhere, international and national laws must be followed to access materials, especially from the formal system. This applies to materials from CGIAR, national gene banks, ARIs and commercial breeders/seed companies.

The CBD encourages bilateral negotiation on access and benefit sharing. Terms of access must be written in a contract, with national state mechanisms for tracking, monitoring and enforcement. Under the ITPGRFA, member countries agree to create a multilateral system (MLS) for facilitated access to a limited number of agricultural crops (64 are listed in Annex 1 of the ITPGRFA) and multilateral benefit sharing arrangements (Vernooy et al. 2016a:52). Accessing materials from the MLS can be an effective means to bring new diversity to breeding programmes and ultimately to farmers' fields. Benefit sharing deals with the division of any benefits deriving from the use of the genetic resources between the provider and receiver of the genetic material, according to rules and regulations set out in the ITPGRFA.

These international agreements have agricultural biodiversity conservation as their objective and promote the role of farmers as custodians of biodiversity. They sit alongside prevailing obligations in the World Trade Organisation (WTO) Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement, as well as the International Union for the Protection of New Varieties of Plants (UPOV). TRIPS requires signatory countries to have some kind of plant breeders' protection, which has to cover certain basic protections, but it is ultimately up to the individual country to decide how to formulate these.

There is a lot of pressure on countries, especially in the global South, to adopt UPOV 1991 as the standard. This particular model is historically based on commercial developments in Europe that favour private breeders' rights over the rights of farmers. Every revised version of UPOV has progressively restricted breeder exemption (to allow other breeders to freely use protected materials for further research and development) and so-called 'farmers' privilege' to recycle and use protected seed on their own holdings. This 'privilege' is optional and excludes exchange of these materials between farmers (Visser, 2015). Farmers' rights to recycle, use, exchange and sell seed are included in Article 9 of the ITPGRFA, but the way in which signatories 'domesticate' this Article is not defined, and in practice few countries have incorporated it into national policy and/or legislation.

A question for a breeding programme is what the laws and regulations say about access, use and benefit sharing of germplasm that is sought for use. Usually, farmer materials are not covered by IP protections and can be put forward by farmers, without any problem.

Signatories of the ITPGRFA and CBD/Nagoya Protocol will have contact people or national focal points for enquiries about access to materials registered in the formal system. Information on member states, laws, regulations, contact points, etc. can be located on the ITPGRFA, CBD/Nagoya Protocol and FAO websites.⁹ Public sector organisations, such as the gene bank and the ARIs will be able to provide information about access and benefit sharing. For accessing materials in the multilateral system, there will usually be a Standard Material Transfer Agreement (SMTA) specifying terms and conditions of use. The SMTA protects the genetic resources of plant species listed in Annex 1 of the ITPGRFA against IP rights and assures continuous and free availability (Haussmann and Parzies, 2009:111). In some instances, use of materials obtained from the multilateral system could lead to 'royalty' payments if derived materials are commercialised. This whole story will generally be left to formal sector institutions to deal with, especially since it applies to access and benefit sharing of materials only from the formal sector. But there should be discussions with farmers if there are any IP considerations. Vernooy et al. (2016a) provide further detail of what is required to access materials from formal collections governed by the multilateral system.

Creative alternatives to exclusive plant breeders' rights are being tested, including the Open Source Seed Initiative (OSSI), formed in 2012 by a group of breeders from the public sector, small seed enterprises, farmer breeders and activists.¹⁰ Originally OSSI was based on efforts to create a licensing framework for germplasm exchange that preserves the right to unencumbered use of shared seeds and their progeny in subsequent use (Kloppenburger, 2014). The General Public License (GPL) is one specific mechanism proposed by the Centre for Sustainable Agriculture (CSA) in India. CSA coordinates the Apna Beej open source seed network, which includes breeders, farmers and CSOs. CSA says use of the GPL can prevent or impede patenting of plant material, bioprospecting/ biopiracy and use of farmer materials in private breeding programmes. GPL can also develop a legal/institutional framework recognising farmers' collective sovereignty over seed: allowing farmers to freely exchange, save, improve and sell seed; enabling farmers and plant scientists to work together to develop new varieties; and allowing the marketing of seed that is not patented or use-restricted (CSA, 2014:8–10).

