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DEVELOPMENT AND DELIVERY OF BEAN VARIETIES IN AFRICA: THE PAN-AFRICA BEAN RESEARCH ALLIANCE (PABRA) MODEL

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) has evolved rapidly in Africa and is steadily transforming from a traditional subsistence to a market-oriented crop, with major impacts on household incomes, food and nutritional security, and national economies. However, these benefits are yet to be felt in many parts of the continent because of multiple constraints that limit bean productivity. The Pan-Africa Bean Research Alliance (PABRA) has been at the forefront of efforts to accelerate the transition of beans from a subsistence crop to a modern commodity in Sub-Saharan Africa. This paper presents a unique partnership model and the breeding and seed delivery strategies used by PABRA to reach millions of beneficiaries with improved bean varieties. The breeding strategy involved the paradigm shift from a monolithic approach where varieties were bred for yield or resistance to single environmental stresses, to a grain type-led and market-driven approach. The PABRA model comprises partnerships between and among Centro Internacional de Agricultura Tropical (CIAT), National Agricultural Research Systems (NARS), public and private sector actors along the varied bean product value chains, and technology end-users. This model led to the release of over 200 varieties during 2003-2011, including beans with resistance to multiple constraints (biotic and abiotic), high iron and zinc content, and those for specific niche markets. PABRA reached 7.5 million households with seed of improved bean varieties during 2003– 2008 and is expected to reach an additional 14 million by 2013. From this undertaking, aspects that lend to policy recommendations to key stakeholders in the common beans value chain include: facilitation of access to credit; promotion of breeder and foundation seed production; easing of restrictions on the release of varieties; facilitation of collective marketing schemes; and deliberate policy frameworks to encourage the use of complementary integrated crop management practices.

Key Words: Participatory plant breeding, *Phaseolus vulgaris*, public private partnership, seed system

RÉSUMÉ

En Afrique, le haricot commun (*Phaseolus vulgaris* L.) a connu une évolution rapide se transformant d'une culture de subsistance traditionnelle en une marchandise commerciale avec des impacts majeurs sur les revenus, la sécurité alimentaire et nutritionnelle des ménages ainsi que sur l'économie nationale. Toutefois, ces avantages ne sont pas tellement perçus dans nombreuses régions du continent en raison de multiples contraintes (biotiques et abiotiques) qui limitent la rentabilité et la commercialisation du haricot. L'Alliance Panafricaine de Recherche sur l'Haricot (PABRA – Pan Africa Bean Research Alliance) est à l'avant-garde des efforts visant accélérer cette transition du haricot en Afrique sub-saharienne. Cet article présente un modèle de partenariat unique, et les stratégies de sélection et vulgarisation des variétés utilisées par PABRA pour faciliter l'accès des millions de bénéficiaires aux variétés améliorées du haricot. La stratégie de sélection exigeait le changement d'une approche monolithique où les variétés étaient sélectionnées pour leur rendement ou leur résistance aux stress environnementaux simples, à une approche basée sur le type de grain et axée sur le marché. Le modèle de PABRA comprend les partenariats entre et parmi le Centre International d'Agriculture Tropical(CIAT), les systèmes nationaux de recherche agricole (NARS), les acteurs publics et privés le long des différentes chaînes de valeur du haricot, et les utilisateurs de nouvelles technologies. Ce modèle a conduit à l'enregistrement de plus de 200 variétés durant la période 2003-2011, y compris les haricots avec résistance à multiples contraintes (biotiques et abiotiques), un contenu élevé de fer (Fe) et du zinc (Zn), et ceux pour les marchés de niches spécifiques. PABRA a atteint 7,5 millions de ménages facilitant leur accès aux semences de variétés améliorées de haricots durant la période 2003 - 2008 et devrait atteindre quelque 14 millions de personnes supplémentaires d'ici 2013. Les recommandations aux décideurs politiques qui visent à renforcer le développement et la vulgarisation des variétés améliorées du haricot comprennent: la facilitation de l'accès au crédit; promotion de la production de semences de base et pré-base; assouplissement des restrictions sur la diffusion des variétés; facilitation des régimes de commercialisation collective; et des cadres de politique visant à encourager la gestion intégrée des cultures chez les cultivateurs de haricot.

Mots Clés: Amélioration génétique, haricot commun, partenariat public-privée, *Phaseolus vulgaris*, recherche collaborative, systèmes semenciers

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is a grain legume grown on more than four million hectares annually in Africa. It provides dietary protein for over 100 million people in rural and poor urban communities, with an annual per *capita* bean consumption in Eastern Africa (50 - 60 kg) being the highest in the world (ISAR, 2011). Within the African regions, bean products tend to be consumed at various stages of plant development, and thus, offer a staggered and prolonged food supply in the form of leaves, green pods, fresh grain, as well as dry grains. They also have unusual health benefits being rich in protein (about 22%) and providing a good source of iron and zinc (both of which are key elements for mental development). Furthermore, bean consumption reportedly reduces colon and breast cancer, and heart diseases (US Dry Bean Council, 2011). Beyond promoting food, health and nutritional security, beans provide a steady and lucrative source of income for many rural households, with the value of bean sales now exceeding US$ 500 million annually (FAO, 2011). As it is quick maturing and can be easily intercropped, bean serves as a key component in intensifying production in smallholder farmer systems. Its ability to fix nitrogen also means that it can encourage much-needed, even longer-term improvements in soil fertility. In a nutshell, the versatility of the bean crop and its contribution to a household's food income, diet, health and even environmental security is remarkable.

The bean-linked public research sector in Africa has been continuously plagued by inadequate government funding, low numbers of scientific staff, and high turnover of skilled staff due to low professional incentives. Acute events such as war, civil strife, droughts/floods, and political instability have also hindered ongoing bean research for prolonged periods.

