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CHAPTER 10

IRON BEANS IN RWANDA: CROP DEVELOPMENT AND DELIVERY EXPERIENCE

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ABSTRACT

HarvestPlus and its partners have successfully developed and delivered iron bean varieties to more than one million farming households in Rwanda, DRC, and Uganda to help combat the adverse health effects of iron deficiency widespread in these countries. Focusing primarily on Rwanda, this chapter summarizes the country, nutritional and consumer background, crop development, release, and delivery of iron bean varieties and synthesizes lessons learned and future challenges.

Key words: Biofortification, iron bean, iron deficiency, micronutrient deficiency, common bean

INTRODUCTION

The common bean (*Phaseolus vulgaris*) is one of the most widely consumed legumes in eastern and southern Africa, including Rwanda, Democratic Republic of Congo (DRC), and Uganda. Rwanda has the highest per-capita bean consumption in the world, with many varieties of beans consumed, covering a wide range of colors and sizes.

Anemia is a condition characterized by a reduction in red blood cell volume and a decrease in the concentration of hemoglobin in the blood. About half of the global burden of anemia is due to iron deficiency. Iron deficiency is largely due to an inadequate dietary intake of bio-available iron, increased iron requirements during rapid human growth periods (such as pregnancy and infancy), and/or increased blood loss due to parasites or infection. Iron deficiency and anemia have seen marked improvement in Rwanda over the past 15 years, but anemia continues to affect 37% of children under 5 years of age and 19% of women of childbearing age [1].

Biofortified iron beans are conventionally bred varieties with relatively higher iron levels than most traditional varieties. Consuming biofortified beans results in increased iron intake and can contribute to resolving iron deficiency anemia.

The first varieties of iron-biofortified beans were approved by the Government of Rwanda for official release in 2010, a full seven years after crop development activities were first initiated at CIAT (the International Center for Tropical Agriculture) through funding from HarvestPlus in 2003. Six years after release and thirteen years after initial research activities began, it is estimated that more than 800,000 Rwandan farm households are growing and consuming iron beans, which contain significantly higher amounts of iron than their conventional counterparts. Iron beans have also been released and delivered by HarvestPlus and its partners in DRC and Uganda, and represent a source of increased dietary iron in diets in these countries. However, the main focus of this chapter is the experience of developing and delivering iron beans in Rwanda.

This chapter provides an overview of: (i) the policy background and justification for developing, introducing, and scaling up use of iron beans in Rwanda; (ii) an overview of crop development activities; (iii) the strategy and experience-to-date with dissemination of biofortified bean varieties in Rwanda; and (iv) completed and planned efforts to measure impact. The concluding section draws lessons learned and describes the steps that Rwanda has taken to sustainably integrate iron beans into the food system, while also drawing on the delivery experience in DRC and Uganda.

POLICY BACKGROUND AND JUSTIFICATION: PRE-RELEASE ACTIVITIES

Prevalence of Iron Deficiency, Iron Interventions, and Dietary Sources of Iron

While crop development is ongoing but before the first varieties are released, it is necessary to develop evidence to demonstrate the viability and cost-effectiveness of biofortification and to use this information to convince policymakers to support a biofortification strategy as a means to address micronutrient deficiencies in human diets.

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This section summarizes the rationale for developing and delivering iron beans in Rwanda.

Iron deficiency. Iron deficiency during childhood and adolescence impairs mental development and learning capacity. In adults, it reduces the ability to perform physical labor. Severe anemia in pregnant women increases the risk of premature births and/or the woman dying in or after childbirth.

Although Rwandans are the highest per-capita consumers of beans on the planet, many of Rwanda's 11 million inhabitants have inadequate dietary iron intake and a high risk of iron deficiency, particularly infants and young children. Despite a marked and progressive decline in anemia prevalence in the past 15 years, 37% of children under 5 years of age and 19% of women of childbearing age still suffer from anemia [2], about 50% of which is caused by iron deficiency [3]. The decrease in the prevalence of anemia between the 2010 Rwanda Demographic and Health Survey (DHS) and the 2014-15 Rwanda DHS was minimal [2].

In Rwanda, malnutrition disproportionately affects rural areas, and children in rural areas are more likely to be anemic (38 percent) than children in urban areas (30 percent). There is little significant variation in anemia prevalence by province, but children in the city of Kigali are least likely to be anemic. For young children, the prevalence of anemia decreases as they grow older, declining from 72 percent among children 6 to 8 months of age to 21 percent among children 48 to 59 months of age [2].

Anemia is less prevalent among women than children. The prevalence of anemia is higher among pregnant women (19 percent) than non-pregnant women of childbearing age, due to increased nutritional needs during pregnancy. The general trends seen in anemia prevalence among children hold for women; prevalence is slightly higher among women in rural areas, and is least prevalent in the City of Kigali.

Addressing iron deficiency. There are no government-sponsored iron supplementation programs for infants and young children in Rwanda. According to the most recent DHS (2014-15), about 8 in 10 women took iron supplements during their last pregnancy. Most pregnant women (68%) took iron for fewer than 60 days and only 3% took iron for the recommended 90 or more days. Iron fortification of commonly consumed foods is absent in Rwanda. Overall, there is a need for additional iron in Rwandan diets, particularly for children and women of childbearing age.

Dietary sources. Among the richest sources of iron in Rwandan diets are meat, fish, poultry, and eggs, but these sources are not available to all Rwandans. While the average iron concentration in beans is high compared to other major staple crops like wheat, rice, and maize, it is still not sufficient to meet daily iron needs in the absence of other iron-rich foods. Many people in Rwanda therefore suffer from iron deficiency due to an insufficient level of bioavailable iron in a monotonous bean-based diet.

Bean Production and Consumption Patterns

Beans are produced throughout Rwanda. Both bush and climbing bean varieties are cultivated in two crop cycles per year. Climbing bean varieties are widely grown in the Northern and Western Provinces, while bush bean varieties are more dominant in Kigali, Eastern, and Southern provinces. One fifth to a third of bean farmers plant both types of beans (climbing and bush) [4].