However, OSSI abandoned the idea of a license when it became apparent that many farmers and organisations do not want to adopt a licensing framework. Licensing was pulling OSSI in a policing and bureaucratic orientation. Instead, OSSI has adopted a pledge, which may not be legally binding, but which is easily transmissible and is an uncompromising commitment to free exchange and use (Kloppenburger, 2014). OSSI also supports plant breeding, PVS, value for cultivation and use (VCU) testing, seed multiplication and distribution activities based on the open source materials developed and selected with farmers. It supports activities in India and the US, and start-up activities in East and Southern Africa. Bioversity International and HIVOS (a Dutch NGO) are collaborating on an open source seed system initiative in Eastern Africa with a strong policy component.¹¹

9. ITPGRFA www.planttreaty.org, CBD Nagoya Protocol www.cbd.int/abs/nagoya-protocol; and CBD ABS Clearing House <https://absch.cbd.int/> and FAOLEX <http://faolex.fao.org/> for laws.

10. Thanks to Sabrina Masinjila at ACB for inputs on this section on OSSI.

11. https://www.hivos.org/sites/default/files/options_for_national_governments_to_support_smallholder_farmer_seed_systems_the_cases_of_kenya_tanzania_and_uganda_o.pdf

gene banks for use by formal breeders. PPB is significantly different, in that collected/identified materials are identified and used by farmers together with breeders for further development. Farmer varieties may be limited to local controls based on identified preferences to compare with new varieties. However, farmers could also have a much more central role in identifying materials, not just as a control for testing against external materials, but for enhancement.

Aside from farmer materials, germplasm and variety collections are maintained in different places, including the national ARIs and CGIAR institutions, gene and seed banks and private/corporate collections. CGIAR institutions are prime movers in the history of PPB and continue to provide materials for practical work. CGIAR material is usually new material brought in from outside the country that has been bred for traits that have been identified as priorities. The material may still need to be adapted for use in specific local contexts. Some of this material may already earlier have been crossed with local varieties from the area, especially if local ARIs were involved in breeding.

There are a series of national, regional and global gene banks that aim systematically to collect germplasm and data on agricultural biodiversity and to make this available on a public interest basis for development. Breeders, including farmers, may approach national gene banks and ARIs for germplasm and request for assistance for repatriation/revival of specific varieties/plant materials. CGIAR plant breeding programmes are structured to have a centralised breeding platform linked closely to a world germplasm collection. Regional breeding programmes draw on support from the central unit. There is differentiated regional support to national breeding programmes, depending on capacity and resources (Lynam, 2011:40). CGIAR institutions relate directly to government departments and ARIs, but farmers can also approach the CGIAR centres directly.

Germplasm entries will be screened in the pre-adaptive phases of research, to find cultivars most closely meeting important identified characteristics, such as maturity, plant height, agro-ecology niche, product



quality, resistance to biotic or abiotic stresses, receptivity to artificial inoculation; or to deal with high incidence of natural infection or pest challenge in 'hot spot' locations (Ceccarelli, 2009:65). Materials may also be screened for diseases. Breeders will then propose materials for introduction to cross with farmer varieties for the desired traits. There are cases of farmer involvement in pre-breeding selection of introduced breeder materials at on-station experimental plots.

Crossing

Once the materials are assembled, some crossing may take place prior to selection and testing in the field. Crossing involves combining genetic material of selected parents with the objective of producing progeny with combined traits. Inbred lines (for example, from CGIAR or gene banks) have been bred for specific traits and are uniform, giving the option to be specifically adapted. The breeding objective can vary from specifically and locally adapted to only one or several environments, with more or less similar features (Hardon et al., 2005; Ghaouti

et al., 2008). Crossing with local varieties is one way to do this. Crossing with wild relatives may be possible, although there may be technical restrictions (Ceccarelli, 2009:64). Crossing is not a necessary element of a breeding/crop improvement programme. Inbred lines could simply be introduced into an environment and tested and locally adapted over time. There may be some comparison with the performance of local varieties, but without crossing the materials. Over time, the materials may cross naturally in the fields, allowing farmers to select their preferred materials. In this way, the materials do get integrated into ongoing processes of selection and enhancement of seed. So the materials do ultimately cross, but not necessarily through a controlled process.

Farmer varieties, landraces and wild relatives harbour large amounts of genetic variability. If this material is to be used, it simply involves the collection of the plants as parents for the next stage (Ceccarelli, 2009:65). PPB can still take place using this genetic material, through in-field crossing, selection and experimentation. In-field crossing is rare as a systematic intervention, mainly because of the technical complexity. However, approaches such as evolutionary plant breeding create greater space for natural processes of genetic intermingling in the field, with farmers selecting from a diverse pool of materials that is continually evolving to specific conditions through natural processes.