Common bean production is constrained by several environmental stresses, notably biotic (field and post-harvest pests and diseases) and abiotic (drought, excessive rain/flooding, poor soil fertility, heat and cold stress), each of which causes significant reductions in yield (Wortmann *et al.* (1998). For instance, Wortmann *et al.* (1998) estimated that yield loss (tonnes yr^{-1}) due to drought, N deficiency and P deficiency were 396000**,** 389900 and 355900, respectively; while losses due to angular leaf spot, anthracnose and bean stem maggot were 384200, 328000 and 297100 tonnes yr^{-1}, respectively. Stresses such as poor soil fertility are long term and predictable (Lunze *et al*., 2011); while others like drought, some pests and diseases spurred by climate change could be short-term, but acute in nature. Soil degradation and drought are serious threats to agriculture and, hence, a frequent cause of crop failure and hunger. These threats are exacerbated by the effects of climate change (Christensen *et al.*, 2007) and crop intensification that leads to soil degradation, fertility decline and surges in pest and disease pressure. Thus, breeding for multiple constraint resistance must deal with both chronic and acute environmental stresses. The Alliance strives to remain relevant by focusing on efforts towards developing sustainable solutions to these stresses, as they come along.

Conventional models of legume seed delivery in Africa, which are relatively top-down and centralised with National Agricultural Research Systems (NARS) have proved to be slow and of limited reach. On the other hand, analysis of seed flows have found that farmer-to-farmer seed exchange, in itself, was insufficient for moving seed, with low diffusion rate and limited geographic and social reach (David and Sperling, 1999). Access to sufficient quantities of quality seeds of improved bean varieties by farmers is still a major bottleneck. The seed systems are predominantly informal and inadequately organised. Although the informal seed sector has been instrumental in dissemination of bean seed, it has not been efficient for wider dissemination outside the localities and seed demands remain unmet (David *et al*., 2002; Rubyogo, 2004).

It was in light of the critical roles of bean and the constraints of bean production and marketing that a collaborative network of research institutes, public and private sector partners formed a partnership known as the Pan-Africa Bean Research Alliance (PABRA). The aim of the Alliance is to improve food security, nutrition, health, income and livelihood of resource-poor smallholder families in Sub-Saharan Africa by addressing all constraints (genetic, biotic and abiotic, market, policy, etc) affecting the bean subsector. To achieve this aim PABRA has focused on implementing strategies for improving bean productivity through increased access to and utilisation of best practices such as use of improved varieties with integrated soil fertility and pest/disease management technologies.

The emphasis in breeding is on (i) increased and equitable access to improved dry bean varieties resistant to multiple environmental (biotic/ abiotic) and climate change-related stresses; (ii) increased access to micronutrient rich bean varieties and bean-based products in the diets of vulnerable communities, and (iii) increased access to high value bean products (varieties) targeted to niche markets.

The objectives of this paper are to: (1) present a unique partnership model developed and used by PABRA to breed and deliver improved bean varieties to millions of beneficiaries in Africa; (2) review PABRA's strategy and achievements in breeding and delivery of improved bean varieties; (3) highlight challenges and opportunities in breeding and delivery of bean varieties; and (4) make policy recommendations for strengthening bean breeding and the delivery of bean varieties in Africa.

Profile of PABRA. PABRA is a consortium of African-owned regional bean networks, an international research organisation [Centro Internacional de Agricultura Tropical (CIAT)] and the donors supporting the Alliance. The three networks that make up PABRA, the Eastern and Central Africa Bean Research Network (ECABREN), the Southern Africa Bean Research Network (SABRN) and the West and Central Africa Bean Research Network (WECABREN), have a combined membership of 28 national bean programmes. The networks are autonomous and are managed by regionally-recruited coordinators who respond to their respective sub-regional organisation - the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), the Southern Africa Development Community's Food, Agriculture and Natural Resources Unit (SADC/FANR) and the West and Central African Council for Agricultural Research and Development (CORAF/WECARD), which provide policy and oversight. The Alliance is guided by the principles of "the network paradigm" (Cooke, 1995) which include: reciprocity, a willingness to exchange information, know-how, proprietary knowledge and goods (Powell, 1990); trust - a willingness to risk placing faith in the reliability of others (Sabel, 1992); learning, a recognition that knowledge develops and best-practice should be learnt; partnership, a preparedness to solidify reciprocal relationships preferentially (Faris, 1991); and decentralism, a realisation that centralised information and decision-processing is inefficient (Aoki, 1986).

The PABRA partnership model - broad methodological framework. A strong feature of PABRA has been to actively catalyse regional collaboration in seeking solutions to problems faced by the bean sub-sector. This is done through joint priority-setting, planning and agreed division of responsibilities; all facilitated by CIAT. Hence, PABRA operates within a common Pan-Africa research for development (R4D) framework, which is based on partners' national interests, shared regional vision and objectives. Partnerships constitute the core of PABRA operations, translating into cost-effective and enduring gains at multiple levels. Three diverse examples of such partnerships include: a) partnerships between and among CIAT and National Agricultural Research Systems (NARS); b) partnerships with actors all along the varied bean product value chains, and c) partnerships with technology end-users, including the poor and women (Fig. 1). The model in Figure 1 appears linear; however, there are built-in mechanisms (e.g. network and alliance steering committees) which ensure that partners in all boxes are interconnected.

Research technologies and other outputs are shared among countries, avoiding unnecessary costs and duplication of efforts. Partnerships among NARS help countries compensate for the inevitable uneven resource endowment of the national bean programmes and also to capitalise on comparative advantages. All 28 member countries in PABRA implement bean R4D activities based on a common research agenda, which helps to harmonise research on beans and harnesses synergies among national bean programmes on the continent. By bringing on board a range of NARS partners offering complementary skills and services, and often operating in different agro-ecological and social economic environments, PABRA ensures that the impacts of bean R4D are felt well beyond the specific countries or locations where activities are implemented. Within each NARS, public-private partnerships are critical for the successful generation, promotion and delivery of technologies to farmers, as illustrated by the case of bean-subsector partnerships in Ethiopia (Rubyogo *et al*., 2011) (Fig. 2).