Rwandans have the highest per capita bean consumption in the world, with an estimated per capita bean consumption of around 164 g/day [5, 6]. In an average Rwandan diet, beans provide 32% of calorie intake and as high as 65% of protein intake, whereas animal source foods provide only 4% of protein intake [7]. On average, households eat beans 5 days a week [8]. The HarvestPlus varietal adoption survey found that nearly all (99.9%) rural households consumed beans in the past 7 days prior to the interview, with an average bean consumption frequency of 6 days a week [9]. Only a quarter of these households had consumed meat, and meat-consuming households, on average, ate meat on 2.6 days per week. The majority of household bean consumption in rural areas comes from own production (79-88%, depending on the season) while the remainder is purchased from the market [10].

Setting Iron Target Levels for Bean Breeders and Establishing Nutritional Efficacy

The general methodological approach for setting target levels for plant breeders is presented in Chapter 1. As discussed, targets are based on age- and gender-specific nutrient requirements, daily consumption amounts of beans, micronutrient retention after traditional storage and cooking, and the bioavailability of iron from beans, i.e. the degree to which the human body can assimilate the iron contained in the beans. Conventional bean varieties contain a baseline content of iron to which a target increment is added through biofortification.

Bean intake. A 24-hour recall study conducted by HarvestPlus in 2011 found the average daily consumption of beans for women, children between the ages of 6-24 months, and children between 36-59 months of age, to be 123g, 47g, and 65g, respectively [11].

Iron retention. Iron retention in beans after cooking is close to 100% in Rwanda, because beans are not pre-soaked before cooking and none of the water used for cooking is discarded. Retention studies were carried out by the Kigali Institute of Science and Technology (KIST) in 2012. Results indicate that approximately 98% of the iron in raw beans is retained through the traditional cooking process in Rwanda. Retention of 90% was obtained in experiments conducted by Brazilian collaborators [12].

Bioavailability. The results of the bioavailabity and efficacy studies on biofortified beans are promising. Based on human studies, the original estimate of 5 percent bioavailability has been increased to 7 percent. A bioavailability study of young women found that the participants absorbed significantly greater amounts of iron from biofortified beans compared to the conventional beans [13].

Based on assumed values for estimated daily average iron requirements, intake, retention and bioavailability, and for realistic iron increments through breeding, a target iron increment of 44 parts per million (dry weight) was set in 2003, aimed at providing children and women with 40 and 30 percent of additional iron, expressed as percentages of respective estimated average daily requirements (Table 10.2). Taking into account that, on average, non-biofortified bean varieties already carry a baseline iron density of 50 ppm, the breeding target was set to 94 ppm.

Although individual values for intake, retention and bioavailability have been updated significantly since the target was set in 2003, aggregate change has remained limited and the original breeding target increment of 44 ppm over a 50 ppm baseline has been maintained. Iron beans with the full target level, 94 ppm of iron, provide 127% and 80% of daily estimated average requirements of children and women, respectively (Table 10.2). As discussed below, released varieties contained about 60% of the iron target level in the first wave, 80% in the second wave, and 100% in the third wave.

Demonstrating Nutritional Efficacy and Consumer Acceptance

Efficacy trials. An efficacy study showed that women between the ages of 18 and 27 who consumed biofortified beans, exhibited increases in hemoglobin and total body iron levels [14]. Participants in this double-blind randomized efficacy trial consumed between 150-175 grams of cooked beans for lunch and dinner for 18 weeks. The biofortified beans used in this study contained 86 ppm iron, while the control beans contained 50 ppm iron. The methodologies used, results, and signifiance of efficacy trials for a range of biofortified crops are discussed in more detail in Chapter 2.

Consumer acceptance. To understand consumer acceptance of iron bean varieties, which are not visibly different from non-biofortified varieties, sensory evaluation and “willigness to pay“ (WTP) studies were conducted in both rural and urban areas of Rwanda. Sensory evaluation studies (Tomlins et al., forthcoming) revealed that while there were substantial sensory differences between beans varieties (biofortified or not) with respect to appearance, texture, odor and taste, these were not related to the iron content. Therefore, it is unlikely that consumers will be able to differentiate beans of differing iron levels by sensory factors alone. Iron biofortification therefore does not constitute an impediment to consumer acceptance.

“Willingness to pay“ (WTP) studies revealed that consumers in rural areas like biofortified varieties as much as – if not more than – their conventional counterparts, even in the absence of information about their nutritional benefits [15, 16, 17]. One exception was the white colored iron bean variety which was, in fact, preferred by consumers in urban areas. WTP studies also showed that providing information about the nutritional benefits of iron bean varieties has significant impact on both urban and rural consumers‘ preferences for these varieties vis-a-vis conventional ones.

In order to shed light on farmer acceptance of iron bean varieties, a farmer feedback study was conducted in 2012, following two seasons of delivery of the first five releases [18]. More than 300 iron bean growers in the Northern, Southern and Eastern provinces of the country were interviewed and it was found that the growers liked various consumption

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and production attributes of iron bean varieties at least as much as – if not more than – their most popular conventional varieties. The primary reason farmers gave for growing iron beans was the yield potential of these varieties, cited by 35% of the interviewed farmers, followed by wanting to try a new variety (30%), and finally, the nutritional benefit (16%). About 80 percent of farmers indicated that they wanted to plant the iron bean varieties in the following season, of which 85 percent stated that they wanted to allocate a larger area to iron beans in the following season. Farmers saved on average 25% of their iron bean output to use as planting material in the next season, 35% of the harvest was kept for household consumption, while 30% was sold and the remainder (about 10%) was shared with others in their social networks. A quarter of the farmers gave some iron bean grain to others in their social networks and over half said that they recommended the variety to another farmer, revealing significant diffusion opportunities for iron beans.

Cost-Benefit Analysis

Ex ante cost/impact. The ex-ante impact analysis uses modeling tools and a 30-year time horizon, with assumptions about future coverage (adoption and consumption rates), costs (of breeding and delivery), and the micronutrient content of iron beans. According to a preliminary ex-ante impact analysis conducted with the assumption of 80% replacement of conventional bean varieties with iron beans (with 94 ppm iron content), the cost per DALY (Disability Adjusted Life Year – a measure of health benefit) saved is $239. According to the World Bank, interventions that cost less than $246 per DALY saved are highly cost-effective. The cost per DALY saved in Rwanda is somewhat higher than in other countries where biofortification is being piloted. This is due to changing conditions during the time that biofortified beans have been developed, in particular, the national reduction in anemia prevalence over the past 15 years.