Systematic crossing will be necessary for the creation of hybrids with the desired trait mix (Box 4). This is not very common in PPB programmes, but there are cases where hybridisation takes place as part of the programme. Some breeders consider systematic crossing to be the essence of breeding.¹²

In any breeding programme, the degree of participation in generating genetic variability is determined by who selects the parental materials. Given the complexities of crossing, it may be less important for farmers to be involved in the actual physical process of crossing if they have participated in the

processes of selecting the parent materials (Ceccarelli, 2009:66). Most authors reviewed agree that crossing is a technically difficult task and farmers can rather be brought in at the assessment and evaluation stages (Trouche et al., 2012). Technical methods for generating variability are provided in various chapters in Ceccarelli (2009).

In defining PPB, we may want to include the requirement that there should be some use of farmer and local varieties in the experiment beyond merely as a control, even if the programme also includes the introduction of other materials from outside. This roots material ownership with farmers. According to de Boef and Ogliari (2008:182), “in the case of self-fertilizing crops, this means that at least one parent in the PPB programme should be a landrace or locally adapted cultivar. In the case of cross-pollinating crops, local varieties should contribute to the development of composite populations”. This involvement should extend beyond just inclusion of farmer varieties, to farmers themselves actively participating in selecting the materials they want to work with in partnership with researchers (Hellin et al., 2008). Otherwise it is just farmers testing outside material, for example, PVS. This testing may be participatory, but if farmer involvement is restricted to this activity, it cannot be considered a fully-fledged PPB process.

Selection

Once the preferred genetic materials are selected and generated, the next step is narrowing down of the large diversity of genetically different breeding material to a number of preferred lines that will eventually produce true to type with the desired bundle of traits. “To unite as many genes or favourable alleles as possible in a single cultivar requires a large number of generations of selection and testing of the best plants” (Federizzi et al., 2012:67).

There are many different possible ways of doing selection, with greater or lesser farmer participation. There are different views on the feasibility of farmer involvement in early stage selection, possibly depending

12. Greybill Munkombwe, Director: National Genetic Resources Centre, Zambia, pers. comm., 10 September 2017

BOX 4: Hybrids and open pollination

Hybrids

Hybrids are crosses involving at least one inbred line. Inbred lines are individuals of a particular species that are nearly identical to each other in genotype, due to long inbreeding. This is often the form of materials that will be used in a breeding programme from a CGIAR centre or the gene banks.

Hybrid seed has to be reconstituted each generation by crossing the parents while avoiding self-pollination. Farmers generally cannot produce hybrid seed themselves because the parent lines are normally not available. Hybrid varieties are, therefore, the main asset of the seed company producing the hybrid seed.

In hybrid crosses, the original parental plants are the P generation. They are of diverse origin and genetic make-up.

The hybrid offspring of the parents are the F₁ (first filial) generation. This gives a genetically diverse population, a “heterogenous population of recombinant genotypes” (CENESTA, 2013:8). F₁ will have the characteristics of the dominant parent for a particular trait.

F₁ fertilisation with itself or with one another produces the F₂ generation. Both alternatives of each parental trait reappear. Self-pollination over generations will reduce the number of individuals with mixed traits (heterozygous); 90–95% of genotypes will be homozygous (uniform) for a trait after 6–9 generations.

(Almekinders and Louwaars, 1999:8–9, 12)

Open pollination

In the case of open pollination, pollen release from the anthers and depositions are not controlled. It may be self- or cross-pollination. Hand pollination is possible but it is time consuming.

In self-fertilising crops, 95% of pollination is from self-fertilisation. Modern varieties have one homozygous pure genotype. Improved self-pollinating cultivars consist of a small number of very similar genotypes. It is relatively easy to isolate the material genetically, so deterioration is slower if the seed is properly managed (Danial et al., 2007). Examples of self-pollinating crops are wheat, rice, finger millet, bean, cowpea, soya, groundnut, sesame, chickpea and tomato.