The Alliance also puts great emphasis on bringing end-users early in the technology development process and keeping them involved in decision-making on critical issues. This is not participation for the sake of ensuring participatory approaches but it is what makes the difference between adoptable and non-adoptable technologies in the technology development and adoption cycle. One of the more comprehensive thrusts has been in the field of participatory plant breeding (PPB) championed by PABRA (Sperling, 1989; Sperling *et al*., 1993). In addition to women

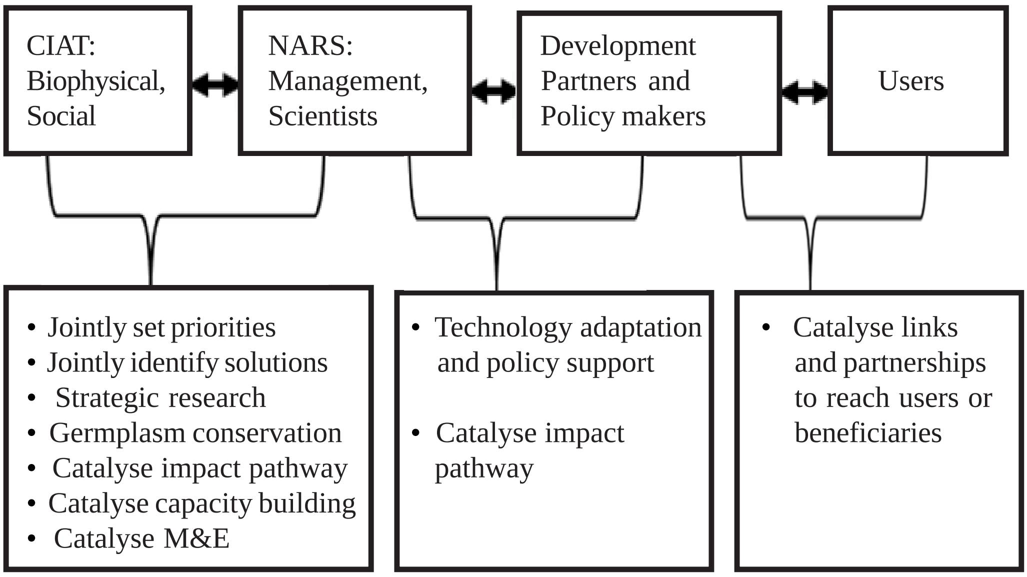

Figure 1. Three principal and interconnected axes of the PABRA partnership model: a) partnerships between and among CIAT and National Agricultural Research Systems (NARS); b) partnerships with actors all along the varied bean product value chains, and c) partnerships with technology end-users.

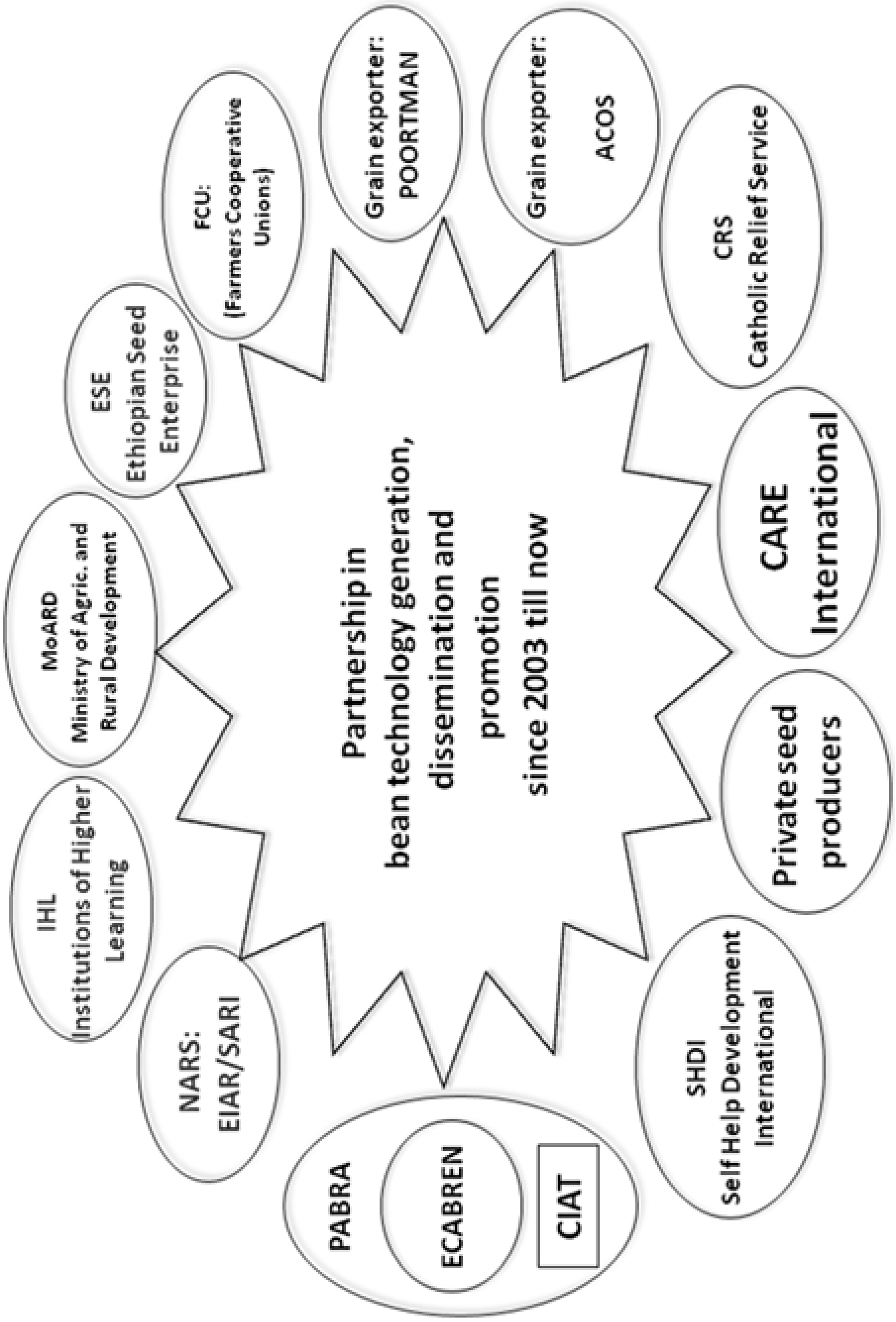

Figure 2. Effective partnerships among diverse public and private sector actors that have helped catalyse the transformation of the bean sub-sector in Ethiopia (Rubyogo *et al.*, 2011).

and men farmers, the Alliance systematically engages other stakeholders in the variety screening process. The process for instance involves local seed/grain traders, who help ensure that emerging varieties have much-desired marketing traits. The PPB approach has also led to a change of attitude of researchers towards the criteria to be used for germplasm evaluation during the breeding process. While yield and disease resistance remain important, three other criteria stand out across sites: *early maturity* (for drought escape and to 'fill the hunger gap'); *marketability* (both domestic and export); and *cooking time* as well as *taste*. Cooking time has been a crucial consideration since rural farmers increasingly supply town/urban markets where consumers are challenged by scarcity of fuelwood (CIAT, 2008).