Biofortification Prioritization Index (BPI). The BPI prioritizes countries for vitamin A, iron, and zinc biofortification interventions based on their production and consumption of target crops and the rate of micronutrient deficiency among the target population. Rwanda ranks as the number 1 country for the introduction of iron beans among 127 countries in Africa, Asia, and Latin America and the Caribbean [19]. Given Rwandan households' high levels of bean consumption and reliance on their own production to meet household bean needs, introduction of iron bean varieties is an effective and targeted public health intervention to alleviate iron deficiency in the country.

Advocacy

In Rwanda, food insecurity, especially among small-scale farmers, is given top priority on the national agenda. In the last 15 years, public health and nutrition have experienced progressive improvements, attributed to the Health Care System Reform and the National Plan to Eliminate Malnutrition [20, 21].

Securing policy and financial support from national policymakers and other key stakeholders for biofortification activities is a key element of a succesful scaling up strategy. Efforts began prior to the release of biofortified varieties and continue today. High level policy engagement at the national governmental level and with donors helped to integrate the production and consumption of biofortified crops, such as iron beans, into national food and nutritional policies. For example, the Government of Rwanda (GoR), through the Ministry of Agriculture and Animal Resources' National Food and Nutrition Policy, highlights biofortified crops as a strategy to improving nutrition in the country. Further, the Ministry of Agriculture and Animal Resources' Strategic Plan for the Transformation of Agriculture in Rwanda – Phase II Report (2009) – recognizes consumption of legumes, such as iron beans, as a major source of nutrition, that includes both protein and essential micronutrients such as iron.

The close working relationship which HarvestPlus established with the Rwanda Agriculture Board (RAB) has been essential to scaling up biofortified bean production. RAB conducts research related to varietal development and release, produces basic seed, and provides extension and seed inspection services in Rwanda. Linkages with the Ministry of Health, through participation in the joint nutrition taskforce, help build stronger nutrition messaging and integration of iron beans into Ministry nutrition policy. For example, iron bean varieties are now being demonstrated at and promoted by community health clinics.

BREEDING PROGRESS AND VARIETY RELEASES

Screening, Pre-breeding, and Population Development

During an exploratory phase (1994–2002) under the Pan Africa Bean Research Alliance (PABRA) led by the International Center for Tropical Agriculture (CIAT), more than 1,000 bean germplasm accessions from the global gene bank held in trust by CIAT were screened, including local collections from 10 countries that belong to the East and Central African Bean Research Network (ECABREN). Grain mineral levels ranged from 30–110 ppm for iron (and 25–60 ppm zinc), with the highest concentrations often found in progenitors or wild relatives of common bean [22, 23]. Furthermore, a substantial positive association (60-80%) was discovered between iron and zinc levels, which provided an opportunity for raising levels of both micronutrients simultaneously [24].

During HarvestPlus Phase I (2003–2008), pre-breeding feasibility and trait heritability studies were completed and population development initiated at CIAT (in Colombia), building on previous research. Early product development involved identifying parental genotypes for use in crosses and understanding the genetics of the trait. High-iron genotypes were used to conduct crosses to combine the high-mineral trait with acceptable grain types and agronomic characteristics [25]. Genotype-by-environment (GxE) tests were conducted to verify that mineral accumulation was stable across sites and generations [26].

In Phase II (2009–2013), a number of lines were developed that expressed more than 80 percent of the iron target level without compromising agronomic performance or end use quality. Wide crosses were conducted with *P. dumosus* and tepary beans (*P. acutifolius*), to introgress higher grain iron to common bean adapted materials [27]. Double-crosses with 2 or 3 high iron parents are another strategy that proved to be effective for further boosting iron levels.

The resulting high iron lines (intermediate development stage products and advanced materials) were then introduced to breeding programs in the two target countries of Rwanda (with cooperation from RAB), and DRC (through technical cooperation with the National Institute for the Study and Research of Agriculture, or as it is known in French – L'Institut National pour l'Etude et la Recherche Agronomique – INERA) for adaptation testing under local growing conditions, both at experiment stations and in farmers' fields. National breeding programs have since started developing crosses locally and are assuming a greater portion of the selection work. Full breeding pipelines, consisting of both locally developed germplasm and CIAT introductions, are now established in both Rwanda and DRC.

Five first-wave iron bean varieties with 71-81 ppm iron were released in Rwanda in 2010, followed by five second-wave varieties with 74-91 ppm iron in 2012. In DRC, existing varieties high in iron were fast-tracked for delivery, followed by varietal releases in 2011, 2012, and 2013. Several full target varieties were in 2016 national varietal release trials in Rwanda, DRC, and Uganda. In Uganda, promising varieties were evaluated by the National Agricultural Research Organization (NARO) over 3 years in different agro-ecological zones for adaptability and resistance/tolerance to pests and diseases. On-station yield trials and on-farm participatory variety selection (PVS) trials led to the identification of three bush and two climbing beans which are well- adapted to local conditions and suit farmer and consumer preferences, and were officially released in 2016. Table 10.3 below indicates varieties released to date in Rwanda, DRC, and Uganda with their performance described in Figure 10.1.

Future Releases

In Rwanda, about 100 climber and bush bean lines are currently in advanced line validation trials to identify agronomically competitive varieties. Breeding efforts at CIAT and national research institutes are focused on developing climate-smart iron beans that are tolerant to drought and heat, higher yielding, robust, and adapted to a wide range of agro-ecological zones covering a broad range of market classes (grain color and size, cooking time, and taste).

Capacity Building

For crops with two or more growing cycles per year – such as the common bean – the development of analytical technologies is crucial for setting up effective biofortification breeding programs. Inexpensive, high-throughput methods are required for pre-screening large numbers of genotypes in plant population development, as well as sensitive analytical methods for reliable high-precision analysis of the mineral trait in lead materials. Under HarvestPlus, inductively-coupled plasma (ICP) is the gold standard for high-precision mineral analysis of iron and zinc, capable of detecting soil contamination [28, 29]. For high-throughput screening, X-ray fluorescence (XRF) spectrometry calibrations and standards were developed. XRF machines were installed and staff trained in National Agriculture Research System (NARS) labs in Rwanda, DRC, and Uganda.