For cross-pollinating crops, in natural conditions 50% or more of pollination occurs through cross-fertilisation (insects or wind). Selfing often results in in-breeding depression, which expresses itself in the general weakening of the plant. Examples of cross-pollinating crops are maize, pearl millet, sunflower, canola, onion and most fruits. Isolation is the major concern for the crossing of these crops. Improved cultivars of cross-pollinating crops consist of a narrowed gene pool with high frequencies of desired characteristics. Maintenance is through mild but continuous selection for desirable plant types. Without this, the improved cultivar will gradually lose its character because it is not possible to isolate the plant genetically from other varieties (Danial et al., 2007:388). Farmers cannot easily maintain cross-fertilised varieties true to their original characteristics and may have to purchase seed if they want to produce relatively uniform varieties. However, cross-fertilising crops are more adaptive to local conditions than self-fertilising crops.

Open pollination with random mating and no selection pressure results in a constant percentage of the different genotypes.

(Almekinders and Louwaars, 1999:11)

Vegetatively reproduced crops

Improved cultivars of vegetatively reproduced crops (for example, potato, cassava, vines) consist of a single genotype. These are easy to maintain and multiply true to type, but are susceptible to pathogens carried by the propagules used for reproduction (Danial et al., 2007:388).

on the type of crop. For example, in self-pollinating or vegetatively reproduced crops, where individual plants are easy to recognise, involvement of farmers in early stages of selection may be feasible. There is an argument that in crops such as wheat and barley, where it is difficult to distinguish between plants, this is not advisable (Danial et al., 2007). However, Ceccarelli (2009), for example, shows that farmers are experts in selecting the best plants of these crops. Methods will depend on the mating system of the crop and the genetic control of the traits under selection. Field trials are expensive compared with on-station trials and this should be considered when structuring the selection and testing stages of the programme (Ceccarelli, 2009:66–67).

In the early stages of selection there are still many segregating lines¹³, which are later reduced to only a few nearly finished lines. At each new round of selection, seed selected from the previous round may need to be multiplied for further selection. This may take place on-station, in parallel with the PPB (Ceccarelli, 2009a:215).

There is no standard methodology for assessing materials, with different selection processes for different crop types (for example, self-pollinating, cross-pollinating, or vegetatively reproduced). Mass selection is the simplest, most common and oldest method of crop improvement, in which large number of plants with similar observable characteristics (phenotypes) are selected and their seeds are harvested and mixed together to constitute the new variety. Evolutionary plant breeding follows this model. Mass selection is important for cross-pollinating crops but has only limited application in self-pollinating crops.¹⁴ Selection of self-pollinated crops is about reducing genetic variance within families and increasing variance between families (Ceccarelli, 2009:66).

If crossed materials are used, early stage selection is a very structured process. Between F₁–F₆ generations, plant materials undergo segregation and are characterised

by high genetic instability. There are large numbers of segregating lines (that is, characteristics are not stable in reproduction on next planting), and this may pose management challenges for farmers who will need to manage hundreds of lines, sometimes with only small plots available. For this reason, farmers may participate through selection from on-station trials, or may be involved only in later stage selection, when there are fewer lines and management is more feasible.

Where materials are going through a formal sector breeding process, farmers may not typically be invited to evaluate materials until after they have stabilised at F₆ generations and above (Humphries et al., 2005:12). Farmer participation in early selection requires farmers to have some understanding of selection from unstable materials, where phenotypic characteristics are unlikely to express themselves consistently in early generations (Humphries et al., 2005). It is a tedious and difficult process for farmers to evaluate a large number of entries, while the pay-off for the farmer may be in the distant future (Danial et al., 2007; Ceccarelli, 2009).

Materials are gradually honed down to a final line that may undergo multi-locational trials. This completes one cycle of breeding/crop improvement. Where farmers were not involved in early stages of selection, a small number of almost finished lines may be introduced to farmers for PVS. According to de Boef and Ogliari (2008:179), “PVS is the term used for selection from among advanced or genetically stable populations and lines in self-pollinated species, or among populations in open-pollinating species, while PPB denotes selection from within segregating populations” (that is, early stage selection). For our purposes we understand PVS as an integral part of broader PPB programmes that cover other elements of breeding as well.