PABRA's bean breeding strategy. The current PABRA strategy for bean breeding in Africa is focused on priority bean grain (market) types and the major biotic and abiotic production constraints. It outlines the technical contributions and responsibilities for various partners: CIAT breeding programme in Cali-Colombia, the two network breeders (ECABREN and SABRN), and the national bean breeding programmes (based on their actual capability). It also outlines the proposed breeding objectives and the collaborative linkages with other partner institutions e.g. universities and advanced research institutes. The rationale behind this strategy is that, in the past, bean breeding in Africa followed a monolithic approach where varieties were identified for their superiority in yield or resistance to a single biotic or abiotic stress, with little or no consideration of the grain size or colour or other socio-economic factors (Wortmann *et al.*, 1995; ECABREN, 2000). Instead, the current approach is grain type-led and is built on the premise that farmers produce beans for food and sale in their localities (neighbours, retail traders, schools and other institutions), larger domestic markets in urban centres, regional and international markets.

Preferences for bean varieties are extremely diverse among farmers, traders, processors and consumers, ranging from colour (red, white, black, red-mottled, cream, cream-mottled, yellow and others), through grain size (small- or large-seeded), growth habit (dwarf or climbing bean), and use (dry bean, canning bean or green/snap bean. Very often, each country has germplasm preferences for more than one of these market types, and the crop in some countries is grown in diverse environments that expose it to different stresses including drought, low soil fertility, pests and diseases. Noting the complexity of developing bean germplasm for different market classes with multiple attributes to overcome various production constraints, PABRA developed a bean breeding strategy which links the breeding programmes at CIAT headquarters in Colombia, the sub-regional breeding programmes in Africa and the NARS breeding programmes at country level (Fig. 3) (PABRA, 2011).

To develop the breeding strategy, bean breeders from different PABRA countries as well as other breeding related experts (pathologists, entomologists, market and agro-enterprise specialists, policy analysts) and other stakeholders (e.g. representatives of seed companies, farmer associations, etc) met and discussed the major thrusts or objectives to be addressed in the bean breeding strategy. Recommendations of the meeting were used to define the broad orientation of the strategy while additional feedback from stakeholders not present at the meeting (e.g. national bean programme coordinators) helped to further refine the details of the strategy. For each market class, the breeding objectives, methodology, and germplasm requirements to meet breeding goals were clearly defined. For instance, in breeding for improved red mottled beans, the objective was to develop improved marketable red mottled bean varieties with resistance to two or more biotic and abiotic constraints, acceptable cooking and culinary qualities. The methodology involved gamete selection from multiple parent crosses and inbred backcrossing, and germplasm requirements were parental lines, segregating populations and advanced lines. Specific activities related to each programme are shown in detail in the PABRA breeding strategy (PABRA, 2011). Since no one bean variety or market class can meet the diversity of market needs in a country or region and because most

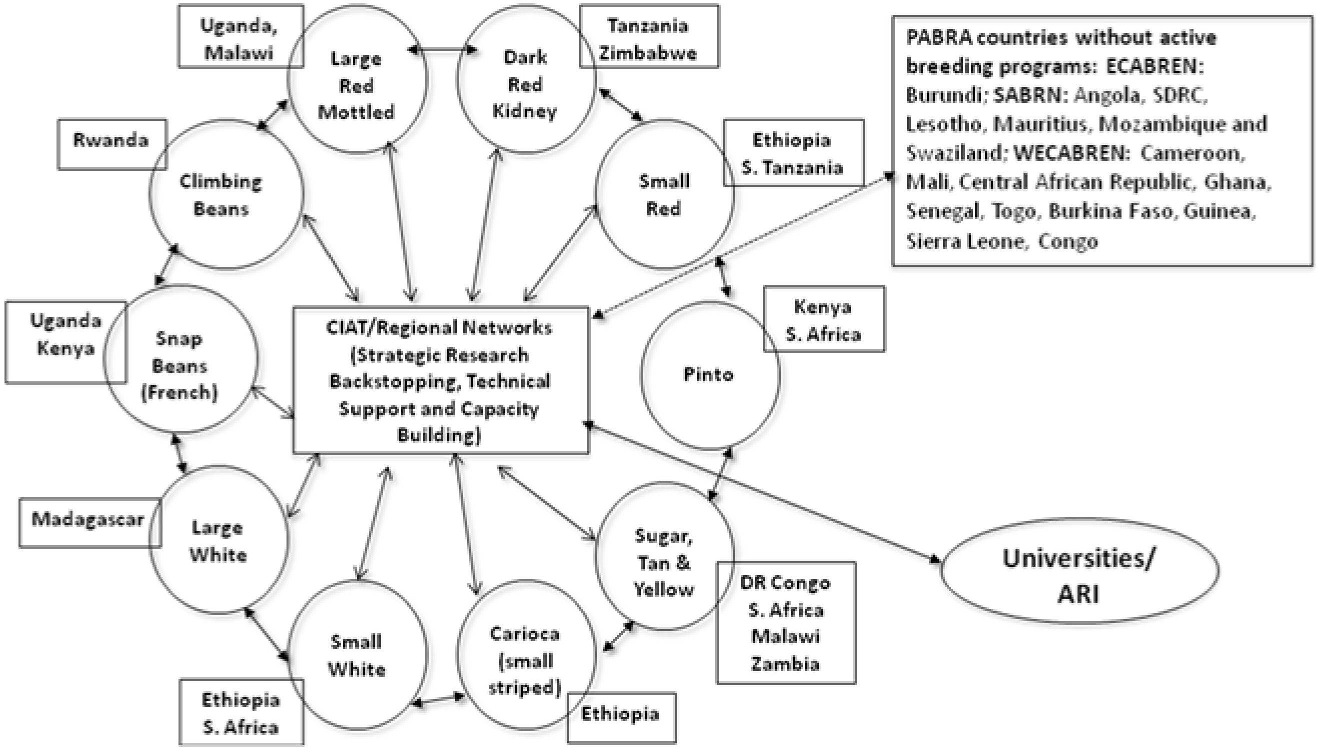

Figure 3. Shared breeding responsibilities under PABRA: involving 1) CIAT Headquarter breeding program in Colombia and the regional breeding programs of ECABREN and SABRN (central rectangle); 2) national bean programs responsible for different types of beans (peripheral rectangles attached to circles); and 3) various universities and advanced research institutes (ARIs). Arrows show the relationships among the different national and regional breeding efforts, which are interconnected. Countries without active breeding programmes (largest rectangle) do not have specific responsibilities but conduct adaptive testing of fixed lines or released varieties obtained through the regional networks.

national bean breeding programmes do not have the capacity to address all researchable issues and provide all the various bean product types the market demands, seven breeding programmes that respond to food and market needs across various countries under PABRA were developed (Table 1).