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Regional Testing

Since 2012, a 50-entry regional nursery comprising released varieties and elite high-iron breeding leads from different countries has been deployed each crop season for GxE testing in Rwanda, DRC, Uganda, Burundi, and Malawi. The regional nursery serves as a germplasm dissemination and testing tool. Agronomic and iron data from multiple sites per country allow high precision identification of fast-track candidates for release, parental lines for breeding, as well as higher effectiveness in targeted breeding for yield and iron stability based on adaptive patterns. Further, by substituting temporal-by-spatial environmental variation in large-scale regional GxE testing, testing steps can be eliminated and time-to-market shortened by one to two years.

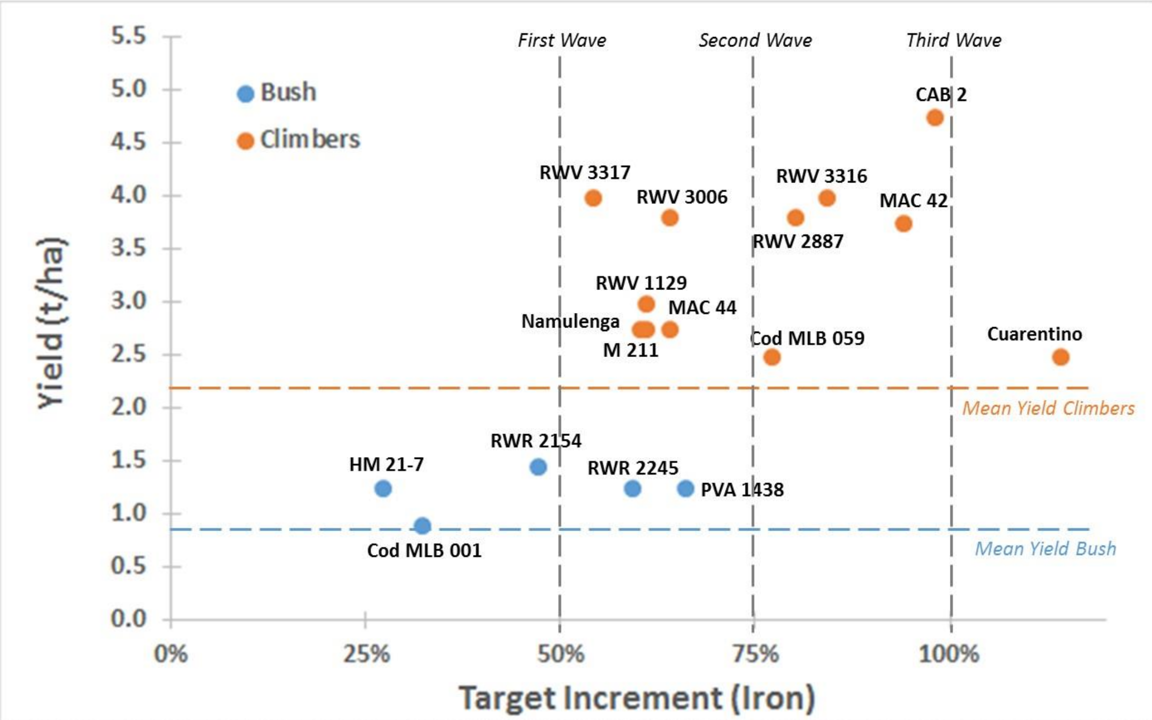

Figure 10.1: Performance of Iron Bean Varieties Released Under HarvestPlus

DELIVERY STRATEGIES AND RESULTS TO DATE

Rwanda

In Rwanda, the crop delivery work began in 2011, following the first biofortified bean varietal releases in 2010. According to monitoring data, HarvestPlus and its partners had delivered close to 3,000 metric tons of iron bean seed to over 800,000 farming households by the end of 2015. Delivery may be conceptualized and discussed as three broad sets of interdependent activities: (i) bean seed multiplication and delivery to farmers; (ii) creating and building consumer demand; and (iii) connecting supply and demand through markets. The foundation for successful introduction of iron beans in the Rwanda food system and, ultimately for its sustainability, is consumer demand. However, investment in strengthening the supply chain must be established prior to

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heavy investment in generating consumer demand. This section presents the delivery activities in Rwanda, followed by additional experiences from DRC.

Iron Bean Seed Multiplication and Delivery to Farmers

Seed multiplication. Foundation seed is produced by the Rwanda Agriculture Board (RAB). To facilitate the production of iron bean seed, HarvestPlus worked closely with RAB, contracting individual commercial farmers, farmer-based cooperatives, and small seed companies to multiply biofortified varieties. From 2011-2015, HarvestPlus procured about 80 percent of its certified seed through registered seed farmers under the supervision and certification of RAB, with the remainder produced through contracts with local seed companies. To increase available seed for the 2015 planting season and beyond, HarvestPlus partnered with established local and regional seed companies for seed multiplication, with RAB certifying the biofortified seed. These partners include SeedCo, Kenya Seed Company, Rwanda Improved Seed Company (RISCO), and Win-Win Agritec.

Following the introduction of iron beans, HarvestPlus strengthened the existing seed system by providing training for government seed inspectors and extension workers, farmer-based cooperatives, seed multipliers and agro dealers. These activities helped ensure that the integrity of the national seed system was developed and maintained through production of various seed classes. HarvestPlus and its partners also proposed a new seed class, ″Declared Quality Seed″ (DQS) or Certified II seed, first in Rwanda and then in DRC. DQS is produced from certified seed and is priced between certified seed and grain, bridging a price gap for farmers who are inclined to plant recycled grain rather than purchase certified seed.

Extension and delivery to farmers. In Rwanda the biofortification crop delivery program started in 2011 in four districts, Nyagatare, Kirehe, Ngoma and Musanze. In 2012, the program rolled out to thirteen additional districts and now operates throughout the country. The delivery program is implemented by HarvestPlus under the framework of cooperation between CIAT and the Government of Rwanda, including the Ministry of Agriculture and Animal Resources (MINAGRI) and RAB. Over the last four years, HarvestPlus has established partnerships with 124 different organizations at various levels in Rwanda, ranging from policy-focused organizations to field-based implementing partners. Partners include the World Food Programme's Purchase for Progress (P4P) initiative, FarmFresh, Development Rural du Nord (DERN), Development Rural Durable (DRD), Rwanda Farmers Federation (IMBARAGA), One Acre Fund, Rwanda Improved Seed Company (RISCO) and Union des Cooperatives Agricoles Integrées (UNICOOPAGI). Partner support comes in many forms, including policy direction, crop variety release, extension services, and seed and grain marketing.