Farmers may evaluate lines in trials conducted at the research station (for example, Kamau et al., 2011), or farmers may

13. Mendel's law of segregation: During gamete formation, the alleles for each gene segregate from each other so that each gamete carries only one allele for each gene, https://en.wikipedia.org/wiki/Mendelian_inheritance

14. Agriinfo (n.d.) Method of plant breeding in self-pollinated plants – mass selection. <http://www.agriinfo.in/default.aspx?page=topic&superid=3&topicid=1750>



be actively involved in the production as well as the selection process. Technically speaking, selection usually occurs at two stages of the plant production cycle. First, an evaluation is done at flowering, and then, at or after harvest. More frequent evaluation becomes costly and does not significantly improve the outcome (Danial et al., 2007). Selection for processing and cooking characteristics, palatability, poundability, food quality, etc. may take place after harvesting and at storage.

PVS is quite commonly used in conventional breeding programmes, even if only on-station. Stable lines developed at the research institution are taken to farmers to test in the field, followed by discussion with researchers about which varieties they prefer, then the breeder finishes the process. There is growing recognition of its value in conventional systems for adapting varieties to specific local conditions; especially marginal, high-stress environments, together with low input systems (Dawson et al., 2006; Laurie and Magoro 2008:672). Often ARIs produce new cultivars but face the challenge – especially in the global South – of lack of capacity or resources to do local evaluations or multiply and distribute these varieties. PVS offers an

opportunity to introduce these materials into local contexts. PVS can assist in widening the range of available genetic material available for local use and increase agricultural biodiversity. It may be faster and more cost effective than the longer PPB process in identifying farmer-preferred varieties if a suitable choice of varieties exist (Witcombe et al., 1996).

Certainly a minimum element of PPB must be farmer in-field experimentation, trials and selection. Therefore, if PVS is limited to farmer days to select from amongst formal breeder varieties at on-station trials, this can't really count as PPB. In PPB, on-station evaluations and selections usually will be conducted parallel to PVS in farmers' fields for comparison and as a backup in case field trials fail. Even where farmers are only involved in PVS, it can serve as an important starting point for longer term PPB processes (for example, de Boef and Ogliari 2008; Laurie and Magoro 2008; Trouche et al., 2012). PVS is contained and allows farmers to build up their technical skills before engaging in other parts of the breeding process. In some cases, PVS is even viewed as a necessary precursor. For example, there is a view "in PCI [participatory crop improvement] that



PPB only commences after several years of successful PVS implementation, as farmers first need to learn to work with genetic diversity and gain some experience in formal experimentation” (de Boef and Ogliari, 2008:182). PVS is considered a “logical step before PPB” (Laurie and Magoro, 2008:672).

At the end of the selection process, which is at the heart of the breeding programme, farmers will have a number of experimental cultivars with selected traits fixed in them and that reproduce true to type.

Testing of experimental cultivars and relation to registration

Once cultivars are selected for recommendation, these may be compared with favoured local varieties to see if they do indeed perform better in localised contexts based on the prioritised characteristics (Ceccarelli, 2009). If cultivars are to be spread to different agro-ecological regions, wider adaptation will be required (Aguilar-Espinoza, 2007). Plants or varieties may perform differently in different environments. Breeders know this as genotype x environment interaction (GxE). Direct selection in the target environment is always the most efficient means of selection. Selection in an environment different from the target leads to a decrease in selection efficiency. Parent selection should include local materials to overcome this (Wakjira et al. 2008:188).

As with the selection process, there are usually two check points (Ghaouti et al., 2008:260):

- Scoring at the onset of flowering on plant height, disease incidence, lodging, biomass yield, end of maturity, visual estimation of

yield at maturity, and personal appreciation of material through visual score;

- After harvest (for grain) – measure of grain yield, thousand grain weight, and grain status (health).

Generally speaking, all stages will follow formal protocols if the objective of the breeding programme is to produce cultivars for official registration and release. This is necessary if they are to be used for commercial production and sale. Parental materials may need to be registered; certain agronomic practices, monitoring and data collection and analysis processes must be followed; and formal VCU and distinct, uniform and stable (DUS) tests will be required. These usually occur simultaneously for a period of 2–3 years.

VCU trials are multi-environment trials (METs) to test the reaction of the materials to a multitude of environments, for example, location, years, different types of agronomic management. The aim is to have as many locations as possible. In PPB programmes, the main limiting factor is the availability of seed. These trials have limited precision, so it is mostly negative selection, discarding obviously inferior breeding material. METs allow the subdivision of GxE into genotype x location (GxL) and genotype x year (GxY) interactions. It allows for identification over time of appropriately-adapted high-yielding, stable genotypes (Ceccarelli, 2009:71). Tests must show added value for farmers of the new variety over existing available materials (Kaimenyi, 2017).