PABRA's strategy for delivery of improved bean varieties. During the 1990s, PABRA members conducted a series of field studies to identify actors already engaged in seed related activities, including those focusing on the local seed system, from which farmers source over 90% of their seed (Sperling *et al*., 1996; David and Sperling, 1999), as well as a diverse range of non-governmental organisations (NGOs), community-based organisations (CBOs) and farmers organisations (FOs) who were involved in seed production for varying periods. From this analysis, an explicit strategy emerged in 2003, called the Wider Impact Programme (WIP), which aimed to catalyse efforts among these multiple seed chain actors. The new strategy was to de-emphasize the standard approach which puts the onus of seed production and delivery on centralised NARS, government extension systems, and formal seed suppliers and embrace a collaboration approach which builds on varied organizational strengths and which generally decentralizes the cores of action (Rubyogo *et al*., 2010). Experiences from the WIP indicate that a fragmented set of actors had much to gain by working together but also by reflecting on what each can do best (Rubyogo *et al*., 2010). So, NARS, private companies, local seed/grain traders, farmers' groups (NGOs, CBOs, FOs), individual entrepreneurs have all joined in ongoing and operation-based platforms, to rework the seed delivery business.

Seed systems operations involve different activities, ranging from the initial identification of farmers' variety preferences; to seed production and post harvest management; to marketing/supply of preferred varieties; to information exchange about varieties; to building the skills of partners all along the production and delivery sequence (Rubyogo *et al*., 2010). These operations cannot be carried out by a single organisation. To leverage partners' complementary skills, the programme went though processes of: a) analysing each type of partner's strengths and weaknesses, and then b) sharpening their respective roles toward an integrated set of production and delivery activities.

Through this undertaking, the Alliance actively sought to develop effective linkages with, and enhance the capacities of, key actors in the seed delivery value chain to improve access to breeder, foundation, certified and other quality seed. Recent studies have shown that the use of small packets can greatly enhance access to and utilisation of improved bean varieties as well as complementary technologies (Rubyogo *et al*., 2007; TL II, 2010). This is because they are more affordable, facilitate farmers (especially women and other marginalised groups) to experiment with new technologies with minimal risks, and build-up effective demand which can stimulate new investment in seed industries (Sperling *et al*., 1996; David *et al*., 1997; David and Sperling, 1999). An innovative two-pronged approach of seed delivery has been adopted, involving affordable small seed packs for directly reaching resource-poor farmers and larger seed packs to meet the demand for foundation seed by partners such as seed companies, farmer organisations and NGOs. The success story of the seed delivery system for climbing bean in Rwanda, which is now spreading across the continent, is one of the best examples of the development and delivery of bean varieties in Africa (Rubyogo, 2004).

Principles underlying the PABRA strategy for breeding and delivery of varieties. Division of responsibilities is a core principle of the strategy. Initially, more capable NARS bean programmes were provided with parental lines by CIAT headquarters and the regional breeding programmes in SABRN and ECABREN for use in generating segregating populations. NARS programmes with intermediate capacity received segregating populations from CIAT headquarters and the regional breeding programmes; while countries without breeding programmes (Burundi, Angola, southern DRC, Lesotho, Mauritius, Mozambique, Swaziland, Cameroon, Mali, Central African Republic, Ghana, Senegal, Togo, Burkina Faso, Guinea, Sierra Leone and Congo) received

TABLE 1. Priorities of decentralised bean programmes under PABRA based on bean market types, production area, major constraints, national interest and capacity

Bean type/market class	Production (ha)	Major constraints	Programme	Countries where the bean types are of high or moderate importance
A. Bush				
I. Red mottled	740,000	ALS, Anth/RR, low P, BSM	Programme –1	**Kenya, Uganda**, DR Congo, **Tanzania**, Sudan, **Malawi**, Sudan, **Zambia**, Zimbabwe, Cameroon, Angola and Mozambique
II. Reds				
IIa. Large red kidneys	350,000	ALS, Anth, low P, BSM	Programme-2a	**Kenya, Tanzania, Malawi, Zimbabwe,** Zambia, Mozambique
IIb. Small and medium reds	670,000	ALS, Anth, /CBB, low P, BSM	Programme-2b	Rwanda, Burundi, Ethiopia, **Kenya, Uganda**, **Tanzania**, DR Congo, Lesotho, Zimbabwe
III. Browns IIIa. Yellow IIIb. Brown IIIc. Tan	380,000	ALS, Anth/CBB, RR, low P	Programme-3	Angola, Tanzania, Kenya, Madagascar, Sudan, **DR Congo, Zambia**, Tanzania, Zimbabwe and Lesotho
IV. Cream IVa. Pinto IVb. Sugars IVc. Carioaca	360,000	ALS,CBB/rust, low P	Programme-4	Angola, **South Africa, Kenya, Uganda**, Zambia, **Zimbabwe,** Lesotho, Malawi and Mozambique
V. White				
Va. Navy	310,000	Rust, ALS, CBB,BSM	Programme-5a	**Ethiopia, South Africa**, Malawi, Uganda, Tanzania, DR Congo
Vb. Large white kidney	220,000	ALS, Anth, low P	Programme-5b	**Madagascar**, Tanzania, Zambia, **South Africa**, **Zimbabwe**, and, DR Congo
VI. Purples	270,000		No programme-6	**Tanzania, Kenya**, Zambia, Madagascar
VII. Blacks	130,000		No Programme-7	**Uganda, Ethiopia**, Sudan and Angola
B. Climbers		Anth., ALS, RR, low P	Programme-8	**Rwanda, Burundi**, DR Congo, **Kenya,** Ethiopia, Zambia, Tanzania and Malawi
C. Snaps				
C1. Bush C2. Climbers C3. Runner climbers		Rust, RR, ALSAnth, RR, ALS	Programme- 9	**Kenya, Uganda, Tanzania**, Zambia, **Zimbabwe,** Malawi and **South Africa**