Delivery of iron beans in Rwanda initially occurred through various platforms and mechanisms, including agro-dealers, farmer-based cooperatives, direct marketing in local markets, and a payback system. For all distribution channels, seed was sold at

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subsidized prices to allow greater farmer access.[1] In the direct marketing channel, farmers paid cash to agro-dealers and marketing agents for small seed packs, while in the payback and cooperative channels, farmers paid in kind after harvesting their crop. In direct marketing, marketing agents sold iron bean seed at local markets, reaching a large number of farmers with relatively small quantities of seed. This allowed farmers to try the varieties before committing to greater production. Agro-dealers sold iron bean seeds directly to farmers and had the advantage of being close to farmers throughout the year. HarvestPlus provided production and post-harvest training to agro-dealers, which they then passed on to their customers. Through the payback system, HarvestPlus and its partners sought rapid saturation of the bean market in specific geographies. In this channel, farmers and cooperatives received large quantities of iron bean seeds prior to the planting season, then “paid back” double the amount of seed received as grain at the end of the season.

By the end of 2014, HarvestPlus marketing data showed that an increasing number of farmers were purchasing iron bean seeds, either through agro-dealers or direct marketing. Seed purchases from agro-dealers were highest in Kigali and Eastern Provinces. While the largest quantity of iron bean seed was delivered through the payback channel, direct marketing reached the highest number of farmers, approximately 260,000.

As biofortified beans gained traction in the market, seed companies and agro-dealers became increasingly interested in iron beans in their product lines. From 2015 on, HarvestPlus has been working closely with the private sector to scale up production and delivery of iron bean seeds. A key aspect of the evolving technology adoption methodology is the use of a “seed swap” program. Working with local farmers and government extension agents (called farmer promoters), HarvestPlus staff and partners trade any conventional variety of seed for biofortified varieties, reducing farmer risk and encouraging adoption. The conventional seed serves as payment for the biofortified seed, and HarvestPlus liquidates the conventional seed as grain in the local markets, channeling sales income back into the project.

In addition to delivering iron bean seed to farmers, HarvestPlus and its partners also provide technical assistance on good agricultural practices to maximize bean production, including practices to reduce post-harvest losses. A multi-level approach to technical assistance, designed to reach a wide audience while maintaining cost-effectiveness, provides training to Rwanda’s decentralized administrative units, from provinces to districts, sectors, and cells. HarvestPlus conducts regular district-level Training of Trainers (ToT) for lead farmers and government extension staff. These trainers then provide sector-level training to cooperatives and farmers, managed by the sector agronomist. A community and cell-level training managed by the cell agronomist, then targets farmers and households for the last mile.

Differentiation in gender roles. Women have historically been the primary seed selectors and producers of beans in Rwanda, and women continue to be important bean

[1] Commercial seed sales are generally subsidized by the Government of Rwanda to encourage farmer uptake of improved seed, including hybrid maize seed.

growers both on their own farms and as members of farmer-based cooperatives. HarvestPlus recognizes the important role of women in bean production and as agents of change at the village level. Participatory varietal selection (PVS) of beans prior to release ensures that biofortified varieties will include the traits that women farmers value. HarvestPlus and its partners ensure that women and men have equal access to program activities, including technical assistance and training. Extension agents are trained on how to address gender-based constraints, and training programs are designed to meet women's preferences in cultivation techniques and input/land constraints. For example, women traditionally grow bush beans in Rwanda, and have been slower to adopt the higher yielding climbing bean varieties because additional labor and materials are required for staking the climbing beans. HarvestPlus and its partners are addressing this challenge through the introduction and testing of alternative staking technologies in the field.

According to the monitoring data recorded from 2011 to 2014, approximately 41 percent of overall iron bean seed purchases were made by female farmers and the distribution of their purchases across delivery channels was relatively even. Women's acquisition of iron bean planting material increased from 33 percent in 2012 to 42 percent in 2014.

Marketing

Having effectively scaled up the supply of iron bean seed, a systematic approach to grain market development was initiated in 2014 to absorb production in excess of household needs. This necessitated developing a better understanding of grain supply chains and building partnerships with grain traders, consolidators, retailers, and other private sector bean value chain participants.

In rural areas of Rwanda, household consumption is estimated to account for only 10% of all harvested beans (both non-biofortified and biofortified), while rural grain aggregators, including informal grain traders, account for 30%. Institutional purchasers for consumer markets account for about 20% of the bean output, and informal wholesalers take up about 40% of the bean output for redistribution to rural markets, commercial clients, supermarkets, urban consumers, and cross-border trade. In rural markets, local aggregators collect excess beans for urban wholesalers. In the urban bean market, wholesalers store beans until market prices rise, and are also connected to international export markets in eastern DRC, Uganda, and Burundi.

With yields comparable or superior to conventional bean varieties, biofortified beans are quickly being taken up by farmers, even without aggressive marketing of the nutritional traits. Because biofortified beans are not easily distinguishable from other beans in the local market, HarvestPlus and its partners are primarily working to replace non-biofortified beans with biofortified varieties in existing value chains. This work includes strengthening linkages between farmers and markets.

For example, HarvestPlus and its partners utilize the unique opportunity provided by the World Food Programme's Purchase for Progress (P4P) initiative to integrate iron beans into the P4P procurement system. HarvestPlus links the P4P initiative with farmers, providing farmers with a consistent market for their excess production and WFP with a consistent supply of highly nutritious beans.

As excess iron bean production outpaces WFP's requirements, HarvestPlus is working with the Rwanda Agriculture Development Authority (RADA) to develop plans to link farmers to markets. For example, traders have expressed interest in improving the reliability of their bean grain supply. HarvestPlus assists in linking traders to cooperatives or individual farmers, often using forward contracts.

There is a secondary effort to brand biofortified beans through the value chain, which requires educating farmers and consumers about the specific characteristics – including shape, color, and size – that allow for the identification of biofortified varieties. Spot analysis provides verification of mineral content. HarvestPlus is also working to identify suitable value-added technologies to increase their marketability and attractiveness to consumers. This includes, for example, work with two companies on partial cooking and packaging of beans.

Connecting Supply and Demand through Markets
Consumer marketing using print and radio media, as well as extensive field demonstration, are used to communicate the dietary importance of iron and how biofortified beans can address iron deficiency.