VCU may be under centralised control of a breeding institution or may be decentralised, with tests in numerous environments through voluntary farmer participation. If decentralised, recommended cultivars are distributed to farmers for testing and comparison with locally favoured varieties. Advantages of a decentralised approach are: i) there is an increase in the number and range of test environments; ii) The costs of VCU testing are reduced, because decentralised institutions can be responsible for only one or a few locations; iii) control cultivars (usually the best in cultivation) are defined previously; iv) rules for inclusion, continuity of test lines and release of new cultivars can be decided in a collective manner; v) it gives breeders an opportunity to test their best lines with

other lines from other breeding programmes. Disadvantages are: i) there is a lack of control over how the trials are performed by the participating institutions and the quality of experimental data, and ii) the new lines will be available to third parties (which is only an issue if exclusive ownership is sought) (Federizzi et al., 2012:69–70).

DUS testing is done to establish the unique character of a variety for IP and certification purposes. The requirement for a variety to be distinct and new primarily is an IP issue. A variety must be distinct from an already registered variety, so that ownership can be conferred for a period. It must also not be genetically the same as a variety previously registered. Uniformity and stability contribute to providing a distinct identity in comparison to other varieties (Hardon et al., 2005). In addition, uniformity and stability test that the variety meets certain user requirements. Uniformity refers to the progeny of the seed having the same characteristics as one another. This is important for large-scale agro-industrial production, but local markets may at times also prefer some level of uniformity, for example, grain/meal colour. 'Stable' means the advertised traits must be faithfully replicated in the progeny, the seed must breed 'true to type', at least for the first crop planting. With hybrid seed, these characteristics disintegrate with further plantings. DUS is not always appropriate for farmer needs, especially the need for diversity and dynamic evolution (CENESTA 2013:16).

Even if cultivars are not going through the formal process, VCU-type testing can be of value to farmers, to test the materials in practice, to see if they do outperform other available varieties in specific contexts. In PPB, materials may already have cycled into farmer systems at numerous points in the process, and final release of a cultivar is not a necessary outcome.

Formal variety release requirements may include (Manu Aduening et al., 2006):

- Description of the breeding procedure used, origin of germplasm, etc.;
- Phenotypic characterisation of the accessions, including resistance to common pests and diseases;
- Performance of the accessions in on-



station and on-farm trials across the agro-ecological zone(s) targeted for release (VCU);

- An inspection plot (generally on-station), where the potential variety can be inspected and where sufficient planting material is available to demonstrate that release is feasible in practice; and
- A description of post-harvest attributes.

Not all registered varieties have plant variety protection (PVP). A variety that is registered but not protected may allow anyone to multiply and sell that variety (conditional on meeting certification requirements). However, registration on its own, including of farmers' varieties, can open the way for biopiracy by making visible the genetic resources held by farmers, and opening these to appropriation, using existing agreements and laws. There are technical and cost barriers to registration and seeking protection in the PVP and registration laws. These may pose challenges if farmers want to register their varieties, since, from the outset of the PPB programme, farmers

must keep in mind the certification and variety release requirements. Once a variety is registered, the registered owner can apply for protection, allowing exclusive use for a period specified in PVP laws and regulations, and the right to license use to others. Commercial enterprises usually apply for protection of varieties to prevent others from using them without payment.

In most countries, farmers may recycle protected varieties for own use on their own landholdings, although this is being narrowed with new PVP laws. Legally speaking (in the standard case), farmers are not supposed to exchange these seeds with others, but in practice this is almost impossible to monitor because it is part of daily human interaction. Protection of their varieties may provide farmers with some legal protection against biopiracy, because anyone wanting to use the variety will need to enter into an agreement with the rights holders. Farmers' and their organisations will need to decide their approach to registration and protection, and perhaps to consider other possible methods to protect genetic materials as a common pool. OSSl suggests one alternative, although they have moved away from a licensing process as it is too time consuming, bureaucratic and politically unpalatable for some.

An underlying principle of PPB is that farmers' contributions should be recognised if property rights are attributed to finished materials (Sperling et al., 2001:447). Benefit sharing may include financial benefit but also other practices and mechanisms, such as community biodiversity management funds, or seed banks with multiple functions supported technically and financially by national government (Vernooy et al., 2016a:57). Taiwan has an access and benefit sharing contract model that provides an alternative to arrangements based on exclusive rights and compels the balancing of interests between public sector, commercial entities and farmers. The model requires recognition by name of any farmer who makes a contribution, as well as the creation of an enforceable fair benefit arrangement agreed by all the named parties, before a license for seed release is granted (Song et al., 2016:22).