Anth = anthracnose; ALS = angular leafspot; RR = root rots; P = phosphorus; CBB = common bacterial blight; BSM = bean stem maggot. Constraints are arranged in order of priority from high to low for each market class. Countries highlighted in bold have well established national breeding programmes that can generate and handle segregating populations. Market class is a grouping of bean grain based on colour, size and shape, which represent different market preferences. Beans are also grouped based on growth habit (bush beans and climbers) and use (e.g. dry and snap beans) fixed lines and varieties from other countries which were either at the pre- release or release stages (Table 2). Marker assisted selection was used in those cases where reliable markers for target biotic constraints had been identified and could be used routinely in the breeding programme (Table 3).

A core guiding principle of PABRA's breeding strategy is participatory plant breeding (PPB) and participatory varietal selection (PVS), of which the Alliance is a trailblaser (Sperling *et al.*, 1993; 2001). The PPB and PVS methods have been adopted by PABRA researchers to focus research on specific client needs and to hasten the uptake of breeding products. Different PPB and PVS methods and tools have been diffused in all PABRA countries and the release of varieties typically involves the use of PPB and PVS approaches.

The Alliance's bean delivery strategy is based on three key principles, and addresses major issues that hinder the successful adaptation and/or adoption of technologies by resource-poor farmers (AATF, 2006): (1) divisibility of the technology; (2) congruence of the technology with farmers' practices; (3) reduction of the cost, risk, and uncertainty associated with adoption of bean varieties. These principles have been applied using the small pack approach, which ensures that new bean varieties are affordable and farmers can experiment with them and gain confidence to adopt the varieties at minimal risk.

PABRA's achievements in breeding and delivery of bean varieties. PABRA's breeding strategy has worked well for the Alliance, whose members (various NARS bean programmes across Africa including those that do not have active breeding programmes) released 146 improved bean varieties during 2003-2008. Each variety had combined resistance/tolerance to two or more production constraints and some varieties have

TABLE 2. Countries with different breeding capacities within PABRA and types of breeding materials and tools used by the national bean programmes

Network/Country	Use molecular tools	Generate segregating populations	Use segregating populations	Use fixed lines and varieties
WECABREN	-	-	-	+
Angola	-	-	-	+
Burundi	-	-	-	+
D.R. Congo	-	-	-	+
Ethiopia	-	+	+	+
Kenya	+	+	+	+
Lesotho	-	-	-	+
Madagascar	-	-	-	+
Malawi	+	+	+	+
Mauritius	-	-	-	+
Mozambique	-	-	-	+
Rwanda	-	+	+	+
South Africa	+	+	+	+
Sudan	-	+	+	+
Swaziland	-	-	-	+
Tanzania	+	+	+	+
Uganda	+	+	+	+
Zambia	-	+	+	+
Zimbabwe	-	+	+	+

WECABREN (West and Central Africa Bean Research Network) countries: Cameroon, Central Africa Republic, Burkina Faso, Republic of the Congo, Ghana, Guinea Conakry, Togo, Senegal, Mali, and Sierra Leone receive fixed lines and released/pre-released varieties. "+" and "-" indicate presence or absence, respectively, of capacity of national bean programmes to use molecular tools and breeding materials

TABLE 3. SCAR (sequence characterized amplified region) markers being utilised to develop multiple disease resistant varieties in PABRA

Marker name	Pathogen	Tagged locus	Genotype	Reference	Country
SAS13	Anthracnose	*Co-4²*	SEL1308, G2333	Young *et al*., 1998 Kelly *et al*., 2003	Uganda, Kenya, Tanzania
SH18	Anthracnose	*Co-4²*	G2333	Awale and Kelly, 2001; Kelly *et al*., 2003	Uganda, Kenya, Tanzania
SBB14	Anthracnose	*Co-4²*	G2333	Awale and Kelly, 2001; Kelly *et al*., 2003	Uganda, Kenya, Tanzania
SAB3	Anthracnose	*Co-5*	SEL1360, G2333	Vallejo and Kelly, 2001; Campa *et al*., 2005	Uganda, Kenya, Tanzania
SAP6	CBB	*Major QTL*	GN#1 sel 27, BelNeb-RR-1	Miklas *et al*., 2000 a,b	Kenya, Tanzania, RSA, Malawi
SU91	CBB	*Major QTL*	XAN 159	Pedraza *et al*., 1997	Kenya, Tanzania, South Africa, Malawi
$SW13_{690}$	BCMV	*I*	Various	Haley *et al*., 1994; Melotto *et al*., 1996; Fourie *et al*., 2004	Uganda, Kenya, Tanzania
ROC11	BCMV	*bc-3*	Various	Johnson *et al*., 1997	Uganda, Kenya, Tanzania
SCAR-OPE4709	ALS	*Phg-2*	México 54	Mahuku *et al*., 2004	Uganda, Kenya, Tanzania
PYAA19	Pythium root rot	*PRR*	RWR 719	CIAT, 2006	Uganda, Kenya, Tanzania
PYBA08	Pythium root rot	*PRR*	RWR 719	CIAT, 2006	Uganda, Kenya, Tanzania
KB126, KB4 Hha	Rust	*Ur-11; Ur-13*	Teebus-RCR 2	Mienie *et al*, 2005, Liebenberg *et al*., 2010	South Africa

CBB = Common bacterial blight, BCMV = Bean Common Mosaic Virus, ALS = angular leaf spot

been released in more than one country, which helps to move seed from one country to another - facilitating regional trade (Table 4).