Radio talk shows and jingles. Radio talk shows increase awareness among farmers and general consumers about iron bean production, seed availability, and nutritional benefits. These activities are conducted in collaboration with local partners such as RAB, the Ministry of Health (MINISANTE), and the Rwanda Broadcasting Agency (RBA). Feedback from the public, through phone calls and information requests during public exhibitions (such as the national agricultural shows and other public fora), suggests that radio is an effective method of demand creation.

A media-based awareness campaign uses entertainment to reach the general public and consumers of iron beans with nutritional messages. This campaign has been conducted in partnership with locally renowned musicians and journalists and included a music video and outreach tour touting the benefits of growing and consuming iron beans in Rwanda.

Agriculture shows and field days. HarvestPlus, in partnership with RAB, participates in agricultural shows and farmer field days to promote production, marketing, and consumption of iron-biofortified beans. Demonstration fields are established to educate farmers on agronomic management, market access, and nutritional benefits; farmers also receive promotional materials. During such events, farmers and the general public are given an opportunity to taste cooked iron beans and participate in quizzes about biofortification-related questions.

Reach in villages. Farmer-to-farmer dissemination, field days, and radio jingles have helped increase awareness of iron beans at the village level. HarvestPlus designed a social mobilization campaign to inform consumers of the importance of iron beans for a

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nutritious diet, including traveling theater groups, radio dramas, and community outreach activities. Nutrition-focused implementing partners, such as Partner for Health and Gardens for Health, provide bean-related nutrition messaging.

Democratic Republic of Congo (DRC)
In addition to the Rwanda delivery program, HarvestPlus and its partners deliver iron beans in DRC. Since 2008, four INERA stations[2], located in four main agro-ecological zones, participate in the breeding and testing program with support from CIAT and facilitation by HarvestPlus. From the start of dissemination in 2012 through 2015, about 1,000 tons of iron bean seed was delivered to smallholder farmers, and HarvestPlus estimates that about 400,000 farming households are now growing and eating iron beans. Iron beans have been disseminated in Eastern DRC (South Kivu, North Kivu), in Southern DRC (Katanga), Western DRC (Bas Congo) and Central DRC (Kasai Oriental). A host of partners is involved in both seed production and distribution, ranging from public institutions, local NGOs and community-based organizations, and farmer associations or groups.[3]

In DRC, HarvestPlus facilitates basic seed production under commercial contracts signed directly with INERA stations. Certified seed is produced by several public and private partners, and by individual farmers, under the National Seed Services (SENASEM) field inspection and quality seed control mechanisms. Declared Quality Seeds (DQS), a separate seed class, is produced by farmers with reduced oversight from SENASEM.

The primary dissemination channels for iron beans in DRC are direct marketing by HarvestPlus and/or agro-dealers, free seed and grain distribution in post-conflict areas for refugees and displaced populations, farmer-to-farmer dissemination, and a payback scheme. The payback model is a channel for reaching many households in a short period, by involving partners that are well organized and able to mobilize farmers at the village level. The partners involved in this channel have a well-structured organization with farmers' liaisons officers or facilitators who are trained by HarvestPlus in monitoring activities.

The practical implementation of the payback channel as applied by HarvestPlus in DRC requires a high number of farmer households to be identified, selected and registered by partners. Partners then determine seed demand and the area under bean production at the household level to determine the total volume of certified seed required. In general, when there is high demand for a new iron bean varieties, HarvestPlus distributes about 1 kg of certified seed per farmer. For other iron bean varieties, where sufficient amount of certified seed is available, this rate can be increased to 3 to 5 kg of seed per farmer. At

[2] Mulungu in South Kivu, Kipopo in Katanga, Mvuazi in Bas Congo, and Gandajika in Oriental Kasai.
[3] For example: UEA (Université Evangélique en Afrique), GAP (Groupe Agro Pastoral du Kivu), CAPSA (Centre d'Adaptation et de Production de Semences Améliorées) , CEDERU (Centre pour le Developpement de Rutshuru) , AGROPRO (Agronomes Professionnels) , AJECEDEKI (Association de Jeunes Agriculteurs et Eleveurs pour le Developpement de Kinyandoni , Plantation Bakulikira, ACOSYF (Association Coopérative pour la Synergie Feminine), PABU(Projet Agricole de Buhengere) , COPAM (Cooperative Agricole Mushuva) , PAV (Programme d'Appui aux Vulnerables).

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harvesting time, the farmer then pays back 1.5 kg bean grain for each kg of certified seed received to HarvestPlus, to recover the cost of seed distribution.

The payback system builds on the fact that farmers find it easier to pay for seed after successful multiplication than before planting. With good agronomic management and weather, most iron bean varieties can produce a minimum of 10 times, or between 25 to 40 times, the amount of seed planted for bush or climber beans, respectively.

Initially, all declared quality seed returned by farmers under the payback scheme was treated and stored at warehouses managed by HarvestPlus, then provided to additional farmers in the following season. From 2015 onwards, an explicit partner component was added. In some areas, farmers pay back 2 kg for 1 kg received, with 1.5kg for HarvestPlus and 0.5 kg for the partners involved in seed dissemination. The 0.5 kg is allocated as a contribution to the strategic seed community bank (SSCB) or as reserve, managed by a consortium of partners, farmer leaders and community authorities at village level. HarvestPlus continues to support and facilitate warehouse management.

In DRC, biofortification is recognized by the Ministry of Public Health and included in the National Strategic Nutrition Plan as one of the most cost-effective, scalable interventions supported by the DRC government. Biofortified varieties are also included in the national catalogue of varieties authorized to be planted for human consumption by the Ministry of Agriculture.

MONITORING AND MEASURING IMPACT

Progress in scaling up the supply and demand for iron beans is measured through both regular monitoring and periodic impact assessment. Monitoring generates information about the progress of country programs, while impact assessment explores in greater depth the rates of adoption and diffusion, as well as micronutrient intake from biofortified crops.

Monitoring

The objectives of the Monitoring, Learning, and Action (MLA) system are to: (i) contribute to and set the basis for accountability to management, donors, and other stakeholders; and (ii) generate and share delivery progress data and results that feed into evidence-supported operational decision making, business planning, communication, and advocacy messaging. HarvestPlus and partner staff regularly collect and report on process, output, and outcome indicators. All data from the monitoring system is disaggregated to improve its usefulness for planning. Wherever possible, data is disaggregated by gender, distribution channel, variety, and geographic region.