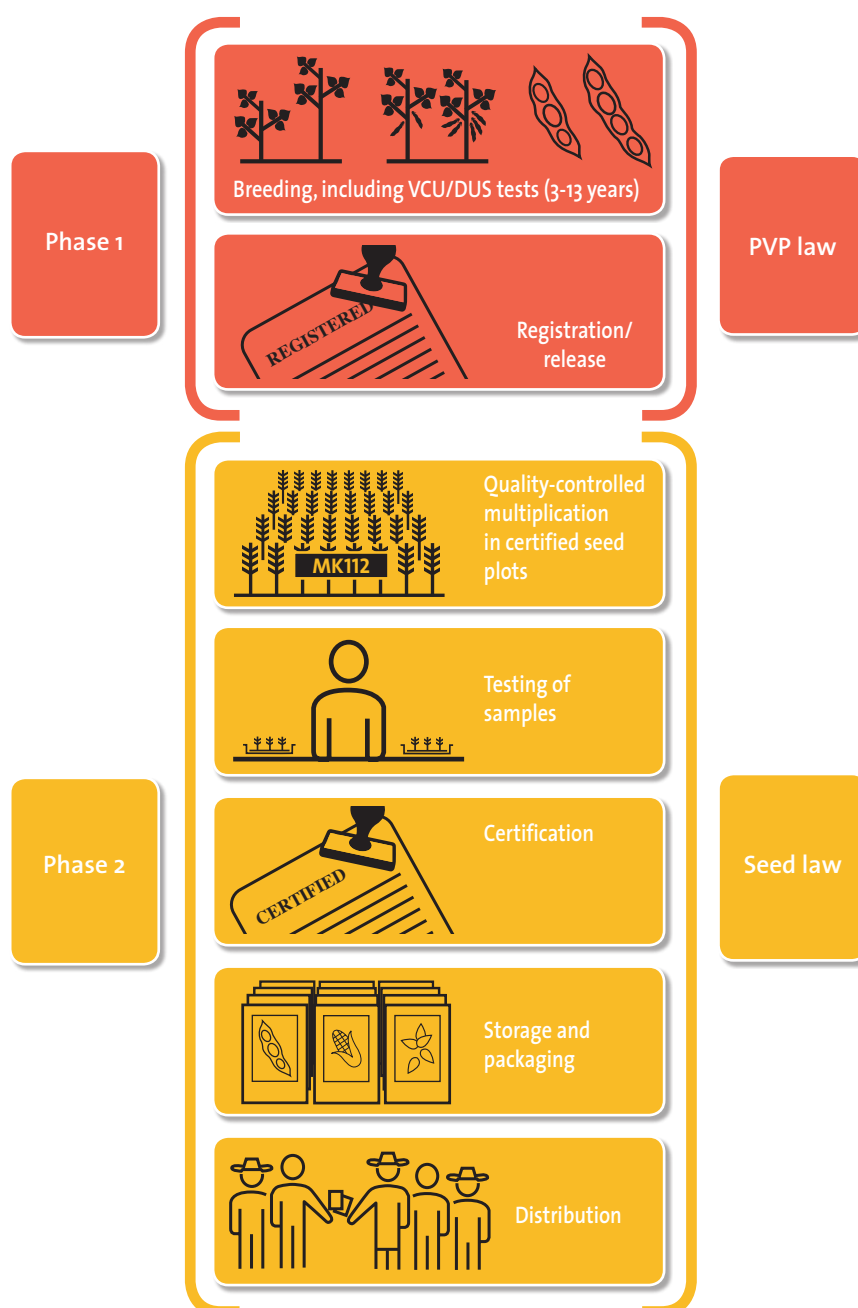
Multiplication and dissemination of cultivars following breeding

Although not the focus of the paper, we must say something about multiplication and distribution, because, if varieties are developed but not shared, it is a wasted opportunity. Once breeding is completed and new cultivars are produced, there are different routes to share. Many PPB programmes share genetic materials with participating farmers throughout the selection process. Farmers can keep and propagate and otherwise use the materials as they wish. Farmers are encouraged to share materials with others who may benefit from it. This free and informal dissemination of germplasm and enhanced materials is at the core of decentralised approaches, where the objective is the development of locally adapted varieties for local use.