During 2009-2011, PABRA released 67 varieties with resistance to 2 or more stress factors, 13 of which were released for high Fe and Zn content, and 14 varieties released for specific niche markets (canning, snap and dry beans). Recent multiple stress resilient bean varieties were released or accepted on the basis of resistance to constraints such as fungal, bacterial or viral diseases, and tolerance to aboitic stresses like low soil fertility and drought, in addition to their high yield potential. Some of these varieties double as biofortified varieties with high Fe and Zn content (e.g. MAC 44 in Rwanda) or as niche market varieties (e.g. SUG 131 for sugar bean market in Malawi, Mozambique and Zimbabwe). Among these releases are the climbing bean varieties developed for heat tolerance in the medium to low altitudes (1600 - 800 masl) where the traditional climbing bean varieties could not grow. The new climbing bean varieties have potential to triple the yield of ordinary bush bean varieties grown by farmers in the medium to low altitudes, and improve food security and nutrition for rural households (Checa *et al*., 2006; 2008). In addition, these varieties are resistant to diseases and nutrient-poor soils, which are common in eastern, central and southern Africa (Lunze *et al*., 2007).

The PABRA model for bean crop improvement and dissemination of improved varieties demonstrates a successful collaborative initiative where germplasm can be quickly developed and efficiently distributed across several countries for wider use by end-users to improve people's livelihoods. It is estimated that during 2003-08, PABRA reached 7.5 million households with seed of improved bean varieties (impacting about 35 million people with bean based technologies). The Alliance plans to reach an additional 20 million households with bean based technologies by 2013, out of which 14 million will be reached with improved bean varieties.

All the 28 PABRA participating countries have adopted PPB and PVS approaches in their breeding programmes. The release of over 200 varieties in the last 8 years involved the use of

TABLE 4. Examples of multiple bean variety releases across PABRA countries (years indicate the year of release of the variety in the different countries)

Variety	ECABREN							SABRN							
	BU	E-DRC	ET	KE	RW	TZ	UG	AN	S-DRC	MW	MZ	ZA	SW	ZM	ZW
AFR708	-	2007	-	2008	-	-	-	-	-	-	-	-	-	-	-
FLOR DE MAYO	1987	-	-	-	1991	2006	-	-	-	-	-	-	-	-	-
G2333	-	-	-	2007	1991	-	1999	-	-	-	-	-	-	-	-
G685	1993	2004	-	2008	1991	-	1999	-	-	-	-	-	-	-	-
GASIRIDA	2010	-	-	-	2010	-	-	-	-	-	-	-	-	-	-
KATB1	2008	-	-	1998	-	-	-	-	-	-	-	-	-	-	-
KATX56	2008	-	-	1999	-	-	-	-	-	-	-	-	-	-	-
KATX69	2008	-	-	1998	-	-	-	-	-	-	-	-	-	-	-
RWR719	-	-	2003	2008	-	-	-	-	-	-	-	-	-	-	-
CAL143	-	-	-	-	-	-	-	1998	2011	1996	2007	-	2007	1997	-
SUG131	-	-	-	-	-	-	1999	-	-	2002	2007	-	2007	-	-
NUA45	-	-	-	-	-	-	-	-	2011	2009	2011	-	-	2011	2010
PC652-SS3	-	-	-	-	-	-	-	-	-	-	-	1999	-	-	2010
OPS-KW1	-	-	-	-	-	-	-	-	-	-	-	2001	-	2009	-

NB: BU = Burundi, E-DRC = eastern Democratic Republic of Congo, ET = Ethiopia, KE = Kenya, RW = Rwanda, TZ = Tanzania, UG = Uganda, AN = Angola, S-DRC = southern Democratic Republic of Congo, MW = Malawi, MZ = Mozambique, ZA = South Africa, SW = Swaziland, ZM = Zambia, ZW = Zimbabwe

PPB and PVS, which led to significant adoption of the released varieties across PABRA countries (Table 5).

Challenges and opportunities in breeding and delivery of bean varieties in Africa. Challenges such as drought, root rots, heat, depleted soils, excessive rainfall, new pests and diseases and increased incidences and severity of existing pests and diseases pose new breeding challenges and require increased efforts to address them (Beebe *et al.*, 2008).

Climate models suggest that some 3.8 million ha of areas suitable for beans would benefit from drought tolerance improvement in the 2020s. An even larger area (7.2 million ha) would benefit from tolerance to heat, which implies further research on heat tolerance, with the establishment of heat stress sites at low elevation, for instance in West Africa. Breeding for water logging or heavy rainfall has not been addressed but is a problem in the Nile valley where flood irrigation is used, as well as areas with higher rainfall (>2000 mm) and is likely to be more common in the future in eastern Africa (Christensen *et al.*, 2007).

To overcome some of the inherent difficulties faced by conventional plant breeding, modern biotechnology tools have been developed and are growing in importance and use (Collard and Mackill, 2008). For instance, conventional methods are time-consuming, cumbersome to use for detection of certain desirable traits in the off-springs, and inefficient especially when handling multiple traits, as is the case for the PABRA bean breeding strategy that emphasises multi-trait improvement. These tools offer alternative and complementary options whose major advantages are in enhancing the efficiency, speed and effectiveness of developing new bean varieties. In the common bean, the implementation and adoption of MAS in breeding for disease resistance is advanced compared to the implementation of MAS for insect and abiotic stress resistance (Miklas *et al*., 2006)

Bean breeding programmes should aim to adapt, improve and widely test under-utilised *Phaseolus* species - the wild ancestors of the *Phaseolus* bean (*P. vulgaris*) and its relatives - to address emerging stresses. Sister species of

TABLE 5. Adoption levels for improved varieties in different countries

Location, year	Data collection method	Levels of adoption	Source
Ethiopia, Melkassa and Awassa	Survey (260 farmers)	27%	Kalyebara *et al.* (2007)
Ethiopia Nationwide, 2011	Expert survey	1 - 29% (depending on location and variety)	DIVA, unpublished
Kenya Kakamega and Vihiga District, 2001	Survey (383 farmers)	35-80% (depending on location and variety)	CIAT (2004); Kalyebara *et al.* (2007)
Tanzania, northern western and north eastern, 2004	Survey (306 farmers)	54%	CIAT (2008a); Kalyebara *et al.* (2007)
Tanzania nationwide, 2011	Expert survey	3 - 19% (depending on location and variety)	DIVA, unpublished
Uganda, six districts	Survey (529 farmers)	20% -80% (average 51%)	CIAT (2008b); Kalyebara *et al.* (2007)
Rwanda, nationwide, 2004	Survey (383 farmers)	94% of climbers by climbing bean farmers and 65% adoption in general	CIAT (2008c); Kalyebara *et al.* (2007)
DR Congo, KivuProvince	Survey (240 farmers)	82%	Kalyebara *et al.* (2007)