From 2011-2015, HarvestPlus and partners disseminated about 2,800 tons of iron bean seed. Based on monitoring records, HarvestPlus and its partners estimated that about 800,000 households were reached by the end of 2015.

Impact Assessment

The aims of impact assessment studies are to: (i) measure adoption, diffusion, and dis-adoption rates of biofortified crop varieties over time; (ii) understand the various variety, farmer, agro-ecological and market level factors that facilitate or hinder adoption and diffusion; (iii) understand the effectiveness of various delivery and promotion strategies in engendering adoption and consumption of biofortified crops; and (iv) measure the micronutrient intake differential between adopters and non-adopters of biofortified crops.

To confirm the monitoring data and operations-based estimates, a nationally representative survey was conducted to provide insight on the reach of iron bean varieties [30]. Interviews were conducted with 19,575 farm households located across 120 randomly selected villages from Rwanda's 29 non-metropolitan districts. The results revealed that 93% of the sampled farm households reported growing beans (any variety) over the last five years and 84% reported growing beans in that particular season of interest. The survey also suggested that since the delivery of iron beans started in 2011, at least 29% (or almost half a million) of all Rwandan bean farming households have grown at least one of the ten iron bean varieties, with the highest proportion (42%) coming from the Eastern province and the lowest from the West (17%).

RWR2245, a red-mottled bush bean variety that thrives well in mid to low altitudes, was the most widely grown iron bean variety, being grown at least once by 56% of the households which reported growing an iron bean variety. For the study season (the second season of 2015, known as 2015B), the growing rate reported by farmers was 21% (about 350,000 households) with the highest proportion again coming from the East (32%) and lowest from the West (11%). The patterns of cultivation across provinces are in line with delivery records and marketing data, which was collected over time and which were highlighted in preceding paragraphs.

Cultivation of iron beans has steadily increased over time due to both supply push and demand pull factors, through incremental production and dissemination of iron bean seed from year to year as well as through informal diffusion and farmer social networks. Friends and neighbors were reported to be the second most popular source of farmers' first iron bean planting material, with the first being direct marketing channels.

Since "adoption" can take on several definitions ranging from farmer or household numbers to intensity of production (land area or quantity planted), the term adoption is used sparingly to describe farmers' growing patterns—stated or revealed. Adoption patterns may vary not only across farmers but even by variety cultivated within a specific farming household, and of course patterns may vary at a higher level by location and time since introduction.

The impact assessment asked farmers about their iron bean growing history over time and that information was used to identify six "grower types".

- Continuous growers (36% of all farming households) are farmers/households that indicated having grown iron beans since first adoption and who continued to do so until the survey season 2015B. Continuous growers have at least 2 seasons history of growing.

- Intermittent growers (18%) are households that have grown iron beans on and off since first adoption.
- First-time growers (21%) are those that grew iron beans for the first time in 2015B.
- One-time growers (23%) indicated growing iron beans in one season only prior to 2015B.
- Discontinued growers (7%) have grown continuously for at least two seasons and stopped in a season prior to 2015B.
- Discontinued 2015B growers (4%) have grown continuously for at least two seasons yet did not grow in 2015B.

Overall, discontinuation was only 11 percent of all interviewed households. Moreover, the percentage of new adopters has been outpacing the percentage of dis-adopters. The reasons for dis-adoption will be investigated in a follow up study.

Two additional components of the impact assessment study, related to nutrition and marketing, will be conducted, focusing on the effectiveness of various delivery and promotion strategies in engendering adoption and consumption of biofortified crops and measuring the micronutrient intake differential between adopters and non-adopters of biofortified crops.

LESSONS LEARNED AND WAY FORWARD

Overall, the HarvestPlus breeding and delivery programs for Rwanda and DRC have demonstrated that large-scale delivery efforts can be implemented effectively for iron beans. HarvestPlus estimates that more than 800,000 households in Rwanda and 400,000 in DRC are now growing and consuming iron beans. Early efforts in Uganda have reached an additional 185,000 farming households. Ongoing research by HarvestPlus and its partners will continue to improve the efficiency and effectiveness of delivery channels, further improving access to more nutritious diets for farmers and consumers.

Lessons Learned

Strong support from the Government of Rwanda to improve nutrition and health has led to rapid integration of biofortification into its agriculture and health programs, complementing existing supplementation efforts. While awareness of biofortification at the national level is high, more effort is needed to improve awareness at the district, sector, and cell levels.

Farmers and consumers in Rwanda and DRC appreciate having a diverse set of iron bean varieties to choose from. For example, preferences for white beans varied significantly between rural and urban consumers in Rwanda. There are numerous macro and micro agro-ecological niches in Rwanda, and bean farmers have historically grown multiple varieties and are likely to continue to do so.

Hence, it is good practice to develop and release a wide selection of iron bean varieties to address the preferences of a wide range of consumers and to ensure that there are appropriate varieties for the differing agro-ecological environments in which farmers grow beans.

A seed payback system represents an efficacious mechanism for promotion and dissemination of biofortified crops. It allows farmers to pay for seed with crops they will harvest at the end of the season. With this tool, upfront investment hurdles are removed for the farmer and the program and partners managing delivery can work cost-effectively by requiring 1.5 or 2 times more seed payback than being distributed. Farming households in Rwanda and DRC accepted and liked the system.

To address capacity issues with strict seed quality certification systems, the introduction of new seed classes, such as declared quality seed, have proven useful. Declared quality seed fills a niche between government-certified seed and non-certified seed for which acceptable market prices and large production and trade volumes can be established.

In consumer education and promotion of biofortified crops, a mix of promotional tools has effectively spread the word about iron beans, employing radio talk shows, media campaigns through songs, jingles and road shows, printed promotional materials, agriculture shows and field days, and high level stakeholder advocacy.

Initial data collection in the delivery process was greatly facilitated by the project's direct engement in delivery activities. However, as the focus turns to the private sector taking on an increasing proportion of seed production and delivery, new challenges to monitoring progress will arise, and new tools must be developed.

The Way Forward

Plant breeding efforts will need to continue to produce high-yielding and competitive iron bean varieties in order to avoid current biofortified varieties from being slowly replaced by future modern varieties without high iron content. Ideally, the iron trait will be mainstreamed in bean breeding, i.e. it becomes a standard rather than an optional trait. To that aim, HarvestPlus is already supporting national research programs to establish in-country capacity for mineral analysis. RAB's and INERA's analytical capacities were strengthened by installing and implementing X-ray fluorescence (XRF) machines for high-throughput screening of beans, including training of staff. In addition to focusing on increasing iron content further, another breeding strategy is that is being tested is to reduce substances that inhibit iron uptake (such as phytates).