However, these practices may fall foul of laws on the dissemination of genetic materials that are common in many countries, including in Africa, and that follow UPOV and International Seed Testing Association (ISTA) standards and procedures for variety registration and release, and for seed multiplication, storage and distribution. These laws are mainly designed to provide an official guarantee that seed is of appropriate quality and is identifiable at the time of purchase (Visser, 2015). In most countries, a variety must be registered and certified before it can be sold. There may be exemptions, but in many places the sale of unregistered seed is outlawed. Current proposals in South Africa seek to include any form of exchange as part of the definition of sale (ACB, 2017). Legally speaking, this means farmers may not exchange any materials if the materials are not officially registered and certified. Across the world, farmers do sell unregistered seed (even in the standard definition of sale as exchange for money). Generally, this may be tolerated and is not monitored closely unless scale becomes significant and authorities get to hear about it. If such activities begin to pose a threat to the interests of commercial seed producers, there will be a clampdown.

This illegality of exchange and sharing of unregistered and uncertified seed poses a significant threat to PPB programmes

Figure 4: Getting through the formal registration and certification system



and to public sector involvement in such programmes where the objective of the programme is to produce enhanced varieties that are to be locally circulated. The public sector will not be able to participate in activities that are deemed illegal (such as distribution of unregistered/uncertified varieties). For farmer innovation to be incorporated into breeding, exemptions are required on the sale and exchange of seed, with flexible quality controls based on farmer-user interactions and agreements (formal and informal).

The other route, after variety development, is formalisation, with registration and official release, as discussed above. After this, there will be quality-controlled multiplication, certification processes, and, finally distribution/marketing. The process to follow for formal registration and certification is indicated in Figure 3. There are two phases: the first phase up to registration and release, dealt with above; and a second phase of multiplication, certification and distribution. The first phase is usually covered by PVP law, while the second phase is often covered by the seed law governing production and sale of seed.



Once a variety has been registered, it will be legally eligible for production and commercial sale. The seed that is registered is breeder seed. This must now be multiplied out in successive batches, with quality controls to ensure the seed retains its registered characteristics and to make sure it performs according to claims. Seed is planted in certification plots with quality control inspections, and post-harvest supervision for sealing of raw seed and processing. Seed samples are sent to a registered seed certification authority to verify conformity to standards, including genetic and physical purity (field test), germination rate, moisture content, and to ensure the batch is free of weed seed and seed-borne disease.¹⁵

If the seed passes inspection, it is certified and the seed lot is released for multiplication or marketing. Previously, public sector seed certification authorities carried out quality controls (inspection, testing and certification). However, structural adjustment and fewer resources have resulted in privatisation of these services, with accredited seed inspectors in private companies. These are the same companies that own and sell the seed; hence, this is a self-regulated system. There may be occasional public sector spot checks in response to consumer complaints. Private inspection services are not set up in all countries and public sector seed certification authorities still play a big role in some countries, though they may lack capacity (for example, insufficient number of inspectors, especially for many dispersed smallholder plots).

Seed laws contain standards and requirements for storage, packaging, labelling, marketing, etc., of seed before it can be legally sold. Many countries have adopted ISTA standards. Again, this is not in every country at this time, but the objective for commercial producers is for a standardised set of criteria for certification that meet the needs of large-scale commercial producers, but that also provide some quality guarantees to the user. As with DUS testing, these laws have been designed for commercial production and not for farmer seed systems, but they might end up regulating farmer seed systems, in the absence of any specific legislation or regulations covering the latter.

The formal standards are fairly onerous for smallholder farmers to abide by, and may not be appropriate, especially when the seed is primarily for local dissemination. Quality control standards may be relaxed, for example, quality declared seed (QDS) for local distribution and sale, but these usually still require certification through formal agencies. Standards could be made more flexible for smallholder farmers, while still ensuring seed quality and seller accountability. In some cases, farmers indicate they are able to meet formal certification standards, but that these are not always necessary because existing social structures are adequate in regulating seed quality (Visser, 2015). Assistance to farmers to produce basic seed may be required for a while to ensure quality production (Aguilar-Espinoza, 2007).

15. Agriinfo (n.d.) Seed certification procedure. <http://www.agriinfo.in/default.aspx?page=topic&superid=3&topicid=2303>