DIVA refers to a CGIAR-wide project called Diffusion and impact of improved varieties in Africa (http://impact.cgiar.org/in-progress/diva) common bean of the secondary gene pool which can be crossed readily with *P. vulgaris* include both domesticated species (such as *P. dumosus* and *P. coccineus*) and truly wild forms (Beebe *et al*., 1997; Singh, 1988; 2001; Beebe *et al.*, 2001; Freytag and Debouck, 2002). The tepary bean (*P. acutifolius* is a fourth domesticate but can be crossed only with great difficulty, and crosses with *P. lunatus* (the lima bean) produce only sterile F_1 plants. These species have unique adaptation traits that are useful targets for introduction into common beans (*Phaseolus vulgaris)* bean either through standard genetic improvement and/or through wide-crossing/introgression (Freytag and Debouck, 2002; Singh, 1988; Singh and Urea, 1995) with the objective of meeting commercial standards of grain type, as well as agronomic productivity.

A pre-emptive breeding strategy that takes advantage of the diversity of agro-ecologies that are found in PABRA participating countries needs to be adopted. The concept of interdependence can be used to assess which Alliance member countries currently experience conditions that will be found in other countries in the future. Breeding and selection can, thus, be undertaken in those environments with the results ready to be transferred at a future date. Recently developed tools in the Climate Change for Agriculture and Food Security consortium research programme (CCAFS) such as 'Analogue' climates are useful for providing the basic information on similar sites according to various climate change scenarios, while initiatives like the 'Global Agricultural Trial Repository' allow for the querying of past evaluation results of varieties in different environments.

Breeding for enhanced micronutrient content requires improving a spectrum of traits essential for varieties to be adopted by farmers (Pfeiffer and McClafferty, 2007). Some countries have already identified or released some bean varieties with high Fe and Zn content; however, there is need to develop other new varieties which combine acceptable agronomic and grain characteristics, resistance to biotic/abiotic stresses and high micronutrient content. The new germplasm should be rigorously evaluated in regional nurseries across countries to establish the genotype x environment interactions and to determine wide or specific adaptation of promising advanced micronutrient-rich lines.

Runner bean has potential in domestic and international markets; however, the current export trade of countries such as Kenya is reliant upon production under artificial lighting and, therefore, is largely in the hands of large-scale producers. There is a need to develop dry and snap runner bean varieties adapted to short tropical day length that small scale farmers can grow in their fields without the need for artificial light.

Even as breeders continue to develop new varieties, a majority of already developed multiple stress resistant varieties are yet to reach all the targeted recipients. This implies the need to increase efforts to promote these varieties. These efforts would require a favourable institutional and policy environment for germplasm development, variety release and seed production to ensure quick delivery of technology to end-users (Katungi *et al.*, 2009).

CONCLUSION

This article has reviewed the breeding and seed delivery strategy of the three PABRA facilitated networks and given a glimpse of some of the gains made in plant breeding and seed sector development spanning over a period of three decades. The accomplishments of NARS partners have been remarkable and have positively impacted over 13 million farmers in terms of seed access alone between 2003 and 2010. However, far from being complacent, the networks see the need to make research even sharper and to allow delivery of improved varieties to proceed on a more expansive scale and at even faster pace. In this vein, we suggest eight concrete recommendations at policy level - as research can flourish if the policy environment is truly enabling.

In terms of plant breeding:

1. Varieties should be released only if they have been shown to be end-user acceptable. Varieties are adopted by farmers and it is a financial waste to develop and release varieties which farmers find unacceptable. Minimally, release data has to include field-

level evidence that farmers (women and men) find the varieties performing well under their own management conditions and that they are acceptable in terms of organoleptic and market attributes.

2. ‘Participatory’ breeding and variety selection work should give due recognition to farmer-breeders, alongside their formal plant breeder cohort. Embracing PVS and PPB implies that varieties have been developed jointly. This joint R+D should be recognized officially, in varietal release statements and in terms of specific access and benefit-sharing arrangements. National policies should entail mechanisms for evaluation of farmer selected varieties and landraces and consider suitable varieties in the national list of varieties.
3. Pre-conditions for release of varieties in one country should build on extensive regional expertise. Varieties released in two or more countries of the same regional bloc (and experiencing similar agro-ecological and user traits) should be validated with users and immediately marketed if they satisfy farmers' needs. This is in line with proposed seed policy harmonisation and trade across regional economic blocs such as the Southern Africa Development Community (SADC), the Economic Community of West African States (ECOWAS), and the Common Market for Eastern and Southern Africa (COMESA).
4. Public sector research has to commit to producing breeder seed - as an integral part of the variety development process. There is no sense in releasing a variety (or engaging in breeding) if that variety is not set on a course for multiplication.

In terms of seed production and delivery

5. Foundation seed multiplication should be carried out by a diversified set of actors. Experience across regions shows that public sector seed facilities cannot meet the needs for foundation seed of the bean crop (or, indeed, many of the legumes). Private sector partners and farmers unions and cooperatives should systematically be incorporated into the foundation seed multiplication processes.
6. Market imperfections in the seed market present a scenario of slow diffusion and adoption of common bean varieties (Katungi *et al*., 2009). Decentralised seed production initiatives need to be facilitated and promoted at the national and regional levels. Varieties do not move by themselves and classic, top-down models of production and delivery are not sufficiently serving a range of farmers, including in geographically disperse or marginal areas. Decentralised models of seed production and delivery have to be promoted actively, and a range of seed classes, beyond certified seed, have to recognised as legitimate in serving small farmer wants and needs. Standards for quality control in decentralised (community-based) seed production should be adapted to local level (social certification) rather than having to meet international or national requirements. The decentralised models also should have a clear marketing component (including niche markets) which will render them sustainable and not subsidised or tied just to institutional clients.
7. There is need for deliberate policy frameworks to encourage the use of complementary improved integrated crop management (ICM) practices so that farmers can realise the potential benefits of improved varieties, as varieties alone will hardly make a big difference in crop productivity farm level.
8. The success of an R4D networks and alliances greatly depends on a high level of partnership, ownership and commitments at both national and regional levels. This requires an enabling national policy environment for partners to work together and share benefits equitable, which is promoted by PABRA.

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