HarvestPlus, in conjunction with the Rwanda Agriculture Board (RAB), has been engaging small scale farmers and cooperatives to multiply planting material for iron bean varieties for onward dissemination. These seed multipliers have been undergoing specialized technical training in various aspects of seed production, strengthening the country's bean seed system. In addition, RAB seed inspectors have been ensuring that seed production requirements are met by producers under this program. These are important and encouraging results with respect to future sustainability of integrating iron beans into the Rwandan seed and food systems.

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The sustainability of operational seed dissemination and adoption and consumption-oriented marketing must be ensured. Until now, iron bean seed marketing and storage systems are mostly operated by HarvestPlus and its partners. Recently, there has been growing commercial interest in marketing of iron beans seed and grain by the private sector, and HarvestPlus facilitates linkages between various value chain actors. HarvestPlus is currently working with private sector firms, farmers, cooperatives, and Non-Governmental Organizations (NGOs) to build strong relationships and ensure the future sustainability of the biofortification program.

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Table 10.1: Prevalence of Anemia in Children (age 6-59 months) and Women, Rwanda 2014-15

Level of disaggregation/ ecological region	Children age 6-59 months (% with hemoglobin <11 g/dl)	All women [pregnant] (% hemoglobin <12 g/dl)
National	36.5	19.2
Urban	30.2	16.3
Rural	37.7	19.9
City of Kigali	30.6	14.9
South	39.3	22.9
West	34.5	17.9
North	33.6	15.4
East	39.7	21.8

Source: 2014-15 DHS Report [1]

Table 10.2: Nutrition Target Setting and Testing for Iron Beans

	Children 4-6 years	**Non-pregnant, non-lactating women**
Estimated Average Requirement (EAR) of bioavailable iron (micrograms per day)	500	1,460
Average baseline iron content of non-biofortified bean varieties (parts per million, ppm)	50	
Additional iron target density	+44	
Average daily bean consumption (grams dry weight) – Rwanda	107	198
Micronutrient retention (percent)· after processing [31, 32]	90	
Micronutrient bioavailability (percent) [33]	7	
Iron provided through baseline content of 50 ppm (percent of EAR)	68%	42%
Additional iron provided through increased content of +44 ppm at full target (percent of EAR)	59%	38%
Total micronutrient contribution of full target biofortified beans (baseline + biofortification, percent of EAR)	127%	80%

Table 10.3: High Iron Bean Varieties Released Under HarvestPlus in Rwanda (RAB), DRC (INERA) and Uganda (NARO)

Name	Year of Release	Origin	Growth Type	Grain Color	Iron Content*	Grain Yield (kg/ha)	Adaptation, Agronomic Properties
HM 21-7	2008 (DR Congo)	CIAT	Bush	Red mottled	62 ppm (27%)	1000-1500	Low to mid altitude; R: AB, AC, BCMV, RR; T: ALS, drought
MORE 88002	2016 (Uganda)	CIAT	Bush	Yellow	70 ppm (45%)	1000-1200	Low to mid altitude; agronomic properties under assessment
RWR 2154	2010 (Rwanda) 2016 (Uganda)	RAB	Bush	Sugar	71 ppm (47%)	1200-1700	Low to mid altitude; R: AB, AC, BCMV; T: ALS
RWR 2245	2010 (Rwanda) 2011 (DR Congo) 2016 (Uganda)	RAB	Bush	Red mottled	76 ppm (59%)	1000-1500	Low to mid altitude; R: AB, AC, BCMV; T: ALS, RR
PVA 1438	2013 (DR Congo)	INERA	Bush	Red kidney	79 ppm (66%)	1000-1500	Mid to high altitude; R: CBB, RR; T: BCMV
MAC 44	2010 (Rwanda) 2016 (Uganda)	CIAT	Climber	Red mottled	78 ppm (64%)	2500-3000	Mid to high altitude; R: AC; T: AB, ALS, BCMV, RR
RWV 1129	2010 (Rwanda)	RAB	Climber	Salmon	77 ppm (61%)	3000	Mid to high altitude; R: AC, BCMV, RR; T: AB, ALS
RWV 3006	2012 (Rwanda)	RAB	Climber	White	78 ppm (64%)	3800	Mid to high altitude; R: AB, AC, ALS, BCMV
RWV 3316	2012 (Rwanda)	RAB	Climber	Red	87 ppm (84%)	4000	High altitude; R: AC, BCMV; T: AB, ALS
RWV 3317	2012 (Rwanda)	RAB	Climber	Sugar	74 ppm (54%)	4000	High altitude; R: AC, BCMV; T: AB, ALS
MAC 42	2012 (Rwanda)	CIAT	Climber	Sugar	91 ppm (94%)	3500-4000	High altitude; R: AC, BCMV; T: AB, ALS
RWV 2887	2012 (Rwanda)	RAB	Climber	Dark red	85 ppm (80%)	3800	High altitude; R: AC, BCMV; T: AB, ALS
CAB 2	2010 (Rwanda)	CIAT	Climber	White	95 ppm (98%)	4000-4500	High altitude; R: AC, BCMV; T: AB, ALS
Namulenga	2013 (DR Congo)	CIAT	Climber	Zebra	76 ppm (60%)	2500-3000	Mid to high altitude; R: AC, BCMV, RR; T: AB, ALS
Cod MLV 059	2012 (DR Congo)	INERA	Climber	Red mottled	84 ppm (77%)	2000-3000	Mid to high altitude; R: AC, CBB, RR; T: ALS, BCMV
Cuarentino	2013 (DR Congo)	INERA	Climber	White	100 ppm (114%)	2000-3000	Mid to high altitude; R: AC, BCMV, CBB; T: RR
Nyiramuhundo	2016 (Uganda)	Rwanda	Climber	Yellow-Orange	67 ppm (39%)	1200-1700	Mid to high altitude; agronomic properties under assessment

Notes: R: Resistance; T: Tolerance: AB: Ascochyta blight; AC: Anthracnose; ALS: Angular leaf spot; BCMV: Bean common mosaic virus; CBB: Common bacterial blight; RR: Root rot

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